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International Symposium held in Vienna, 2–6 October 2000
Organized by the International Atomic Energy Agency
in co-operation with the OECD Nuclear Energy Agency,
the Nuclear Energy Institute, the World Nuclear Association and the
Office of the Supervising Scientist — Environment Australia

The Uranium Production Cycle and the Environment

INTERNATIONAL ATOMIC ENERGY AGENCY

P R O C E E D I N G S

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I N T E R N A T I O N A L A T O M I C E N E R G Y A G E N C Y

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FOREWORD

The IAEA has the statutory functions to foster the exchange of scientific and technical information on peaceful uses of atomic energy. The IAEA is designated by the United Nations as the UN organization responsible for uranium resource related activities. Within its co-operation on uranium with the OECD Nuclear Energy Agency, the IAEA has agreed to continue collaboration to ensure that environmental issues related to uranium mining and ore processing are given appropriate consideration under the scope of activities of the Joint OECD/NEA–IAEA Uranium Group.

Within the international community it is widely recognized that the responsibility for management of uranium production and all related activities should be independent of the organization providing for the oversight and regulatory function. Each organization has its own responsibilities and its own function.

An important role of the IAEA is establishing international safety standards for protection of health and the environment against exposure to ionizing radiation. Once legally binding laws, regulations and standards are established, either through national or international programmes, it becomes the responsibility of the management and operators of uranium production projects for carrying out all activities to meet these requirements.

In so doing, the uranium producers may use planning and management systems, and both evolving and new technologies to assure that the requirements are met in the most efficient and cost effective manner. It is only by addressing the entire uranium production cycle in planning, from exploration, through development, production, waste management, final closure and decommissioning, and site remediation that many of the problems and risks, as well as associated costs, can be avoided or reduced. To assure that all activities in the cycle are completed, the planning must include the provision of financial surety to assure final closure. In many cases in the past, such surety has not been provided for. It has then become the responsibility of the government to address the problems associated with uranium production sites ("orphan sites") that no longer have an economically viable owner.

For more than three decades there has been an increasing awareness that substantial negative environmental and health impacts may result from uranium production projects, particularly if they are put into operation without proper concern for the environment, health and safety. Consequently, today many people are aware that the resulting environmental and health impacts of uranium production facilities can be greatly reduced when those responsible for the projects follow best practice in planning, operating and closing projects. Proper planning and operational practice has an important economic and environmental impact. As stressed in the advice and counsel of the World Commission on Environment and Development — it is much more effective to prevent pollution than to clean it up. Many modern uranium production projects already pursue this strategy.

The major emphasis of the IAEA's Project on Raw Materials for Reactor Fuels is to improve and strengthen the practice of preventative measures by establishing guidelines for environmental impact assessment and mitigation and the recognition and promotion of good practice and modern technology. The Waste Technology programme provides advice on the cleanup and remediation of old production sites and wastes.

One important mechanism for recognizing and promoting best practice in environmental management of uranium production is fostering information exchange among specialists. The

IAEA exercises this mechanism, for example, through publications, electronic information exchange and, particularly, through large gatherings of specialists and decision makers at international conferences, symposia and seminars.

In this context, the International Symposium on the Uranium Production Cycle and the Environment was organized by the IAEA and held from 2 to 6 October 2000 in Vienna, Austria, to bring senior experts from five continents to address current problems and issues, to recognize and promote best practice in environmental management, to promote an international consensus and to foster further information exchange on issues related to the uranium production cycle and the environment.

The symposium was organized by the IAEA in co-operation with the OECD Nuclear Energy Agency, the Nuclear Energy Institute, the World Nuclear Association (formally Uranium Institute) and the Office of Supervising Scientist – Environment Australia.

The IAEA officers responsible for this publication were J.-P. Nicolet and D.H. Underhill of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

IMPACTS (Environment & Safety) — Session 2 (b)

IMPACTS (Impact Assessment) — Session 2(c)

PRODUCTION TECHNOLOGY — Session 3

WASTE MANAGEMENT AND DECOMMISSIONING — Session 4

REGULATORY AFFAIRS — Session 5

POSTER SESSION

SUMMARY

The International Symposium on The Uranium Production Cycle and the Environment took place in Vienna from 2 to 6 October 2000 within the framework of the IAEAs regular programme for the year 2000. More than 115 senior officials and scientists from 31 Member States and 8 international organizations participated in the symposium.

The symposium was organized by the IAEA, in co-operation with the OECD/Nuclear Energy Agency (NEA), Nuclear Energy Institute (NEI), World Nuclear Association, and Office of the Supervising Scientist — Environment Australia.

The officers of the symposium were as follows:

(a) President: R.M. Fry, Supervising Scientist (retired), Office of Supervising Scientist, Environment Australia.

(b) Chairpersons of the technical sessions:

- (i) F.H. Barthel, Bundesanstalt für Geowissenschaften und Rohstoffe, Germany; and Chairman of Joint OECD/NEA-IAEA Uranium Group

  A. Rising, Senior Advisor, Nuclear Energy, Vattenfall, Ringhalls, Sweden; Chairman European Nuclear Society; and Chairman Elect, World Nuclear Association
- (ii.a) B. Labonne, Senior Advisor, Department of Economic and Social Affairs, United Nations
- (ii.b) P.R. Navarra, Head, Economic Geology Section, National Commission of Atomic Energy, Argentina

  P.W. Waggitt, Principal Environmental Scientist, Office of the Supervising Scientist - Environment Australia, Australia
- (ii.c) J. Slezak, Head, Department of Geology, TUU Division, DIAMO, Czech Republic
- (iii) A.V. Boitsov, Leading Scientist, All-Russian Research Institute of Chemical Technology, Russian Federation
- (iv) S.E. Frost, Consultant, Cameco Corporation, Canada
- (v) D.B. Chambers, Principal, Director of Risk and Radioactive Studies, SENES Consultants Limited, Canada; and Member of United Nations Scientific Committee on the Effects of Atomic Radiation

(c) Programme Committee members:

- (i) F.H. Barthel, Bundesanstalt für Geowissenschaften und Rohstoffe, Germany
- (ii) W.E. Falck, International Atomic Energy Agency, Division of Nuclear Fuel Cycle and Waste Technology, Vienna
- (iii) S.E. Frost, Consultant, Cameco Corporation, Saskatoon, Canada
- (iv) S. Kidd, Head of Programme, World Nuclear Association, London
- (v) I. Lindholm, Fuel Manager, Nuclear Fuel and Environment, Sweden (deceased)

(vi) R.S. Needham, Project Director, Environmental Protection Agency, Queensland, Australia
(vii) D. Reisenweaver, International Atomic Energy Agency, Division of Radiation and Waste Safety, Vienna
(viii) I. Vera, OECD/Nuclear Energy Agency, Nuclear Development Division, Issy-les-Moulineaux, France

The topics covered by the symposium were:

- Energy needs and challenges for the 21st Century;
- Uranium supply for the short and long term;
- Sustainable development, energy resources and nuclear energy's role in greenhouse gas abatement;
- Economic impact of world mining;
- Impacts of mining on developed and developing countries;
- Environmental and social impacts of uranium mining in several countries;
- Examples of positive and negative impacts of uranium mining projects on local communities;
- Environmental issues and performance in several countries;
- Prob lems of acid rock drainage at uranium mine sites;
- National examples of environmental impact assessment in the uranium industry;
- Natural background radioactivity of the earth's surface at and away from uranium production facilities;
- Technology and the uranium industry;
- Environmental design aspects of uranium mines and mills;
- Design, management and closure of uranium tailings facilities;
- National experience with management and disposal of liquid and solid wastes from uranium mining and milling;
- National experience with treatment and restoration of waste water from both conventional and in situ leach uranium mining;
- Safe management of radioactive waste from mining and milling activities;
- Evolving regulation and rehabilitation standards for uranium recovery operations;
- National experience with regulation of uranium production.

SESSION 1: SETTING THE SCENE

This session provides an overview of several topics making up the background for the theme of the meeting. Energy is the driving force towards economic and social development [1][1]. The primary chances and challenges for the 21st Century relate to the interaction between energy and the environment. To be effective, the problem solving power of science and technology must link with acceptance by society. The potential for this linkage justifies an overall message of guarded optimism.

The new IAEA report "Analysis of Uranium Supply to 2050" presents various uranium supply/demand scenarios to the year 2050 [2] over a very wide range of use. The range varies between a phase out of nuclear and demand growth from today's levels to a high case that equals nearly 5 times current use. The study is based on current knowledge and should not be considered as a prediction or forecast of uranium supply. The analysis, however, does indicate that uranium resources exist to sustain nuclear power to 2050. However, as known low cost conventional resources ($40/kg U, or less) are depleted it will become necessary to rely on higher cost resources (> $130/kg U) conventional and non-conventional resources. To avoid reliance on very high cost resources industry must discover new low cost deposits currently classified as undiscovered or speculative resources. In addition, the world community must be convinced that the environmental impacts can be reduced to acceptable levels when projects are properly planned, developed, operated and closed.

The relationship between uranium supply and demand has varied considerably since the early 1980's [3]. Before 1985, annual primary uranium production exceeded the demand. More recently, primary production has decreased to around 50% of demand, but inventories plus other sources have continued to meet the demand. Even if other sources continue to increase, and, for example, nuclear reactor life is extended, the uranium supply could become critical in the next 10 years. The nuclear industry needs political and legal guarantees, as well as secured economical environments in order to maintain the existing nuclear capacities and to assure the investment required for future growth.

Producing the World Report "Uranium, Resources, Production and Demand" or "Red Book" is the main function of the Joint OECD/NEA-IAEA Uranium Group [4]. The evaluations and supplemental information it provides on supply/demand scenarios has made it one of the best selling publications of the OECD. In 1999 a companion publication "Environmental Activities in Uranium Mining and Milling" on environmental restoration of uranium production facilities was initiated. Activities that are currently in progress on a worldwide variety of mine sites are presented. The Joint NEA-IAEA Uranium Group is committed to continue addressing both supply-demand issues and environmental activities in uranium mining and milling.

The concept of "sustainable" embraces (1) saving natural resources, (2) building and using long lasting economic capacities for economic growth and continued societal progress [5]. Sustainable development has a high priority in the international agenda. Key elements for integrating sustainable development goals are energy efficiency, development of new competitive energy technologies, and using adequate public incentives.

Nuclear energy can play an essential role in avoiding greenhouse gas emissions [6]. The ultimate objective of the international action on climate change is to stabilize atmospheric greenhouse gas emissions at a "safe level". Climatologists suggest that this will require a 60% reduction in these emissions. Nuclear energy can make an important contribution to both meeting the increasing

[1] The number in square brackets refers to the paper number (IAEA-SM-362/).

global demand for energy and assisting in sustainable development. The scale of that contribution will depend on how nuclear energy is treated in emerging environmental legislation.

Mining can and does contribute positively to economic development and human well-being, but these benefits do not come automatically [7]. The negative impacts of mining, and there can be many, must be mitigated. Governments, mining companies, and local communities must cooperate to address issues over a time span covering from exploration to mine operation, and to post-mine closure. Also, governments must establish an adequate regulatory and institutional framework. The process includes cultural changes which should not be underestimated. Fundamentally, sustainable development is a different philosophy — not another management problem.

Nowadays, mining is as much about economics as emotions [8]. The activities of this industry fuel passionate debates that industry, governments, and civil society are often ill prepared to address in a constructive, proactive, and candid manner. Mining is first and foremost a risky business. The industry can address sustainable development concerns only as long as it is profitable. Uranium production projects that are not profitable or that require economic subsidies are ill prepared to address both social issues and the surrounding concerns. The economic benefits it can provide should pave the way to sustainable livelihood. In many developing countries, the mining climate can be greatly improved by governments making policy changes, and abiding by these changes. A national debate is required to build consensus over the need to reconcile the collective interest with local economic and social expectations.

SESSION 2.a: IMPACTS (Socio-Economic)

SESSION 2.b: IMPACTS (Environment & Safety)

SESSION 2.c: IMPACTS (Impact Assessment)

This session addressed the socio-economic and environmental issues related to uranium mining and milling. Several papers [18, 20, 21, 22] referred to the very significant levels of environmental damage caused by uranium mines in the past, and the major challenges to be faced in identifying contamination, acquiring funds for cleanup programmes, and conducting programmes to clean up these sites. In some countries where uranium mining has taken place since the late 1940s, very extensive damage has been caused because of the numerous locations of mines and poor practices, especially relating to the containment of tailings and placement of waste rock [18, 27].

Much of the radiation risk associated with these old sites can be removed by relatively simple techniques involving burial under thin (<1 metre) covers of non-radioactive soil and rock, although approaches involving the covering of tailings and waste dumps in situ and without landscaping does raise the issue of the stability of steep slopes in the long term, and the amount of monitoring and maintenance required to maintain the level of hazard reduction achieved. However it is clear that in many instances that radiation flux can be lowered to within natural ranges, allowing beneficial agricultural use of the rehabilitated land. A reasonable and justifiable target for restoration of mine sites, in terms of radiation levels, can be determined by back-calibration of the natural radiation levels from airborne or carborne radiometric data [25].

The main message from this session is that the approach to environmental management at many (or most) uranium mines today is very different from the approaches used in the past. This new way of doing things will result in a very significant reduction in the level of

impacts, and it is highly unlikely that the mistakes of the past will be repeated. Similarly, the cleanup costs of modern mines will be much less than those of old mines.

Today's mines generally apply a proactive approach to environmental management, utilising environmental management systems which integrate the principles of waste minimisation, waste re-use and minimal disturbance, and incorporate monitoring systems to keep track of performance and detect impacts at an early stage [19, 21]. There is evidence to demonstrate that the concern for environmental protection is now worldwide, and that regulatory regimes have changed to reflect the higher expectations from government and society for environmental protection [11, 13]. It is clear that modern uranium mining can involve for large volumes of material and over long periods of time without running the risk of the environmental disasters of the past — the key is a proactive approach to mine environmental planning throughout the life of the mine, beginning at the planning stage [15].

Environmental Impact Assessment is a process increasingly being adopted by government to thoroughly canvas the many issues related to development of a uranium mine. Opportunities for community input are seen by some as a critical component to ensure adequate consideration is given to the issues [26], although in the Canadian experience the EIA process is used as a delaying tactic by opponents to the industry [24]. In some cases the EIA process can become so lengthy, detailed and costly that the viability of smaller projects may be affected. While EIA should be undertaken, duplication because of overlapping jurisdictional interests and repeating the same issues common to projects in the same area should be avoided. The process should be completed in reasonable time frames to reflect commercial considerations.

The first countries to implement the new approaches to environmental management were Canada and Australia, where monitoring over the last 20 years demonstrates that very high levels of protection are achievable [16]. Key components to ensuring high levels of protection are the application of comprehensive risk management techniques [14], commitment to good performance, continuous improvement, a willingness to perform beyond regulator requirements [17], and development of new monitoring techniques which clearly demonstrate to regulators and the community that their expectations for environmental protection are being met [16]. In areas of high conservation value, these techniques should directly measure the biological condition of organisms and ecosystems at risk.

Environmental issues commonly carry with them a social dimension, so it is preferable to consider both of these together in management of impacts, mine planning, and reporting of results. The environmental/social link is particularly strong when mining is on land where traditional indigenous culture persists and people retain strong cultural ties with the land and the earth [9, 10]. Objectives for environmental protection should always be defined in consultation with the community, but this is particularly relevant when dealing with aboriginal peoples.

Because of the concern that communities generally have about the risks of uranium mining, both in terms of human health and ecosystem damage, it is advisable to consider social and environmental issues as "one package" [9]. In addition to health risks, other human impacts can relate to health services, employment/income, cultural change etc. These need to be carefully considered at the early stages of project development; misjudgement can lead to significant negative societal impacts, particularly for aboriginal people, which in turn can lead to deeply felt resistance to mining and rejection of the significant benefits that it can bring to the community [11].

These significant benefits largely relate to employment and skills development opportunities, which are very often lacking in many parts of the world where mining occurs in relatively remote regions with poor infrastructure and few jobs. It is possible to achieve high levels of employment of local people, provided that sufficient attention is given to training, so that the right skills needed for the mine can be developed in the local population [12]. A successful approach has been applied in Canada, where a partnership arrangement has been struck with the indigenous people, built around development of sound and sustainable businesses owned by the indigenous people, and which will provide economic independence for their communities after the mines have closed [10]. Care must be taken that communities directly affected by mining do receive significant benefits which can be directly attributed to mining. In an Australian case the royalties from mining were partly used to substitute government funds for education and health and other services. Few direct benefits from mining were evident, and eventually the affected community developed a strong anti-mining position [11].

A strong message delivered at this meeting was that communication with stakeholders, and particularly the community directly affected by mining, is paramount [13,10,17]. Communication should start at mine planning stage or earlier; should continue throughout mine life; recognise and take account of community views; avoid technical complexity (e.g. use simple language); and clearly convey risk/consequence information and management as a way of building understanding and trust. Trust and understanding are key requirements to building a more positive attitude to the industry within government and the general community [13].

When compared to conventional extractive uranium mining, ISL techniques offer obvious advantages in terms of surface disturbance and volumes of waste solids. Further research is needed to address public concerns about the risks of this mining method and reduce the potential for damage through aquifer contamination or liquid waste disposal [20]. Other, non-radiological risks associated with some uranium mines should not be overlooked (e.g. acid drainage [22]). Also significant radiological risk is not limited to uranium mines (e.g. some high-U coal mines [22]).

SESSION 3. PRODUCTION TECHNOLOGY

Few industries have been subject to more stress than the uranium industry [28]. During the past two decades, uranium concentrate prices have fallen by an order of magnitude. Continuing advances in technology are required to counter expending economic and regulatory pressures and to maintain sustainable operations. Manifestation of the uranium industry's commitment to advancing technology can be seen in recent improvements related to exploration methods, mining practice, processing methods, tailings disposal and operational safety. Continued sharing of information on these advances can benefit all phases of the industry.

The innovative mining practices being used at the high-grade (17% U_3O_8) McArthur River uranium deposit exemplify a major technological advance [29]. The raise-boring technique selected for this operation had not been used previously as a primary mining method. The method minimizes direct handling of ore and reduces radiation exposure levels to essentially those predicted in the Environmental Impact Statement. During start up operations, serious plugging problems with the original ore-collection shut system were solved, and the new remotely operated load-haul system functions effectively. In addition, data from the first 6 months of operation, confirm that the desired radiation safety has been incorporated into the McArthur River operations.

In recent years the China National Nuclear Corporation has concentrated on locating and developing uranium deposits amenable to in situ leaching [30]. The No 512 Yili Xingian sandstone deposit is a typical example. The exploration programme progressed through the following four stages: (1) reconnaissance, (2) prospecting, (3) general exploration, and (4) detailed exploration. After the resource was confirmed an ISL leachfield was installed at the deposit. During three years of injection and pumping operations both the economic efficiency and environmental viability have met expectations.

Currently, pilot scale in situ leaching tests are in progress at the *Khiagda* sandstone deposit in Russia [31]. Hydraulic conductivity in the confined productive horizon averages 2 to 3 m/day. The existing ground waters in the aquifer are not suitable for either potable or industrial use. Sulfuric acid (5–25 g/l) is used as the leaching agent. Available information indicates that the concentration of all contaminants decreases significantly outside the leaching contour, and that natural attenuation is occurring. Projections suggest that the ground water in the productive aquifer at this deposit will return to their initial composition in approximately 10 years.

The Australian Nuclear Science and Technology Organisation (ANSTO) is conducting studies to identify and develop technologies that have potential to minimize the environmental impact from uranium mills [32]. Experimental results indicate that a system which includes leaching followed by belt filtration and then direct precipitation of yellow cake presents a promising option. ANSTO is also investigating resin-in-pulp and resin-in-leach flow sheets. This work includes industrial collaboration on the development an ion-exchange resin that can be selectively recovered from the pulp by wet-magnetic separation.

SESSION 4: WASTE MANAGEMENT AND DECOMMISSIONING

Planned and progressive decommissioning of an operational site is the key to [33]:

- Minimizing environmental impacts,
- Satisfying public and regulatory concerns,
- Minimizing operational and decommissioning costs,
- Minimizing corporate liability, and
- Shifting public resistance to public support.

Tailings management in Saskatchewan has evolved through four stages. Prior to 1977, the first stage began with uncontrolled tailings discharge. The second generation included engineered surface facilities located above the water table. The third generation included pit disposal below the water table and incorporated the pervious surround system. The fourth generation facilities uses natural geologic barriers and conditioning of tailings to control porewater chemistry, thereby reducing long term solute migration.. This evolution was in general a response to increasingly strict regulatory requirements. Through a combination of careful operation, improved technology and rigorous engineering a progressively greater degree of environmental protection has been achieved.

The various types of mine water that have been treated in the Czech Republic include the following [34]:

- Neutral mine water pumped from deep mines,
- Weakly acidic water derived from horizontal dispersion during ISL mining operations,
- Weakly acidic water from vertical dispersion, from ISL wellfields,
- Solutions from tailings impoundments, and
- Strongly acidic solutions from ISL wellfields.

The level of contamination varies in each of these mine water types, and tailored flowsheets were developed to achieve regulatory compliance for each type of solution.

Uranium mining and processing in Hungary was terminated in 1997 [35]. Since that time, treatment of mine water has become one of the primary tasks of the operating companies. The treatment process is in part based on uranium recovery by ion exchange technology. It is anticipated the long term water treatment will be required for a number of sites.

The new tailings management system being used at the McClean Lake uranium operation in Northern Saskatchewan represents state of the art technology for engineered tailings deposition and controlled releases of soluble contaminants [36]. The "natural surround" design selected involves subaqueous deposition of the tailing, which allows for uniform tailings deposition, decreased tailings segregation, and maximum consolidation. The contrast in hydraulic conductivity between the consolidated tailings and the surrounding rock is expected to be two orders of magnitude. Under these conditions, the consolidated tailings behave as an impermeable plug and ground water flows around the tailings mass. Initial test results indicate that the system is performing as predicted. However, it will take many years to validate the long term performance of the system.

Uranium is produced in Niger in operations at SOMAIR and COMINAK [37]. SOMAIR uses openpit mining and COMINAK is an underground operation. The overall mining and processing operations involve the following conventional processing steps: Mining, Crushing, Grinding, Acid leaching, Solid-liquid separation, Solvent extraction, Yellow cake precipitation, and Tailings management of both solid and liquid wastes. A portion of the liquid waste is recycled and solar evaporation controls the volume of the remaining tailings solution. Solid tailings are currently stored in engineered tailings ponds. The ponds are lined with impervious PVC (Polyvinyl Chloride) membrane placed on top of a clay base to further minimize potential seepage. Studies have been initiated to determine procedures for minimizing radon release from the tailings after mill closure.

The IAEA has become increasingly concerned with the radiological and environmental impact of closed uranium mining and milling facilities [38]. It is recognized that inappropriate practices in waste management and the lack of closeout plans have lead to environmental hazards and the potential for human exposure worldwide. The IAEA is continuing to provide a series of documents and other means that provide guidance and examples for the selection and application of adequate remediation and restoration practices. The overall objective of the programme is to enable regions in the world with restricted resources, and which are technologically advanced, to focus their efforts and chose appropriate strategies for abatement.

A number of Central and Eastern European (CEEC) countries are currently in discussion with the European Commission over future membership in the European Union (EU) [39]. In recent years, these countries have come under close scrutiny by the European Institutions to access their progress in implementing environmental and health issues. Uranium mining and processing is one area of particular concern. Technical planning for long term stabilization of mine waste, tailings ponds, and other wastes is a significant component of these evaluations. The PHARE programme, administered by the European Commission, is providing assistance to these countries for assessing the situation and identifying applicable remediation priorities and objectives. Projects are now progressing in at least seven CEEC countries.

The National Atomic Energy Commission of Argentina (CNEA) started its activities nearly 50 years ago. Nine of the sites that produced uranium are now in various stages of the restoration

process [40]. At sites such as the Malargue operation major restoration work have been completed while others are in various stages of the planning and engineering process. The overall process includes work on all major restoration phases including mine waste, process tailings, and contaminated water.

A North Bohemian uranium bearing region was detected at the beginning of the 1960's as a result of systematic prospecting in the Hamr na Jezere region [41]. Ultimately conventional mining and processing uranium operations were developed at the Hamr and Brevniste deposits, and ISL leaching was used at the Straz deposit. The Straz operation is of particular concern because of major ground water contamination. It is expected that the contaminated water will require treatment, and the technology chosen will be influenced by the time for development and economic factors.

Reliable consolidation data are required to provide input for the modeling and design of applicable covering practice for each uranium tailings material [42]. A special oedometer was developed to make the required measurements for the tailings materials at WISMUT. Based on test results, it is now possible to determine the compression curves and the permeability void ratios for the existing settled fine tailings. The results obtained are in good agreement with expected theoretical calculations and will be used to engineer contouring and covering procedures.

The concept of "natural attenuation" has been studied for restoration of ISL leaching sites in Kazakhstan [43]. In essence this approach utilizes the reactivity of the host rock in the ore horizon to purify the residual leach solution from the ISL operations and return the water to pre-mining quality. Both chemical and bacterial reactions can be involved. Laboratory and field tests indicate that essentially complete restoration of the ground water to background levels can be achieved in tens of years or less.

ISL mining was first introduced in Uzbekistan in 1962, and with modifications, its' application has increasingly expanded [44]. Since 1994 it has been the sole method for uranium recovery in the Central Kyzylkum, Desert of Uzbekistan. Both strong-acid ISL leaching and weak-acid leaching are being used. The weak-acid process uses a dilute sulfuric acid solution (pH 4.0–4.5) to react with the carbonate minerals in the deposit and form bicarbonate ions, which are the complexing-leaching agent for the uranium minerals. The oxygen required for dissolving reduced uranium minerals is provided by repeatedly injecting compressed air into the ore horizon. This procedure forces out the water and allows direct oxygen contact with the uranium minerals. Currently approximately 50% of the ISL operations use the weak-acid process. The weak-acid technology has proven to be economical, efficient, and environmentally compatible. A main advantage of the method is that after the ISL mining is completed, the composition of the stratal water differs very little from that of the original pre-leaching ground water.

The Zirovski VRN uranium mine in Slovenia operated from 1960–1990, and the mill operated from 1984–1990 [45]. The mine-mill complex closed in 1990 for economic reasons. The following alternatives were investigated for final disposal of the mill tailings:

(A) Leave tailings at present site. (Stabilize and improve site as much as possible)
(B) Move tailings into the underground mine openings.
(C) Move tailings to the mine waste disposal site at Jazbec.

The decision matrix developed by UMTRA in the USA was used to evaluate and compare the three variants. These calculations indicate that stabilizing the tailings in the present location (Option A) is the best solution for the present state. For the 1000-year consideration, moving the

tailings into the underground mine is best (Option B.) However, the evaluations also indicated that the UMTRA procedure should be modified to be more site specific, and that additional evaluations should be carried out before a final decision is made.

During the period from 1948–2000, French uranium operations produced 73 000 tonnes of uranium from 52 million tonnes of ore [46]. The ore came from more than 200 mining sites, and 165 million tonnes of mine waste were also produced. Eleven mills were built. Both conventional and heap-leaching operations were used and lead to 22 disposal sites for tailings residues. COGEMA was the only operator for all sites, and continues to have responsibility for remediation. The primary remediation objectives include:

- Ensuring perennial stability, in terms of security and public health, and
- Reducing as far as possible any residual impacts.

Planning work involves site-specific designs for each location. In general mill tailings will be covered with mine waste, and long term water treatment is anticipated for at least some sites. The overall remediation will continue to be a multi-disciplinary process that will meet regulatory requirements and be integrated with local concerns.

Most of the uranium mines that were developed in the former Eastern Germany were located in complex geological structures [47]. As a consequence, the groundwater flow systems at these hazardous sites are also highly complex. An integrated hydrological investigation procedure is proposed for achieving efficient remediation of these sites. The integrated methodologic approach includes the following steps:

- Target-oriented field investigations,
- Improved hydrogeological conceptual models based on the newly acquired data,
- Quantitative assessment using numerical models, and
- Optimum management of the environmental impact.

The proposed approach is based on extensive experience and expertise gained during investigation programmes for the disposal of radioactive wastes. The procedure helps to reduce global costs by preventing conceptual mistakes, unnecessary actions, and the loss of time.

The IAEA is developing a Safety Guide on the management of radioactive waste from the mining and milling of uranium and thorium ores [48]. The document will be sent to the IAEA Member States for review and comments within the next few months. The new Safety Guide addresses strategies and protocols for siting, design, construction, operation, and closure of facilities in relation to the protection of workers, the general public, and the environment. The Safety Guide also acknowledges that uranium mining and milling wastes involve non-radiological hazards in addition to the radiological hazards. Both hazards must be considered in the planning stages of a project and should be periodically re-assessed throughout the project life cycle. All concepts presented in the Safety Guide are intended to be practical and to provide appropriate safety conditions for the workers, the general public, and the environment.

SESSION 5: REGULATORY AFFAIRS

A wide variety of approaches towards regulation of uranium production is evident amongst different countries. In countries with a long history of regulatory development, in some cases dating back 50 years, generally highly complex systems have evolved. These complex systems have expanded beyond the radiation protection of mankind, to radiological and non-

radiological protection of the environment and ecosystems, to land access and indigenous issues, rehabilitation, post-mine land use, and stakeholder involvement [50,51,53,55]. This underlines the fact that the environmental risks at uranium mines are not limited to radiological issues. In fact non-radiological matters such as acid mine drainage, or access rights to aboriginal land, may be just as important [52].

In countries where environmental protection has become a significant issue in relatively recent times, regulatory systems are generally less complex and may still be under development. Increasingly, international considerations affect the development of regulatory systems and setting of standards. For example, as well as having to consider the recommendations of the ICRP, eastern European countries wishing to join the European Union are having to develop systems compatible with the requirements of the European Commission [54].

Words of caution were sounded by countries with highly developed and complex regulatory systems, in regard to the cost and inflexibility that can result. This inflexibility, arising from overly prescriptive and interconnected legislation, may prevent the application of optimal site-specific solutions, continual improvement and best practicable technology at mine sites [50]. Furthermore, the involvement of too many regulatory bodies tends to lead to duplication, efficiency losses, and a slow down of the regulatory process.

Jurisdictions with more than one level of government are particularly susceptible to duplication, such as the USA, Canada and Australia (i.e. federal and state level government with overlapping interests). Australia has recently addressed the issue of complexity at the federal level by integrating five environmental protection acts into one act; and potential duplication with the state government is avoided through a Memorandum of Understanding between the relevant authorities [51].

Environmental Impact Assessment processes apply in many countries with comprehensive environmental regulation regimes. It is essential for the rights of stakeholders to be recognised in legislation, and for the general public to be aware of their rights and opportunities to input to the EIA process. Because of the complexity of issues to be considered at uranium mines, and the high level of public interest, EIA processes can take up to several years (and many millions of dollars) to complete, leading to significant financial pressures on the proponent company [50,53]. The trend is towards risk based assessment of issues to avoid the process being unnecessarily delayed by trivial issues (a common tactic employed by anti-nuclear interests). For example, many of the environmental issues associated with a conventional mine are not relevant for an ISL operation; the ISL operation should be assessed only against the real risks posed. Without a risk-based approach, it is possible that conditions may be set by the EIA process which are beyond the capacity to deliver operationally, or for measuring compliance [50]. Public consultation is considered essential to good practice, but it should not be allowed to obfuscate, trivialise, or delay the process. Maximum timeframes can be set for the EIA process to avoid these delays [26].

Regulatory systems need to be able to accommodate the changing situation at a mine, from the proposal and planning stages, through operational mining, to decommissioning and closure. Systems designed to be very comprehensive tend to be prescriptive and reduce flexibility. The Australian approach is to provide demanding but broad environmental requirements, based upon the application of best practicable technology. The way in which the requirements are met can be changed over time to meet operational needs and changes in technology; the requirements include the need to address social impacts [51]. The Canadian

approach is to require the company to apply for different types of licence as the mine operation evolves (i.e. site preparation, construction, operation, decommissioning, abandonment), which allows issues not addressed at an earlier stage, or in the EIA process to be examined [53].

The cost of regulation is a significant issue for both government and industry. Smaller budgets in many countries has led to the reduction in staff in regulatory agencies, and the need for high skills levels in environmental science and other technical areas is progressively harder to acquire. One approach to address this has been the “user pay” approach used in the USA, although this removes the need for accountability from the regulating agencies to deliver services efficiently, and places greater financial burden on the company; the regulatory process tends to become more focused on process that outcomes [50]. An alternative approach being applied in Australia is to move away from frequent site inspections to twice-yearly audits [51,55] in which the two levels of government and the mining company work collectively to identify and remedy problems.

Comprehensive systems are available to provide for effective regulation of uranium mines. However, care must be taken to allow sufficient flexibility to respond to changes in technology and evolving community (i.e. government + public) expectations over time, and through the whole of mine life from the planning stage to mine closure. The regulatory process needs to be transparent to ensure accountability by the authorities, clarity of obligations by the miner, and understanding of the process by, and the rights of, the general community.

Generally, many of the features of sound regulatory requirements for uranium mining are not very different from best practice approaches to other forms of mining. However, both regulator and miner should pay particular attention to open processes to reduce the level of fear and mistrust felt by the public. The issue of mine closure is yet to be adequately addressed. Mine stewardship, funding for maintenance, responsibility for remediation, and standards to measure the adequacy of rehabilitation and revegetation are all areas requiring further development. A most important feature of effective regulation must be a system of funding for rehabilitation. Whilst this is possible for operating mines and is being applied in several countries already through requirements for adequate financial security before mining commences, the responsibility for regulation and repair of orphaned mines in terms of regulatory arrangements and funding, rest wholly with government.

SESSION 6: PANEL DISCUSSION AND CLOSING SESSION

The Panel Discussions of Session 6 posed the following three topics:

(1) Community involvement and oversight. Is this an essential part of planning and oversight of a uranium production project?
(2) Decommissioning and closure of tailing impoundments: Should decommissioning aim at a "walk away" situation? Is a long term institutional control of decommissioned sites viable? Or necessary? Or should it become the standard.
(3) What are the positive and negative socio-economic effects of uranium mining operations? Industry and non-industry views.

All three panels expressed consensus that realistic planning is a key requirement for the successful implementation of either a new uranium production project or a decommissioning programme. The planning process must consist of the integrated consideration and application of both socio-economic and technological factors.

During the original implementation activities of the uranium industry, essentially all of the planning related to technological and production centered objectives. Today, the technological factors are still critical, but socio-economic considerations have become equally important. The socio-economic and cultural factors become increasingly sensitive when the local stakeholders are an aboriginal population. The following socio-economic and technological components of the planning process were discussed:

Socio-economic factors

During the very first phases of a project-planning operation, the company must recognize that a perception of secrecy probably exists among the local stakeholders and other interested parties such as non-governmental organizations (NGO's). This image probably survives from the early days of the industry when secrecy was a legal requirement. Therefore, from the start, establishing a culture of openness and transparency becomes both realistic and pragmatic.

Stakeholder involvement and information exchange must start at the very inception of the planning process. To a significant degree, the involvement approach becomes site-specific for each location. The approach must consider a variety of factors such as local culture, population density, the economic situation, and the isolation of the site. NGO's nearly always become involved. Their interest can vary from interested concern to uncompromising opposition. Again, openness becomes a must when attempting to deal with this situation.

When the local stakeholders and land owners are an aboriginal population, the most appropriate and successful approach has involved a inclusive and continuing association. Training, employment, and preparation for post the closure situation become important considerations.

Since all mining operations have a finite life, provisions for funding reclamation and the post closure circumstances should be a mindful component of the planning process. This situation has become critical for some developing countries where the money available for restoration may be almost non-existent.

Technological factors

The technological factors that interrelate with the socio-economic elements are primarily associated with the disposal of mine waste and mill tailings. Both radiological and heavy metals contamination become concerns to the various stakeholders. Regulatory requirements can be quite site specific and range from 100 year- 200 year-1000 year-10000 year stability. The variation between different jurisdictions can be considerable. Baseline environmental data is of crucial importance. Establishing this data for a new operation can be relatively straightforward, but for older sites the data at best may be minimal. This is particularly true in developing countries.

In general the design assurances for civil engineering structures such as tailings dams is no more than 200 years. Also, passive controls do not appear to be realistic for much beyond a few hundred years. In some northern locations, even potential glacial activity makes any projections for 10000 year stability questionable. In many instances institutional controls will be necessary. The initial responsibility for implementing and maintaining these controls will probably lie with the operating company and then would pass to the government. Therefore, financial funding provisions for long term institutional controls will be necessary for most operations. Bonding funds should be large enough so that the income from reasonable interest rates will sustain the institutional controls. Walk away decommissioning may be possible in a few instances, but for most situations it is probably not realistic.

In general some form of below ground level final storage of mill tailings will be the most desirable option for a majority of uranium production operations. Even if this type of remediation is possible, unrestricted land use may not be feasible. Under the best conditions, restricted land use must at least include a provision that no housing will be constructed on the site. Predicting future land use and aspects like zoning changes will always be risky because anticipatin how future generations will look at the problem becomes an unknown.

Realistic planning must carefully consider both the technological and socio-economic impacts of all uranium mining, milling, and restoration projects. In recent years, the socio-economic aspects have gained increasing prominence, and could in all probability either seriously delay or destroy the proposed project.

OPENING ADDRESSES

V.M. Mourogov
Deputy Director General,
Department of Nuclear Energy,
International Atomic Energy Agency, Vienna

It is a pleasure for me to welcome you warmly on behalf of Dr. Mohammed El-Baradei, the Director General of the International Atomic Energy Agency, to this International Symposium on The Uranium Production Cycle and the Environment.

This event is organised by the IAEA with the co-operation of the OECD/Nuclear Energy Agency, the Nuclear Energy Institute, the World Nuclear Association and the Office of Supervising Scientist — Environment Australia.

I wish to emphasize that this is a unique opportunity. It is the first time ever that representatives of the world community have met in a major meeting exclusively dedicated to consideration of the environmental impacts of the uranium production cycle. It is clear from the high level of participation that this topic is of interest to many people.

Let us now consider the theme of the meeting. The uranium production cycle includes all activities related to mining and processing of uranium ore to extract uranium concentrate — commonly known as “yellow cake”. It includes steps from planning through developing, operating, closing and finally remediating uranium production sites. This includes the management and final disposal of all wastes and residues, as well as any required arrangements for long term monitoring and surveillance of the tailings. All of the activities making up this cycle are the responsibility of the management of each uranium production facility operating today. The uranium production cycle is similar to the mining cycle for any commodity (See Fig. 1).

What is the environment? The environment is composed of interacting systems including plant and animal life, physical and chemical elements, the atmosphere, land and water, as well as social and cultural elements. Impacts to the environment can be defined as those effects that alter the existing system either temporarily or permanently. The definition and measurement of impacts are highly dependent on location, country, and social and economic factors. Areas of great concern include tailings management and disposal, as well as contamination of ground and surface waters. As indicated, at some facilities consideration for social and cultural values have recently taken on much importance.

Uranium production activities form the very front end of the nuclear fuel cycle. They are unique, as mining and milling is quite different from other industrial activities of the fuel cycle. Although it makes up only one step in the fuel cycle, uranium production activities contribute the largest volume of radioactive fuel cycle wastes. While the specific activity of the bulk residues from mining and milling activities is generally low, the volumes are very large. The radionuclides occurring in these wastes are naturally occurring and are very widespread in the environment. Therefore, they are characterized as low activity, high volume waste, but do not pose an acute hazard as associated with other steps of the nuclear fuel cycle. Never the less, residues of processing such as uranium tailings have a long life and require appropriate management and disposal. In addition to the radioactive components, other constituents of the tailings may have toxic or other negative effects and may also require proper management.

In many ways uranium mining is much the same as any other mining. However, it is differs because of the more highly radioactive elements in the ore such as radium and radon. As compared with other mineral extraction activities, uranium production may result in increased environmental effects, unless proper procedures are complied with both during and following operations. For this reason its planning and operations are subjected to a higher level of scrutiny, control and oversight than are other mining operations. This is also the reason the public express a high level of interest and concern in uranium production operations.

Uranium production is essential for all nuclear power programmes. As the front end of the nuclear fuel cycle, uranium mining and milling was one of the first fuel cycle activities to be established during the initial development of nuclear programmes. Following the initial development, the number of uranium mines and mills and the associated employment grew rapidly in many countries. The Red Book reports this led to facilities operating in more than 35 countries worldwide. While there is no total count of these operations, uranium production probably came from more than a thousand mines. In recent years uranium production has been reported in about 25 countries. There are proposals to initiate production in a few other countries, given favourable uranium market conditions.

For more than three decades there has been a increasing awareness that substantial negative environmental and health impacts may result if uranium production projects, particularly if they are put into operation without proper concern for the environment, health and safety. Consequently, today many people are aware that the resulting environmental and health impacts of uranium production facilities can be greatly reduced when those responsible for the projects follow best practice in planning, operating and closing projects. Proper planning and operational practice has an important economic and environmental impact. As stressed in the advice and counsel of the World Commission on Environment and Development — it is much more effective to prevent pollution than to clean it up.

There is a need to clearly distinguish between today's properly planned and operated uranium production sites, and those from the past that, because of little or no planning, may have significant associated negative environmental impacts. While this distinction between the old and new may be evident to the specialist, the public perception is more likely very different.

There may be a tendency in a meeting such as this to dwell on the potential negative impacts of uranium production. It is also necessary to bare in mind that uranium production has several positive impacts. First of all, uranium is essential for the sustainable development of nuclear power. Nuclear power has several environmental benefits, such as being one of the few technologies that makes a major contribution to the reduction of green house gases. For example, a strong case has been made by the World Energy Council that "Should the climate threat become a reality, nuclear is the only existing technology which could replace coal in baseload". Furthermore as compared with other energy fuels the impact per unit of energy produced is much less than for the other fuels. In most cases uranium production has a positive effect on the local economy, providing for employment and other benefits. In some countries export sales of uranium make a substantial to the gross national product. These and other benefits must be given proper credit when an environmental impact assessment of a uranium production operation is conducted.

The symposium will examine the environmental and safety impacts of uranium production. Based on its deliberations, the membership should be able to develop recommendations for uranium to provide a long term, environmentally sustainable energy source for nuclear power programmes. It may be expected that the presentations will be able to demonstrate the

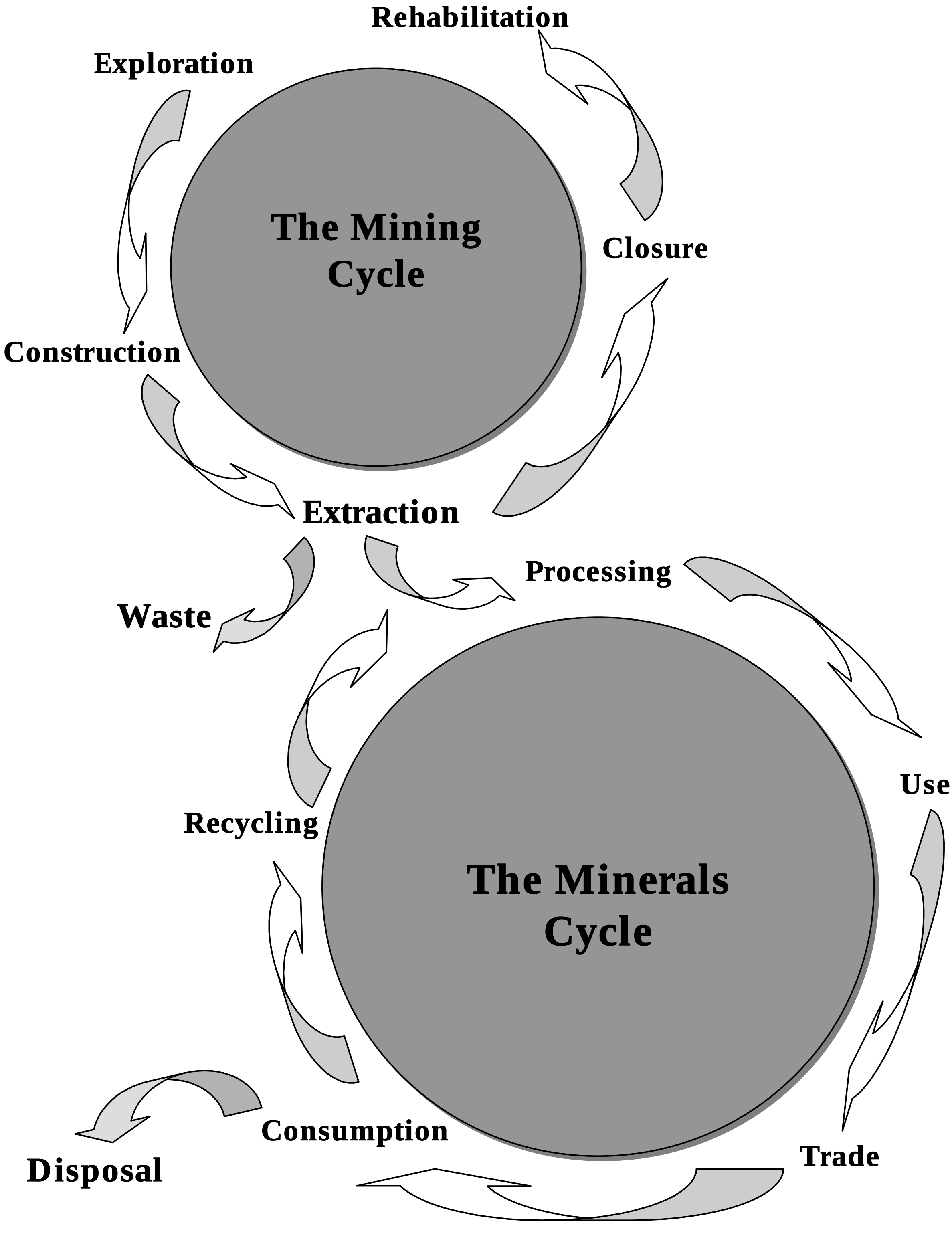
sustainability of today's uranium projects. They will also show how these projects are using improved technology, planning and best operational practice to minimize health and environmental impacts, while adapting to new regulatory requirements. The meeting participants may be expected to conclude that project operators must be responsible for carrying out all activities of the uranium production cycle. This includes the provision of financial surety, from exploration through development, production, waste management to final decommissioning and reclamation. This is fundamental if the world community is to support production of uranium which is essential for the long term benefits of nuclear electric programmes.

In this welcoming address, my intention has been to summarize the scope of the meeting and to anticipate some of the expected outcomes. This is intended to provoke thought. In closing, I would also like to express the IAEA's appreciation for all those who have made this event possible. I wish to express the IAEA's particular recognition of the participation in the Symposium of the organizations that helped to plan and organize this meeting — the Nuclear Energy Agency, the Nuclear Energy Institute, the World Nuclear Association and the Office of Supervising Scientist — Environment Australia.

Now, allow me to introduce a colleague who, for 15 years was the Supervising Scientist of the Alligator Rivers Region, northern Australia. In this statutory position of the Commonwealth Government of Australia, he led the organization responsible for oversight of the environmental and public health aspects of uranium mining developments in north Australia. During this period he was responsible for oversight of the Ranger Uranium mine and mill during its planning, development and several years of operation. I am referring to your symposium President for this week, Mr. Robert Fry. His many activities include positions in Australia, as well as in the international arena. He has represented his government in many activities at the IAEA, the OECD/NEA and the ICRP, as well as in other international organizations. One of his most recent roles was as the Technical Projects Manager of the IAEA's Evaluation of the Radiological Conditions at French Pacific nuclear weapons test sites at Mururoa and Fangataufa.

Dr. Fry is a very appropriate person to guide you to a successful completion of the symposium. Dr. Fry, I would like to express, in the name of the IAEA and of all participants in this symposium, including myself, our gratitude for accepting this challenge.

Figure1: The Minerals' System



R.M. Fry

President of the Symposium, Australia

I feel most honoured to have been invited to preside over this symposium. I am also very pleased to be able to take part in this meeting, both because it enables me to renew contact with some erstwhile colleagues, and because this week's programme provides me with a review and update of matters that occupied me during the last 20 years of my professional life but which I have not given much time to over the past few years. I am particularly pleased to see that, as well as the Nuclear Energy Institute and the World Nuclear Association, the symposium has been organised in co-operation with the OECD/NEA and the Australian Office of the Supervising Scientist. I set up the OSS 25 years ago — the current Supervising Scientist, Dr. Arthur Johnston, is with us this week — and I was much involved in the work in the 70s and early 80s of the NEA's CRPPH on radon and the long term management of uranium mill tailings.

The 70s was a time of deepening public concern over the way the world's environment was being mismanaged. The United Nations Stockholm Conference in 1972 was a focus of this concern and the concept of ecologically sustainable development (ESD) was elaborated there. The object of ESD is to meet the needs of the present generation without compromising the ability of future generations to satisfy their own needs. As applied to mining, ESD gave increased emphasis to improving environmental protection and management, particularly the management of toxic wastes during mining and milling, and in the long term. At the same time there was growing public opposition to nuclear energy. Taken together there was much pressure on the uranium mining industry to get its environmental act together giving particular attention to the long term management of uranium mill tailings, not only in new developments but in the rehabilitation of old sites. Current thinking on tailings management was developed at this time in the USA (particularly by the NRC) in Canada and Australia and in technical committees and Symposiums, such as today, of the IAEA and the NEA. Some of this work will be reviewed during the week.

The Australian Government established the OSS in 1977 following a lengthy public inquiry, the Ranger Uranium Environmental Inquiry (RUEI), into a proposal to mine uranium in the tropical far north of Australia (specifically the Ranger development). The Inquiry was wide ranging and comprehensive and the issues canvassed were very much the same as the matters we will be discussing during this week's Symposium. Among the generic issues considered were the hazards and benefits of the nuclear fuel cycle, the status of nuclear power generation and its prospects, and the future demand and supply of uranium — matters that will be reviewed in the 'Setting the Scene' Session of our Symposium. (The Inquiry concluded that the hazards associated with the nuclear power industry, and with uranium mining and milling, were not such as to justify a decision not to develop and export Australian uranium).

The major part of the Inquiry dealt with site specific issues associated with the Ranger development and foreshadowed matters that are still of concern today and with which we will be occupied for the rest of the week. The location of Ranger was such that it raised environmental, social and regulatory concerns at the extreme. Uranium, a highly politically and socially sensitive mineral, was to be mined on Aboriginal land, in a tropical wet lands area that was to be declared a national park, in a self governing territory (the Northern Territory) that was responsible for the regulation of mining, but which, in the case of uranium, was required to implement environmental conditions laid down by the Federal Government of Australia.

Based on the recommendations of the RUEI, environmental conditions were developed (in consultation with the Aboriginal land owners, the mining company and the Northern Territory Government) which had as their goal the highest level of environmental protection achievable: or, to put it the other way round, the goal was the reduction of environmental detriment to as low a level as could reasonably be achieved. Essentially this was to be done by the use of Best Practicable Technology (BPT) in all parts of the mining and milling operations – in the design of the milling circuit, in the control of the release from the site of water born contaminants (e.g. in site runoff, in mine pit water, in tailings dam seepage), in the management of the tailings and waste rock dumps, and in the decommissioning and rehabilitation of the site to ensure its long term stability. Because the mine site was eventually to be returned to the national park, rehabilitation, including re-vegetation, requirements were particularly demanding. A major theme of this Symposium is BPT in a modern mill.

BPT for Ranger was defined as 'that technology from time to time relevant to the Ranger Project which produces the minimum environmental pollution and degradation that can reasonably be achieved having regard to:

- the level of effluent control achieved, and the extent to which environmental pollution and degradation are prevented, in mining and milling operations in the uranium industry anywhere in the world,
- the total cost of the application or adoption of that technology relative to the environmental protection to be achieved by its application or adoption,
- evidence of detriment, or lack of detriment, to the environment after the commencement of the Ranger Project,
- the physical location of the Ranger Project,
- the age of equipment and facilities in use on the Ranger Project and their relative effectiveness in reducing environmental pollution and degradation, and
- social factors including possible adverse social effects of introducing new technology.

The close relationship between this definition and "radiological ALARA" will not go unnoticed. The 'economic and social factors' of ALARA have been replaced in this 'environmental ALARA' by more explicit factors related to available technology, costs relative to the protection achieved, the adequacy of the protection already being achieved, and local site conditions.

There will be much talk this week of 'minimising health and environmental impacts'; the phrase is used by the Secretariat in introducing the purpose of this Symposium. In the case of radiation exposure of humans the concept of ALARA is well entrenched and the ICRP has given some guidance on how 'optimisation' of radiation protection may be implemented, for example, by the use of incremental cost-effectiveness analysis. Various attempts (for example by the NRC of the USAEC and the CRPPH of NEA) to use such an approach to evaluate options for the long term management of uranium mill tailings, have not proved helpful, but the concept is straight forward. There is a clear end point — the induction of premature cancer in future populations — and the relation between radiation dose and the probability of inducing a health effect is defined (though this relationship, the linear non-threshold hypothesis, is scientifically questionable at low doses). Radiation detriment is said to have been minimised when it has been demonstrated that further expenditure on protection would not be justified in view of the value (in dollar terms) of the reduction of the detriment that additional expenditure would achieve.

It is not, however, at all clear how one might establish whether or not environmental detriment has been 'minimised'. There is no simple measure of the health of an ecosystem, no well-defined end point, and no simple relationship between the magnitude of the imposed environmental stress and the response of the ecosystem: and if there are difficulties in assigning a dollar value to a human life, how are environmental values to be charged? No formal monetised approach to the 'optimisation of environmental protection' would seem feasible. Even empirically, how is one to measure effects of significance in ecosystems; and having detected effects, how is one to ascertain whether or not those effects are below some level of ecological concern, and in fact are as low as can reasonably be achieved? Environmental ALARA is touched upon in one or two papers and we will hear how these matters have been addressed in the Alligator Rivers Region. There are not, I think, many ecologists among us but there may be some profit in spending time this week discussing just what 'environmental ALARA' means and how a miner might satisfy a regulator that the environmental impact of his operations has been minimised. And not only the regulator; anti uranium, scientifically competent, sceptical ecologists must also be persuaded. If society is to be convinced of the environmental acceptability of a mining operation it will be necessary to have the support of such people, or at least not their active opposition. The case to be made will need to be based on a monitoring rationale and on monitoring techniques of the highest scientific credentials.

I would like to congratulate the Secretariat and its advisers for the coherence and scope of the scientific programme we have before us; it promises to be a stimulating week.

SETTING THE SCENE

(Session 1)

F.H. BARTHEL
Germany

A. RISING
Sweden

The global energy context — chances and challenges for the 21st century

G. Ott[1]
German Member Committee of the World Energy Council

Abstract. Energy is the driving force towards economic and social development. Global demand for energy will keep growing for many years to come due to ongoing, although reduced population growth, and due to the needs of up to 2000 million people who are still without access to commercial energy. To meet this growing demand for energy, all options have to be kept open, with fossil fuels, nuclear and hydro dominating the energy mix for the next decades, and "new" renewables coming in only slowly. Considering the resulting strain on the environment, and looking at existing disparities in energy supply, the next few decades will not be free of tensions. A turning point may appear in the mid 21st century with world population coming to a halt, distinctly improved energy efficiency also in the Developing World, and with new technologies available. Thus, mainly challenges will determine the first half of the century, whereas chances are on hand for the second half of the century – **if** we act **now**. The single most important instrument to meet these challenges and to take advantage of the chances is a concentrated move towards energy efficiency and innovation, supported by market reform and appropriate regulation.

1. INTRODUCTION

Any discussion of global energy problems in the 21st century has to take into account three fundamental aspects:

First, the chances and the challenges in the first half of the 21st century will be quite different from those dominating the second half (with development of world population as the determining factor).

Secondly, energy must never be discussed in a one-sided way, but always in its interactions with the other important "E"s: the Economy, the Environment and, last not least, with Education.

Thirdly, notwithstanding rapid globalization in such elemental fields as energy, information technologies, biotechnology etc., which seem to call for global answers, it is very likely that the best answer will lie in local capacity building and local decision taking rather than in ever larger, faceless supra-national or even global bureaucracies.

2. THE 21st CENTURY – A TURNING POINT?

Within the 21st century, two different periods have to be distinguished: The next few decades, leading us, roughly, to the year 2030, and the time beyond:

- Exploring, producing, distributing and supplying energy is, even in fast-moving times like today, characterized by long lead-times. Over the next decades, therefore, no radical changes in energy trends are likely to occur. This is too short a time-frame for new technologies, changes in capital stock, different lifestyle patterns, and institutional reforms to have a major impact on a global scale.
- World population – still the decisive factor for the growing need for energy and an increasing strain on the environment – is still growing, although slower and slower. It might come to a halt before the mid of the century, thus signalling a turning point for world development as a whole.

It is for these reasons, why we can predict the decades lying immediately ahead of us rather precisely, although we can influence the actual developments only to a very limited extent. On the other hand,

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the far future has more uncertainties, but offers a much greater scope for initiating new developments. In short: The challenges are prevailing today, whereas the chances wait in the future – but only if we begin to act on them *now*!

3. THE CHALLENGES

What now are the foreseeable developments and challenges during the next few decades?

- We know that today's world population of 6 billion people will continue to grow, according to the latest estimates to as much as 8 billion people in 2020, and 9 billion people in 2050 (1900: 1,6; 1950: 2,5).
- We know that this growth in world population will lead to a growing need for energy: 13 G toe in 2020 and up to 20 G toe in 2050 are not an unrealistic expectation (2000: 10 G toe). Growing need for energy, by the way, means in particular a growing demand for electricity. These dry figures conceal alarming specific developments: Rapid urbanization – by 2050, more than half of the world's population will live in big cities; rapid increase of the "car population" of the world – 700 persons per car in China as against less than 2 persons in the USA is a rather threatening potential; and, consequently, a steady growth in CO_2–emissions.
- We know also that meeting this demand for energy will be possible only, if we can provide on a global basis sufficient – and "sufficient" here means large additional – quantities of oil, coal, natural gas, nuclear, hydropower.

Some question the need for fossil fuels and nuclear, recommending different priorities: Saving energy, and development of wind, solar, biomass and other "new" renewable energies. Unfortunately, these priorities are – at least for the next decades – illusions rather than real options:

Saving energy *will not be able to stop the growing demand for energy. At best, saving energy can help to delay this process, mainly in Industrialized Countries which have the necessary know-how and finance available. Energy saving in Developing Countries is quite a different story, not to mention the almost 2 billion people who have to exist without any access to commercial energy – "saving" energy certainly is no solution to their problems!*

New Renewables *are a nearly unlimited supply for energy if one considers the energy needs of mankind compared with the energy we receive from the sun. They are also mostly domestic or local and therefore secure. The trouble is that new renewables cannot generally compete with conventional energy sources or replace them without large subsidies. However, this does not mean that it is not worth promoting renewables to benefit from the likely economies of scale and learning curves that increased deployment and competition will bring. In 2020 new renewables could contribute some 5% and in 2050 well over 10% to global energy supply. To achieve a more rapid growth, the underlying additional cost would be enormous.*

The contribution "new" renewables can make realistically in the foreseeable future should be aimed not at substituting fossil fuels or nuclear, but at substituting so-called non-commercial energies, which in many discussions are overlooked, although they are a serious problem on the way to achieving a sustainable energy supply:

Non-commercial energy *still represents 14% of the world's total final energy consumption, most of it taking place in developing countries, and just over 12% of the world's total primary energy supply. Most of this energy (fuel wood, crop wastes and animal dung) is not sustainable unless it is developed into modern biomass. It still represents almost double the quantity of energy supplied by hydropower, and nearly six times the amount supplied by "new" renewables. It is to be feared that "traditional" non-commercial (mostly biomass and wastes) contributions will remain on the same level of annual consumption to 2020, unless modern biomass or other "new" renewable energies can be brought in as a substitute.*

- We then know, or should know, that securing a sufficient supply of energy – which we, living in Industrialized Countries, tend to take for granted – is everything but a natural thing to Third World countries. For them, it is an enormous challenge. Energy poverty for many countries is not just empty words but a serious threat.

Without an adequate supply of energy, however, it will hardly be possible to break the vicious circle of poverty and uncontrolled consumption of natural resources, nor will it be possible to improve the standard of living in the Third World. "Improved standard of living", in this context, by no means is the standard of living we have become used to in many affluent societies of the West. To call for a better standard of living in the Third World rather is aimed at fighting mass poverty as it still exists in large parts of Latin America, Africa and South Asia, is aimed at the 25% of the world population which still today are without clean drinking water, and is aimed at the 15 million children who die each year unnecessarily from malnutrition or diseases.

- Furthermore, we know that the next few decades may bring far-reaching geopolitical changes and shifts. Just a few facts and figures may serve to illustrate this: Twenty years from today, less than 20% of the world's population will live in Industrialized Countries (consuming, however, the major part of all energy produced), whereas more than 80% live in the so-called "Third World" (having to be content with consuming the remains). Or take resources: More than 80% both of the global oil and the global natural gas resources are concentrated in only two regions or the world which are certainly not amongst the most stable ones – the former Soviet Union and OPEC-Countries. A run of resource-poor regions, such as Western Europe and Asia-Pacific, for access to these vital resources is more than just a theoretical possibility, and such a run might well develop into a fight, hopefully carried out with peaceful weapons only. These are just some of the disparities and discrepancies typical for today's global energy picture. Should they persist, they might very well lead to serious political tensions, reaching beyond the sector of energy.

- Finally, we are becoming more and more aware of the severe test to which we put the environment of our globe due to the dominance of fossil fuels which is bound to continue for at least a few decades more.

4….AND CHANCES?

The perspectives for the decades lying immediately ahead of us, which I have just mentioned, namely increased world population, increased energy demand, increased strain on the environment may seem threatening. And yet there is no reason to despair, to fall into resignation, or pessimism, because there are a number of long term factors which justify a "guarded optimism" for the second half of the 21st century:

- Population growth rates have already started to decrease in many, if not in most countries. It should be noted, however, that such a slow-down of growth rates, which eventually will lead also to a lower demand for energy, always goes hand in hand with – or rather is the consequence of – a positive economic development. In other words: Only where the minimum subsistence level is guaranteed, there is the willingness and the ability to learn, which again is the precondition not only for family planning but also for a more rational and efficient use of energy.

The same, by the way, is true for man's approach to and use of the environment: As long as he has still to fight for his own survival, he will not give much thought to preserving the environment – consciousness for the environment has come and will come only from and through prosperity.

- As just mentioned, economic development in the Third World will eventually – as was the case in all Industrialized Countries – lead to higher energy efficiency, thus easing the pressure from an ever growing need for energy.

- As another positive factor, we can be certain that a few decades from now, and for the rest of the century new, more efficient energy technologies will be available. Nobody can predict exactly today whether this will be the fuel cell, hydrogen or nuclear fusion. We know from experience, however, that technological development is not loosing, but gaining speed. Obviously, such developments will not come by itself. This means that we have to invest in them – on the broadest possible scope, and careful not to rule out any specific technology too early – already today, even if we can expect to reap the benefits only tomorrow, or even later.

To illustrate that the future holds many surprises indeed, let me give you a little piece of experience from the past:

In the thirties, the American President Franklin D. Roosevelt commissioned his administration to undertake a vast study of the coming technologies. When the study was published it made a very big impression. There was just one problem: it had not predicted the coming of television, nor that of plastic, or jet planes, or organ transplants, or laser beams, not even of ball-points pens!

5. THE STRATEGY: BRIDGING THE GAP

What is the conclusion, now, from the fact that the challenges lie immediately ahead of us, whereas the chances become visible and tangible rather in the future? The logical consequence is, I think, to follow a strategy of “bridging the gap”. The gap – this is the period of the next 30 years, after which we can expect an easing of tensions due to a reduced growth of world population, increased energy efficiency and the benefits of new technological developments. Such a bridge to the future cannot, however, be built on black-or-white solutions, nor on utopias or on illusions. What is needed, is action based on reality, which means above all two things:

- First, in order to solve the short and medium-term problems, we need the intelligent and responsible use of fossil fuels and of nuclear energy on a worldwide level, combined with resolute energy efficiency measures, and with the enhancement of “new” renewable energies.

- Secondly, in order to prepare ourselves for the far future, we need long term research and development, opening up horizons for altogether new energy systems.

Again: It will only be towards the mid, and in particular during the second half of the 21^{st} century, that population growth may come to a halt. Then, and only then, we shall see greenhouse gas emissions stabilized or decreased. Then, and only then, will new energy systems such as fuel cells, solar, advanced nuclear technologies, super conductors etc. be likely to come on stream. But, if all of this is to become reality, we must start taking the necessary decisions *now*.

Above all, we need a realistic approach. It is far better to act and use even modest tools available now than to dream of, or wait for solutions achievable only in the future. Two practical examples may serve to illustrate this: The – literally – burning problem of slums in the megacities of Africa, Asia and Latin America can hardly be solved with the idea, tempting as it may be, of constructing strictly biologically designed buildings like the one used by Amory Lovin’s Rocky Mountain Institute. And the 1.5 litre automobile, built with carbon-fibre, will hardly be available in time to stop the avalanche of motorization just begun in China, India and elsewhere.

6. THE GOALS: ACCESSIBILITY, AVAILABILITY, ACCEPTABILITY

A detailed discussion of these three energy goals can be found in the World Energy Council's Statement 2000 "Energy for Tomorrow's World – *Acting Now*!" Here it may suffice to highlight just the most important aspects.

Accessibility to modern energy means that energy must be available at prices which are both affordable (low enough for the poorest people) and sustainable (prices which reflect the real costs of energy production, transmission and distribution to support the financial ability of companies to maintain and develop their energy services).

This definition may sound rather theoretical, but the problems concealed by this formula are very real: It is the problem of the 1.6 billion people who do not have such access to commercial energy, a number, which could grow to 2 billion in the year 2020; the growing problem of supplying both exploding megacities and remote rural areas with the appropriate energy; the problem of non-payment, a serious signal of social problems (and often aggravated by the process of liberalization).

Availability covers both quality and reliability of delivered energy. The continuity of energy supply, particularly electricity, is essential in the 21st century. Unexpected power cuts bear a high cost for society that cannot be ignored. The world's growing reliance on information technologies makes reliability even more critical. Energy availability requires a diversified energy portfolio consistent with particular national circumstances. It should be obvious that all energy resources will be needed over the next 50 years, and that there is no case for the arbitrary exclusion of any source of energy.

Speaking here at the IAEA, obviously calls for a particular word on the future role of nuclear, as seen by the World Energy Council:

(a) At present, with providing 18% of global electricity production, and as a $C0_2$ – free energy source, nuclear energy plays an important role globally and in many countries which base the better part of their electricity on nuclear.

(b) While the future of nuclear power is questioned by some WEC members, the great majority of WEC's almost 100 Members Committees believes that the role of nuclear power needs to be stabilized with the aim of possible future extensions.

(c) Nuclear is still a relatively young industry, both in terms of technology and in terms of institutional management. A number of problems, therefore, are still on the nuclear agenda: long term demonstration of operational safety, the treatment and disposal of waste, risks of proliferation to name a few. Another concern is the general feeling that nuclear is a "secret" industry which provides limited and sometimes biased information and which is not democratically controlled.

(d) To secure a role for nuclear in the global energy mix also in the future, it is imperative, therefore, that the nuclear industry must become completely transparent, impartially regulated and controlled, and accountable for its safety and economic record, with waste disposal as a major concern for winning acceptability.

(e) Should, however, the present stagnation in nuclear power development in some countries lead to a long term worldwide decline of nuclear power, it has to be clearly seen that the goal of reducing greenhouse gas emissions would be jeopardized unless there were a break-through in terms of increased energy efficiency, in the cost of new renewables, or in the commercial availability of carbon sequestration technologies.

Acceptability is an issue for both traditional and modern energy This covers many issues: Deforestation, land degradation or soil acidification at the regional level; indoor or local pollution such as that which exists in Africa and Asia from burning traditional fuels, or in China or South Africa because of poor quality coal briquettes; greenhouse gas emissions and climate change; nuclear security, waste management and proliferation; and the possible negative impact of the building of large dams or large-scale modern biomass developments.

In this context, a few principal remarks on **environmental problems** may be in place:

(1) Energy and the environment must not be seen as an alternative, or even as a contradiction: Those who want to develop or use energy have to take into account the possible impact on the environment ("eco-audit", in fact, is becoming more and more the state of the art). Those who want to protect the environment, will have to realize that this, in most cases, requires the direct input of energy and, in all cases, an economic basis for which again energy is an indispensable requirement.

(2) Regrettably, the issue of environment very often is discussed in a too narrow and in a one-sided way:

- Too narrow, because in many discussions environmental problems are dealt with as being identical with the problem of climate change – obviously an unjustified simplification and a much too narrow approach: For the majority of the world's population, it is not climatic change, but other environmental problems – contamination of air, water and soil – which give cause for concern, and which are considered as alarming.

Those who are in danger to suffocate with the smog and dust obscuring the megacities they have to live in – or think of the recent garbage avalanches in Bombay and Manila! – will hardly think of the possibility of a climate change in the next century as a real threat.

- Too isolated, because improving the environment in our Western countries has only a very limited global effect. The environmental problems will shift more and more from Western countries to the Third World: Within a few decades, more than 80% of the total world population will be living in this Third World. The consumption of energy, which will more or less stagnate in our Western countries, will triple in the Third World. The consequences for the environment: Nearly 70% of the global sulphur and dioxide emissions, and almost 60% of the global $C0_2$–emissions will soon come from these countries.

(3) We, who live in Industrialized Countries, therefore, should not be content with keeping our own house in good order, because even with ever higher absolute investments the achievable improvements in energy efficiency will become smaller and smaller. Our financial capacity, our technical know-how is better placed in the Third World, where with the same US-Dollar, the same Euro, the same British Pound a much higher improvement of efficiency can be achieved.

(4) As to the specific problem of a possible climate change, a dual strategy should be followed:

- Firstly: Intensification of the scientific work on climate change, in order to clarify the still existing grave scientific uncertainties, and in parallel

- Secondly: Intensification of all activities aimed at improving energy efficiency, because such activities also help to reduce $C0_2$–emissions – "minimum regret policy" or "win-win-strategy".

Let us hope that such a dual strategy will be carried out through solid technical and scientific work, undisturbed by excited or even sensational public and political discussion as was – regrettably – so often the case in the past.

(5) Apart from all arguments, facts, figures, modelling etc., we would be well advised, I think, to remember from time to time that neither the environment nor the climate is something static, but has always undergone change. Therefore, not every change of the climate or the environment is, by law of nature or by necessity, a catastrophic event.

7. THE INSTRUMENTS

There are long lists and catalogues of instruments to be used, and of actions which should be taken on the different levels. I am not going to repeat all of them here, but will restrict myself to highlighting the two decisive aspects:

All listed instruments and actions, although differing in detail, have one common denominator, namely the improvement of **energy efficiency** on all levels of production, transportation and use of energy. Whether you take the extraordinary technical achievements in the oil & gas sector – unfortunately overshadowed by events like Exxon Valdez or Brent Spar – or the drastic reduction of emissions from coal-fired power plants, or many other examples: They all – through improved efficiency – serve more than one purpose: Reduction of production cost, extension of the lifetime of resources, protection of the environment. A concentrated move, a campaign directed towards efficiency improvement and innovation is therefore the best we can do, both under energy and environmental aspects, at the beginning of the 21st century!

Obviously, such programmes will require high investment and – equally important – a reliable policy framework for the energy sector. It is for this reason that the World Energy Council is opening its recently published decalogue of Policy Actions for the 21st century with: “Reap the Benefits of **Market Reform** and Appropriate Regulation”.

It would lead too far to discuss all these actions here in detail. The wide range and the weight of these recommendations is well enough illustrated, however, by quoting the titles:

(1) Reap the Benefits of Market Reform and Appropriate Regulation
(2) Keep All Energy Options Open
(3) Reduce the Political Risk of Key Energy Project Investments
(4) Price Energy to Cover Cost and Ensure Payment
(5) Promote Greater Energy Efficiency
(6) Foster Financing Partnerships Linked to Environmental Goals
(7) Ensure Affordable Energy for the Poor
(8) Fund Research, Development and Deployment
(9) Advance Education and Public Information
(10) Make Ethics a Strong Component of Energy System Governance

8. THE MESSAGE

What, now, are the prospects, what is the overall message for the 21st century as to the two critical and crucial concerns – Energy and Environment?

On a broader basis, TIME Magazine in its last edition of the year 1999 had identified three truly historical developments which came out of the last century, and which will impact and determine also the future. They were:

— the emergence of democracy as the dominating form of government, together with its economic twin, the market economy;
— the recognition of civil rights, for which people like Mahatma Ghandi, Martin Luther King, Nelson Mandela and others have taken up the fight;
— and finally the progress of science and technology as the very motor, the driving force of change in human life.

It will be science and technology also in our field of interest, Energy and the Environment in the 21st century, I think, which will help us to find the right answers, and which justifies an overall message of "guarded optimism".

Powerful as science and technology can be as a driving force in devising innovative ways of utilizing the resources of the world, they have to be – and this is an equally important part of the message – acceptable to society. M. Menon, the famous Indian scientist and philosopher, called this *"Combining Science and Wisdom to build Bridges with Society"*, pointing out that sustainable development cannot be brought about through a purely technological fix. To understand and respect this link, this inner connection is the challenge and test before us as we seek from science new solutions that will – to quote the World Energy Council's Mission Statement – *"promote the sustainable supply and use of energy for the greatest benefit of all"*.

Analysis of uranium supply to 2050

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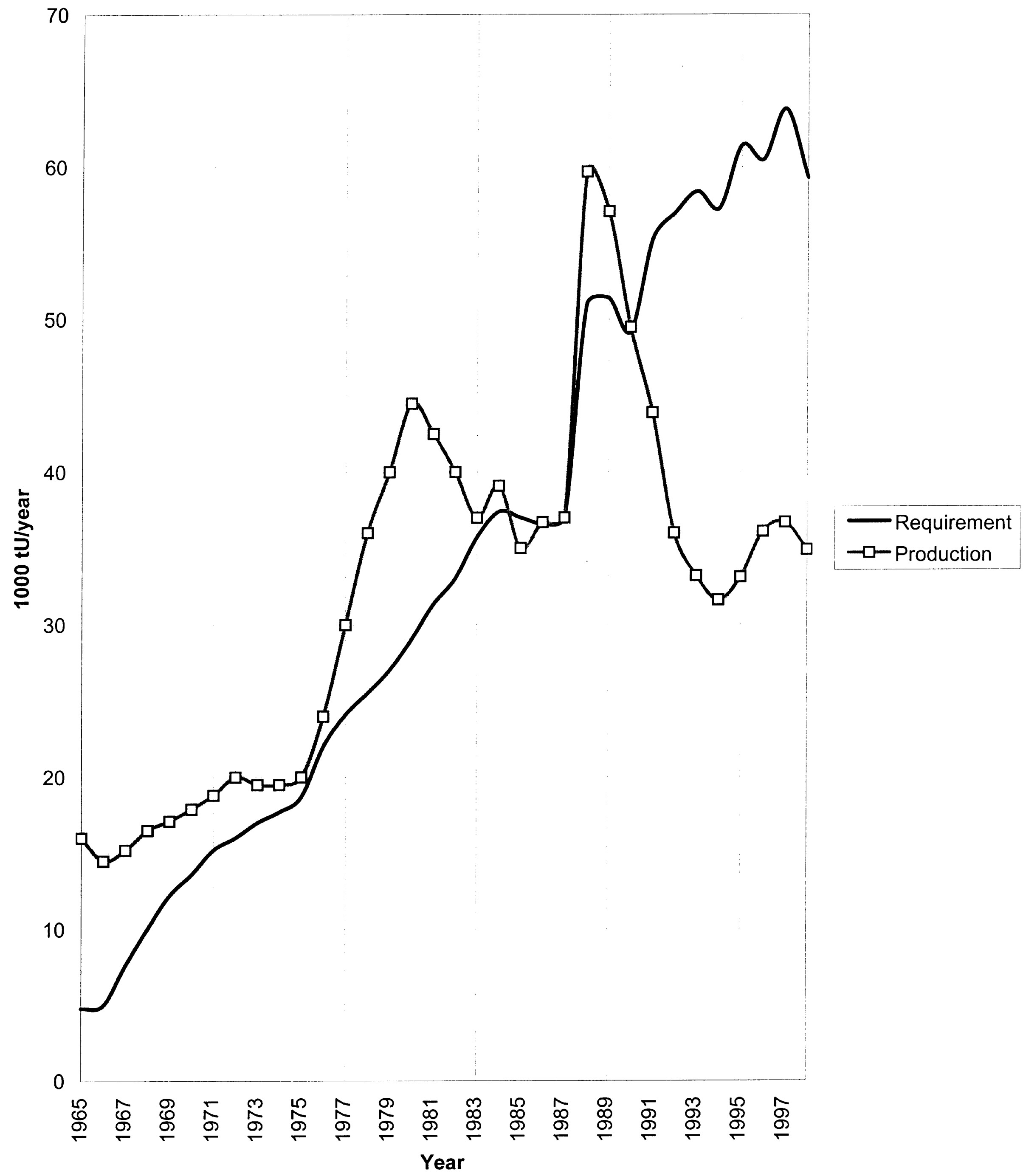
Abstract. The 1999 uranium mine production was about 55% of the 61 500 tonnes uranium (t U) used by the nuclear industry, with the balance met by secondary supply. Based on a recent WEC-IIASA study which defines a wide range of possible future levels of nuclear electricity generation, it is estimated that by 2050 annual uranium requirements could increase to 177 000 and 283 000 t U respectively, in the mid and high cases, or fall to 52 000 t U in the low case. Cumulative requirements to 2050 for the low, mid and high cases are, respectively 3.39, 5.35 and 7.58 million t U. A new IAEA analysis describes how known uranium resources (RAR and EAR-1) plus undiscovered resources (EAR-II and SR), supplemented by secondary supplies, could be utilized to supply reactors to 2050. Secondary supplies include: existing inventories, blended down warhead material (LEU blended from HEU), MOX, Repu, and re-enrichment of tails. The methodology of this analysis estimates the amounts and annual deliveries of the secondary supply, plus non-market supply. The balance of demand is met from Market Based Production (MBP) or: "Uranium produced at or below market price to satisfy requirements not met by other supply sources". The analysis then evaluates the production role for 125 uranium deposits, which supply MBP considering individual deposit resources, production cost and capability, and timing. Production costs are classified from low (<\$33.80/kgU), to very high (>\$130/kgU). Annual supply and demand balancing is used to allocate the resources on an individual deposit basis, assuming use of the next lowest available cost production. Secondary supplies will continue to supplement mine production to about 2025, but their relative importance will decrease over the period. An analysis of the benefit of lowering the enrichment tails assay from 0.30% ^{235}U to 0.15% ^{235}U, when economically justified is also discussed. The report also discusses projected production cost trends to 2025 under the mid and high cases. The final conclusion is that significant exploration efforts will be required to discover new large, low-cost deposits, or it may be necessary to rely on resources with a very high production cost (i.e. >\$130/kgU). Because of the long lead times for discovery, environmental assessment and project development, exploration will need to be started within the next few years if the discoveries are to have an impact on uranium supply prior to 2050. It will also be necessary to convince the world community that uranium can be produced with acceptable environmental impacts if projects are properly planned, operated and closed.

1. INTRODUCTION

Nuclear power is expected to be an important part of the worldwide energy mix at least through the next 50 years and by most projections well beyond. That is, of course, provided an adequate supply of uranium is available to sustain the nominal growth rate for nuclear power of 1 to 3% per year that is projected by many analysts. The importance that a reliable supply will have on the future of nuclear power led the IAEA to undertake a study of uranium supply-demand relationships through 2050. The ultimate goal of the study is to evaluate the adequacy of supply to meet demand, and to characterize the level of confidence that can be placed in the projected supply. This report describes key conclusions of the study. A detailed report describing the results of the study is available as an IAEA special publication.

Uranium supply-demand projections must realistically account for a broad range of uncertainties. On the demand side of the equation, there is a wide range of opinions as to the future of nuclear power. Even when there is agreement on power projections, there may be considerable disagreement as to the mix of reactor types that will eventually fill the projections. Similar uncertainties also characterize the supply side of the equation including availability of secondary supply, impact of environmental opposition to uranium mining and the lack of incentive to explore for and develop new deposits in the face of the depressed market. To accommodate these uncertainties it has been necessary to consider a range of supply and demand projections.



Excludes the following countries because detailed information is not available: Bulgaria, China, Cuba, Czech Republic (and preceding states), GDR, Hungary, Kazakhstan, Mongolia, Romania, Russian Federation, Slovenia, Tajikistan, Ukraine, USSR, Uzbekistan, and Yugoslavia

FIG. 1. Relationship between newly mined uranium and reactor requirements in selected countries.

FIG. 2. Relationship between newly mined uranium and worldwide reactor requirements 1988–1998.

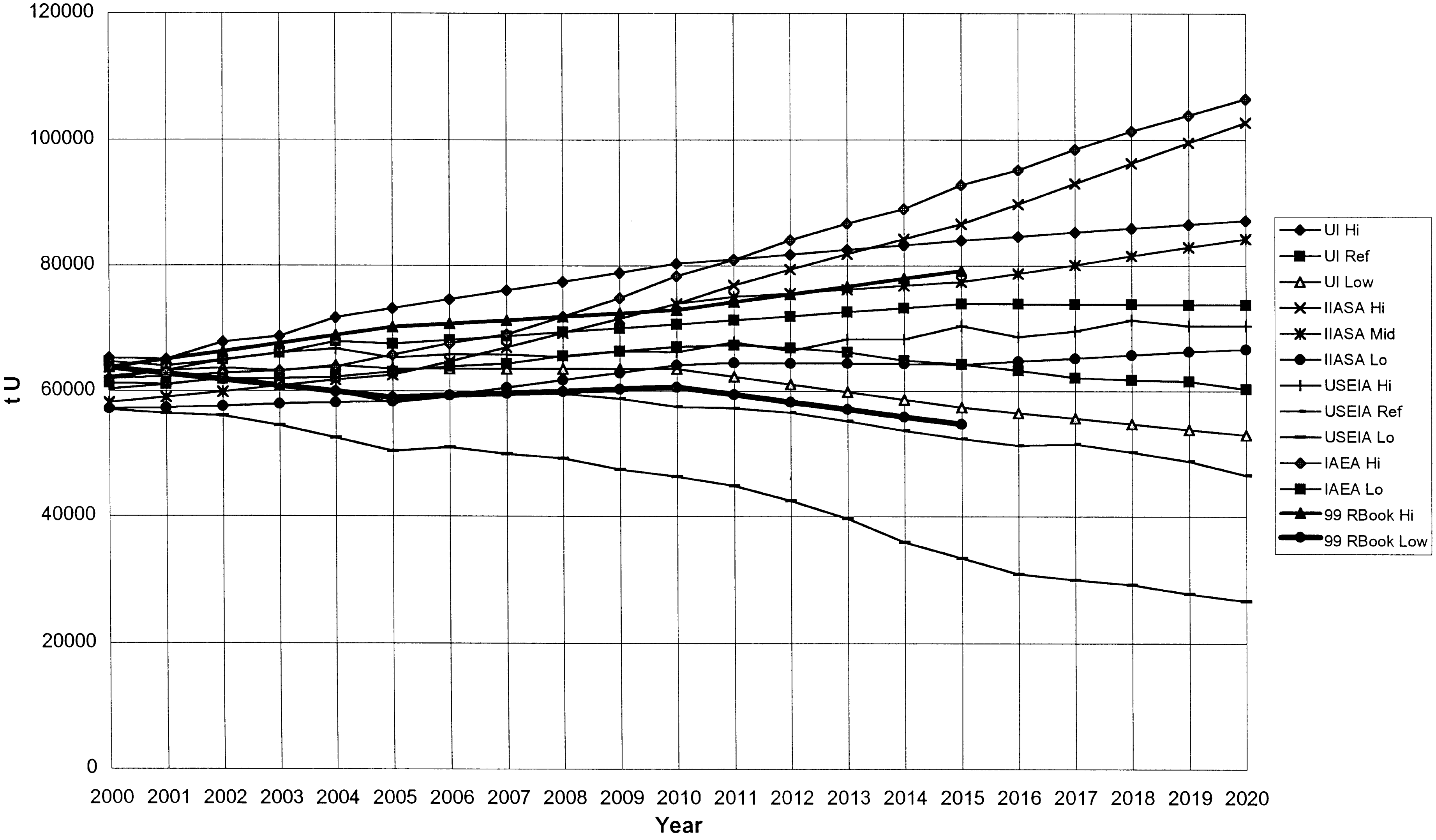


FIG. 3. Previously published projections of annual uranium requirements to 2020.

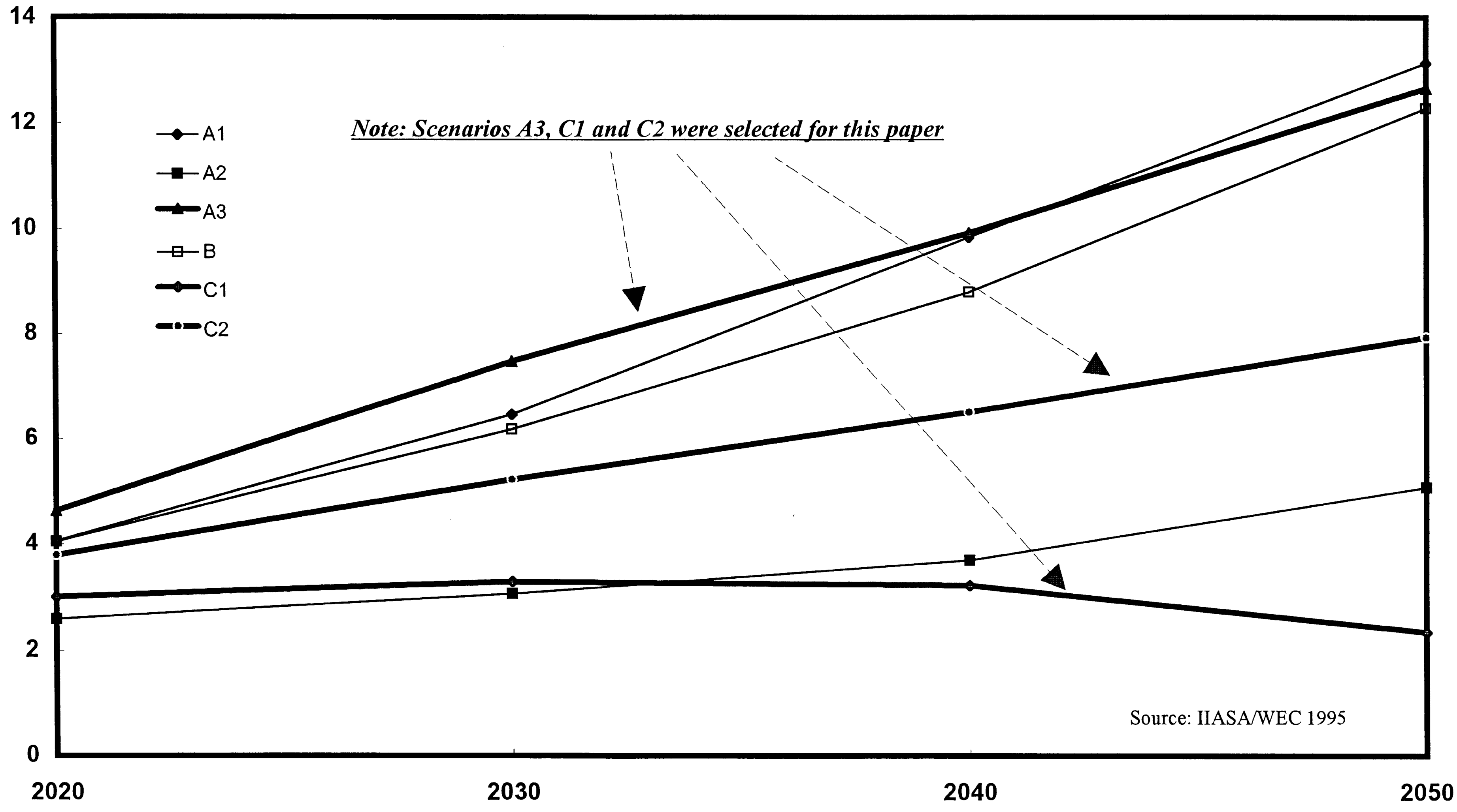


FIG. 4. IIASA/WEC scenarios to 2050 —nuclear generation (10^3 TW(h)).

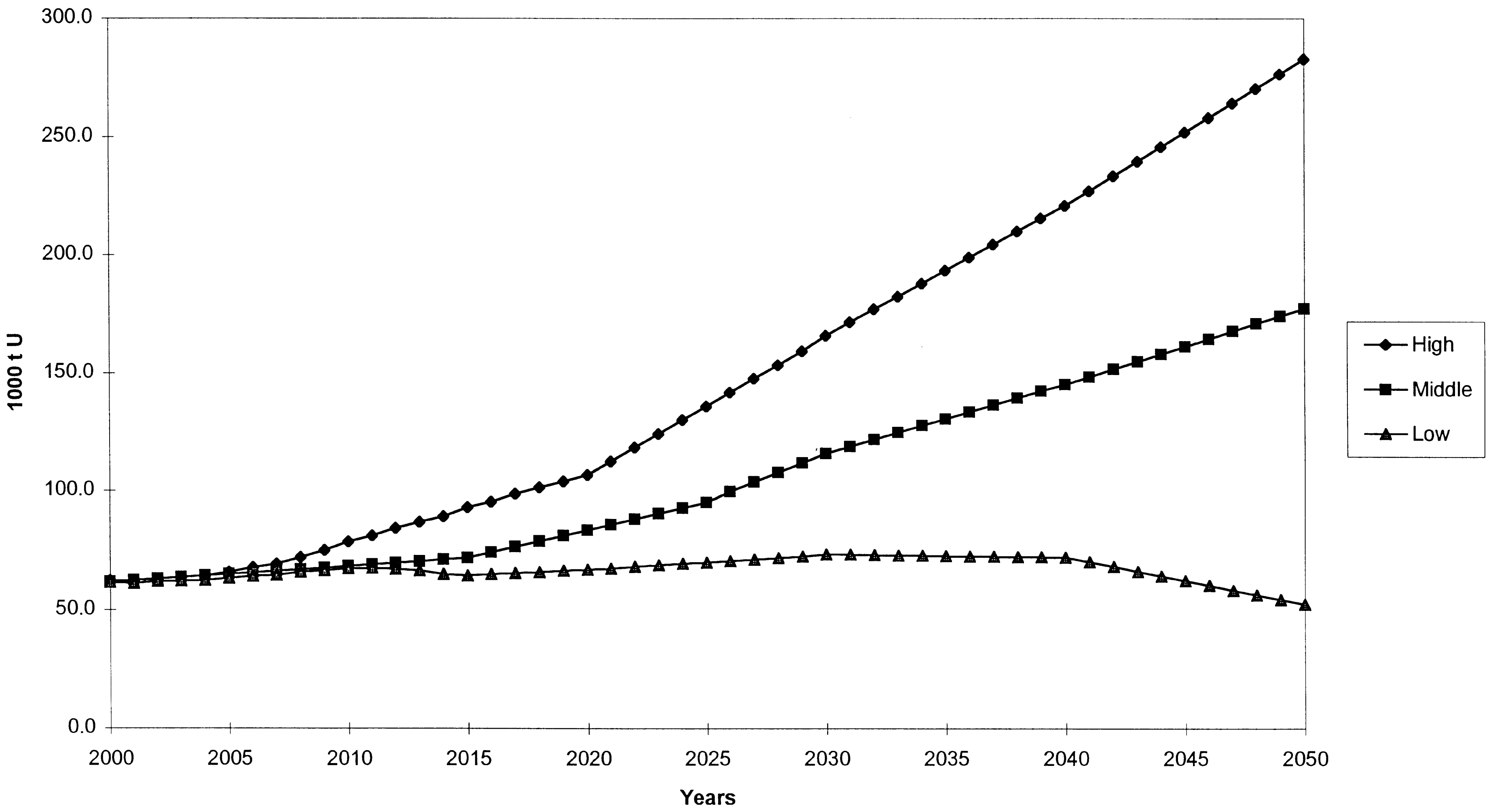


FIG. 5. Projections of annual uranium requirements 2000 to 2050.

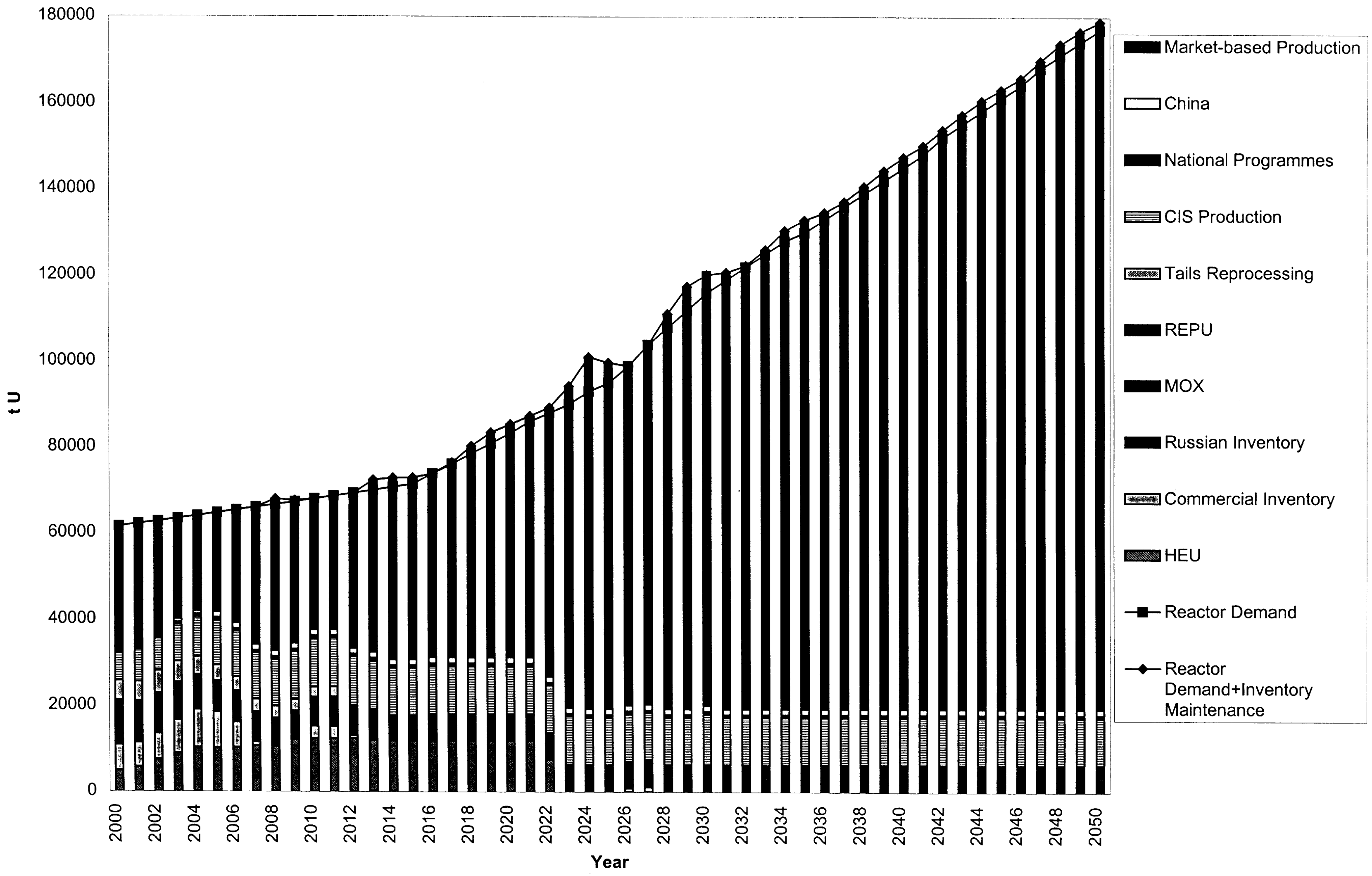


FIG. 6. Uranium supply-demand relationship 2000 through 2050 — middle demand case.

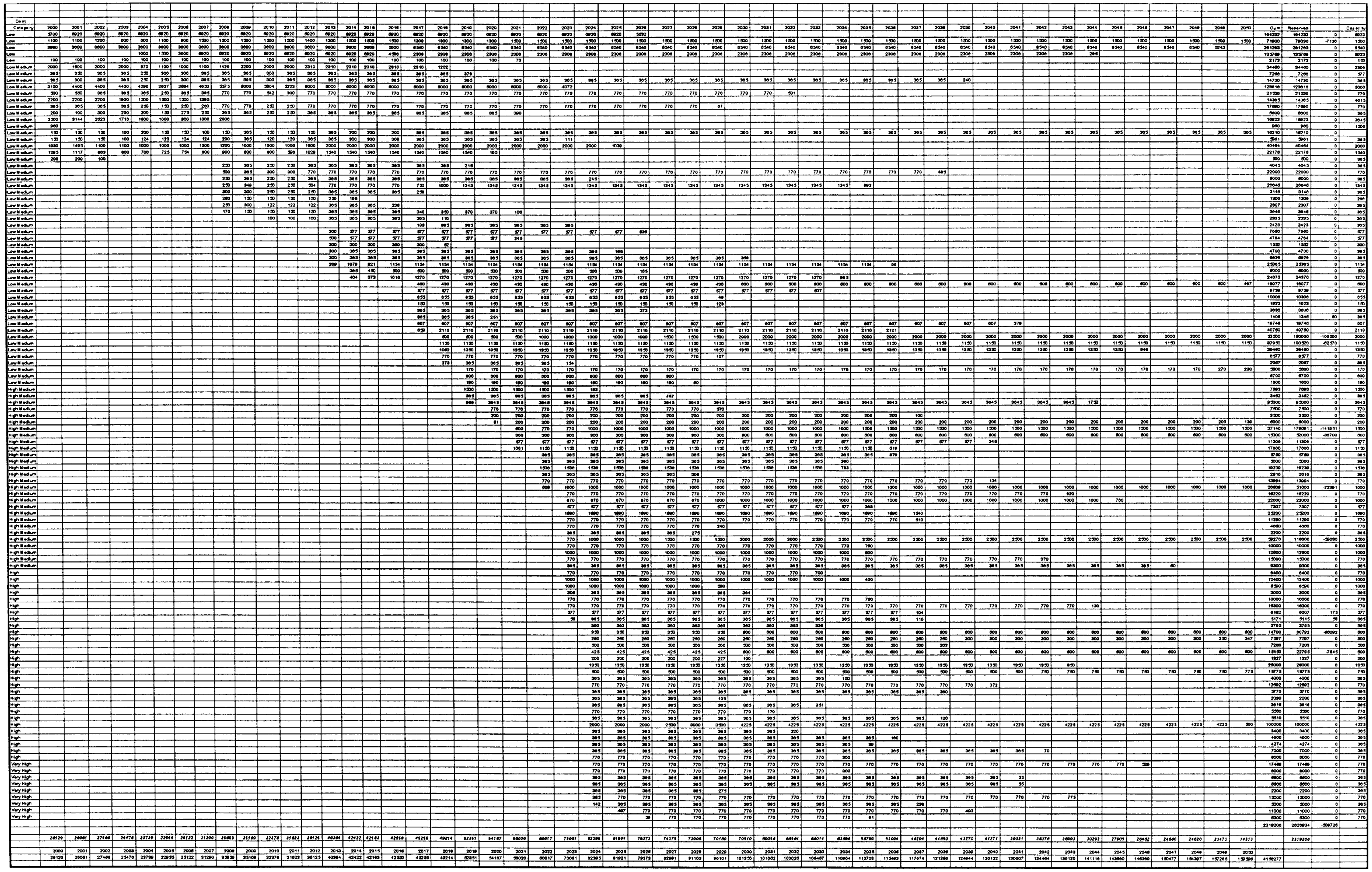


FIG. 7. Practical supply-demand balancing for market-based production — middle case study RAR.

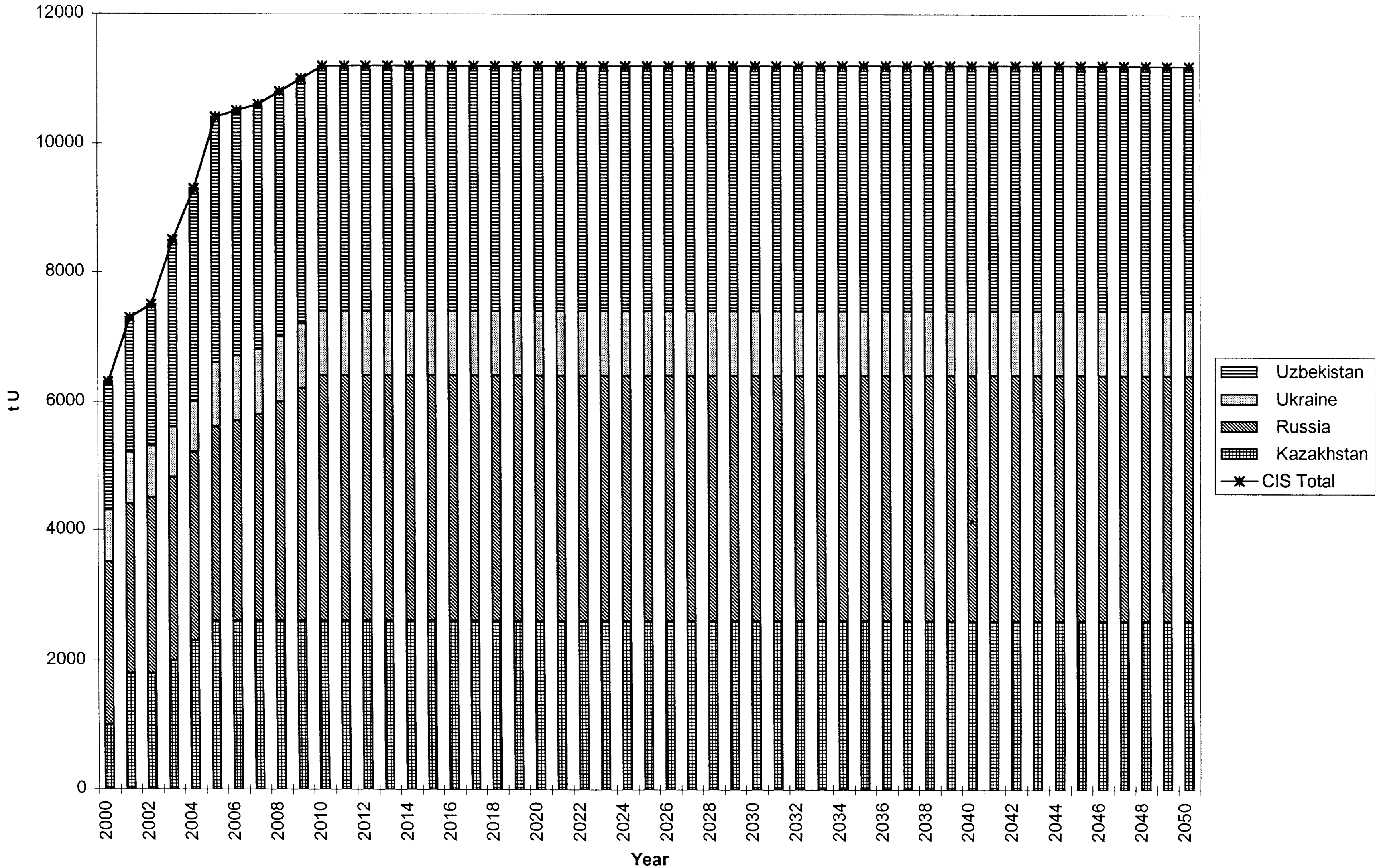


FIG. 8. Projection of annual CIS production to 2050 — conservation scenario.

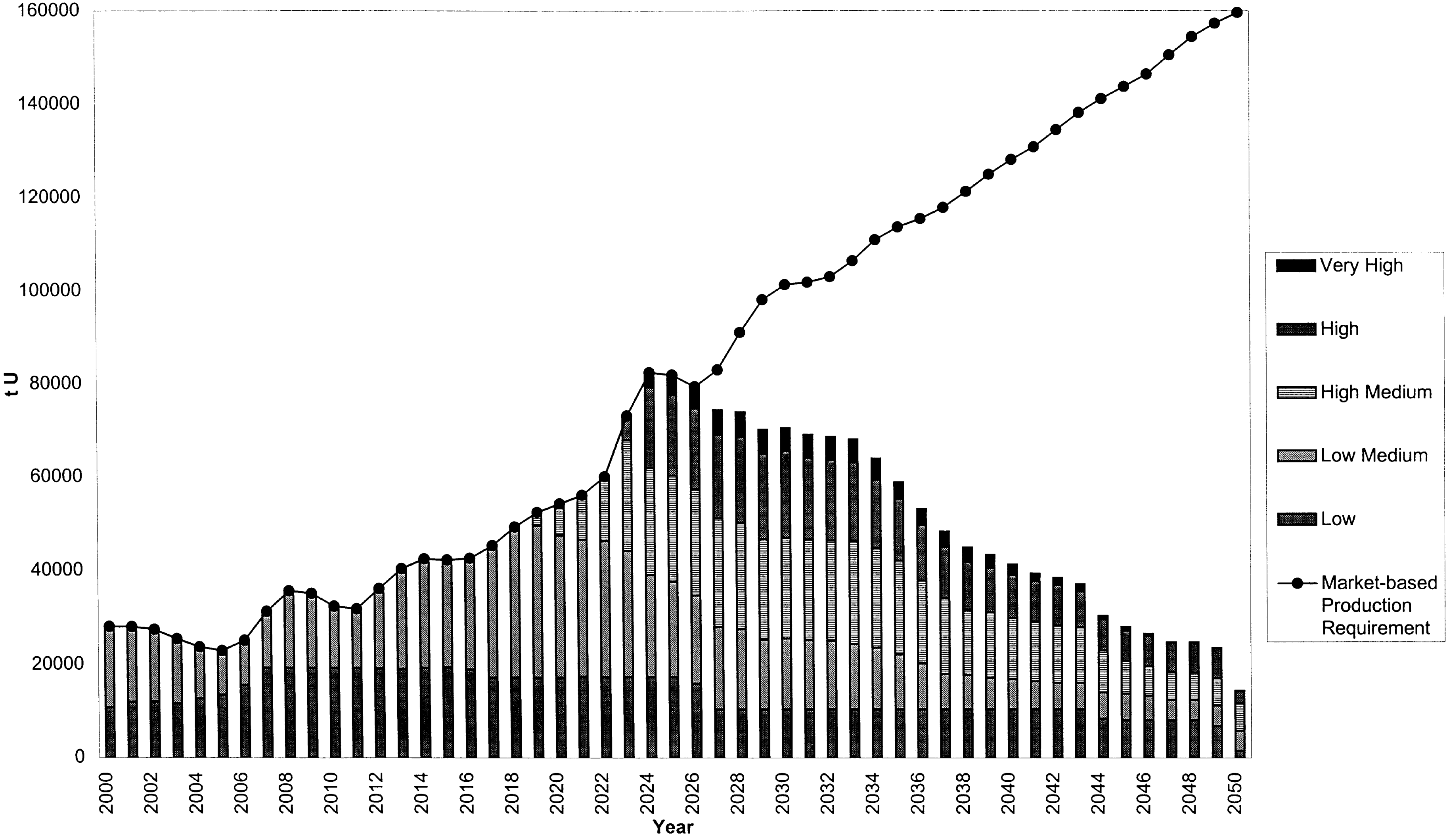


FIG. 9. Projection of market-based production from study RAR by cost category — middle demand case.

To understand the future of the nuclear fuel cycle, one must first understand its past. Fig.1 shows the relationship between Western production and reactor requirements from 1965 through 1998. Fig.2 shows a near-term comparison between production and requirements that also includes the former Soviet Union and the Eastern bloc countries. Early forecasts predicting a dominant role for nuclear power were overly optimistic. Consequently, in each year prior to 1983, Western production exceeded reactor requirements, leading to a significant inventory build up. Since about 1983, however, Western reactor requirements have exceeded production; the deficit between requirements and production has been filled by a combination of secondary supply and imports from non-western countries. Draw down of secondary supply is expected to be important in the near-term, but at some point this finite supply will be reduced to strategic levels, and newly produced uranium will clearly become the dominant supply source. Therefore, the objective of this report is to evaluate the adequacy of uranium supply to meet demand through 2050. The following steps were taken in completing the study:

- Establish annual world-wide reactor demand.
- Identify all sources of uranium potentially available to fill reactor demand, including both primary and secondary supply.
- Determine the most likely contribution that each source will make toward satisfying annual demand.
- Establish known uranium resources and evaluate exploration requirements to convert lower confidence resources to higher confidence categories.
- Assess the adequacy of projected supply and broadly define market prices required to ensure supply availability.

2. DEMAND

Projecting worldwide reactor uranium requirements (demand) for the next 50 years requires detailed analysis involving a number of uncertainties. The process begins with estimates of total energy demand, followed by projections of the role that nuclear power will play in satisfying that demand. Once nuclear power's role in the total energy mix is established, there still remains the question of how to model the fuel cycle that will satisfy nuclear requirements. Issues such as numbers and types of reactors, load and burn up factors and reprocessing-recycling strategies are only a few of the variables that must be resolved in modelling the nuclear fuel cycle. Once the fuel cycle is modelled, an estimate of uranium requirements can be established. The final step in the process is to project how these requirements will be met.

Several sources were used to project demand between 2000 and 2020. As shown in Fig.3, there is a broad range of opinions as to annual uranium requirements through 2020. Most published forecasts of energy demand and the role of nuclear power end in 2020. There is, however, one notable exception – Global Energy Perspectives, published jointly, by the International Institute for Applied Systems Analysis and the World Energy Council [1]. This study (hereafter referred to as the IIASA/WEC Study) provides a comprehensive analysis of energy use through 2050, which is used in this report to provide the basis for projection of long-term uranium requirements. Fig.4 presents the projection of nuclear electric generation developing in the IIASA/WEC study. These projections are the same as the "Nuclear variants" in "Key Issue Paper No. 1" presented at the IAEA's "International Symposium on Nuclear Fuel Cycle and Reactor Strategy: Adjusting to New Realities" held on 1-6 June 1997 [2]. Studies by the IAEA [3] and the International Institute for Applied Systems Analysis and the World Energy Council were used to extend demand projections to 2050. Information from these sources was combined to establish three demand projections that cover a broad range of assumptions as to worldwide economic growth and related growth in energy and nuclear power (Fig.5). The cumulative uranium requirements through 2050 for these demand cases and the economic assumptions on which they are based are as follows:

	Cumulative Requirements 2000 to 2050 (t U)	Economic Assumptions
Low demand case	3 390 000	Medium economic growth; phase out of nuclear power by 2100
Middle demand case	5 394 100	Medium economic growth; sustained but modest growth for nuclear power
High demand case	7 577 300	High economic growth; significant development for nuclear power

3 .URANIUM SUPPLY

3.1. Methodology

Uranium supply is broadly divided into two categories – primary and secondary supply. Secondary supply includes HEU, natural and low-enriched uranium inventory, MOX, reprocessed uranium (RepU) and re-enrichment of depleted uranium (tails). Primary supply includes all newly mined and processed uranium. In the middle demand case, in 2000, primary and secondary supply are projected to cover 58% and 42% of demand, respectively. However, by 2025 secondary supply's contribution is projected to drop to only 6% of demand. In the middle demand case, primary and secondary supply are projected to supply 89% and 11% of cumulative demand through 2050, respectively.

Primary supply is divided into two broad categories – that which is not constrained or controlled by market conditions, such as production in the CIS, China and the small national programmes, and production that is market-based. Market-based Production requirements are determined by subtracting the total of secondary supply and primary supply from the CIS, China and the national programmes from annual demand. Fig. 6 shows the role that each of the supply components is projected to play in filling the middle case demand.

Assessing the adequacy of uranium resources to satisfy Market-based Production requirements is the main focus of this report. Resources are categorized by confidence levels using IAEA/NEA terminology, from the highest confidence known conventional, resources (RAR + EAR-I) to lower confidence undiscovered resources (EAR-II and Speculative Resources). Production centres and their associated resources are also ranked by projected production cost within the cost categories shown in Table I.

TABLE I. PRODUCTION COST CATEGORIES

Cost Category	\$/kg U	\$/lb. U_3O_8
Low	$\leq$ 34	$\leq$ 13
Low Medium	> 34-52	> 13-20
High Medium	$\geq$ 52-78	$\geq$ 20-30
High Cost	$\geq$ 78-130	$\geq$ 30-50
Very High	> 130	> 50

The order in which individual production centres are projected to begin operations to satisfy Market-based Production requirements is based on a combination of confidence level, production capacity and cost. It has been assumed that the lowest cost producer in the highest resource confidence category operating at capacity will fill the first increment of demand, followed by progressively higher-cost producers until annual demand is filled. Production from higher-cost projects is deferred until they are projected to be cost- competitive. Fig.7 is a spreadsheet that shows how the next higher-cost production centres are added as needed to satisfy annual increases in Market-based Production requirements. *It is important to emphasize that the model used to project production and resource adequacy provides neither a prediction nor a forecast of precisely how the uranium production*

industry will develop during the next 50 years. Instead, it presents a number of scenarios based on current knowledge, each of which shows alternatives as to how the industry could unfold given changing sets of conditions.

3.2. Secondary Supply Assumptions

Projecting the potential contributions from secondary supply sources is a key step in determining Market-based supply requirements. Following are the basic assumptions on which projections of secondary supply are based. Details on these assumptions and other aspects of secondary supply are included in the longer version of this report.

— ***Highly enriched uranium from surplus defence inventories (HEU)***. It is assumed that the current agreements between the governments of the USA and Russia will be expanded to increase availability of low-enriched uranium derived from Russian HEU through 2022. Commercialization of US HEU will extend through 2023. HEU contribution is projected to total 249 500 t U in the base case.

— ***Commercial inventory.*** Inventory held by Western utilities, uranium producers and government agencies is projected to total 168 500 t U equivalent, including strategic and discretionary/excess inventory. Draw down of utility and US government inventories is projected to end in 2006 and 2014, respectively. Uranium producers are assumed to maintain inventory levels equal to two-thirds of the previous years' requirements. Draw down of producer inventory will fluctuate accordingly.

— ***Russian inventory.*** Draw down of Russian natural and low-enriched uranium inventory with fluctuate depending on HEU deliveries. As the contribution of HEU increases, inventory draw down will steadily decrease, and will finally end in 2014, after a cumulative contribution of 47 000 t U.

— ***Mixed oxide fuel (MOX) and reprocessed uranium (RepU).*** MOX use is projected to grow steadily through 2012 after which usage will stabilize at 3600 t U equivalent through 2050. Use of RepU is assumed to grow gradually through 2016 after which it is capped at 2500 t U equivalent through 2050.

— ***Depleted uranium stockpiles (tails).*** Tails re-enrichment is constrained by availability of low-cost SWUs and by safeguards limitations on transferring large quantities of depleted uranium to Russian enrichment plants and leaving the secondary tails in Russia. Therefore, tails re-enrichment is scheduled to end in 2011 after having contributed a cumulative total of 43 000 t U equivalent.

3.3. Non-Market Based Primary Supply Assumptions.

It is assumed throughout this study that the uranium production industry world-wide is gradually adopting market-based economic principles. This assumption has been the main guideline in determining the contributions from the CIS, China and the national programmes.

— ***Commonwealth of Independent States.*** This study considers two categories of production from the CIS. Production from existing facilities, with minor expansion potential, is assigned to the "CIS Production" category. Fig. 8 shows the projected annual contributions from the four CIS producing countries - Kazakhstan, Russia, Ukraine and Uzbekistan - in this category. Resources not directly associated with current facilities are available to satisfy Market-based Production requirements. These resources are assumed to begin operations when they are cost-justified to help satisfy Market-based Production requirements.

— ***China.*** China's production has the potential to expand from the current annual level of 400 t U to 1380 t U by 2005. For purposes of this study, China's output is capped at 1380 t U per year between 2005 and 2050.

— ***National Programmes.*** Countries that currently maintain small programmes dedicated to meeting domestic reactor requirements include Brazil, Czech Republic, France, India, Pakistan, Romania and Spain. The Czech Republic, France and Spain are scheduled to shut down their programmes between 2001 and 2003. It is assumed that the remaining programmes will continue to produce at approximately their current levels through 2050.

3.4. Market-Based Production

3.4.1. Reasonably Assured Resources (RAR) – Middle Demand Case

The adequacy of resources to satisfy Market-based Production requirements has been evaluated for three demand cases at different resource confidence levels. Consultants that contributed to the study were able to attribute 3.276 million t U to 125 deposits about which they have specific information, compared to 3.128 million t U RAR listed in the IAEA/NEA 1999 Red Book [4]. The difference between the two totals is largely attributable to conservative reporting by some countries that did not include deposits with well-documented resources which are not recoverable at current market prices. RAR directly attributable by the consultants to specific resources are termed "Study RAR". More specific information is publicly known about the geology, mining methods and production costs for these resources, and this knowledge is used as the first step in assessing resource adequacy. Fig.9 projects production cost trends as output derived from Study RAR expands to meet growing requirements for Market-based Production. As shown in Fig.9, Study RAR will be adequate to satisfy Market-based Production requirements through 2026, after which lower confidence resources will play an increasingly important role. Fig.9 also indicates that resources in the low and low medium-cost categories will be adequate to satisfy Market-based Production requirements through about 2018. Therefore, market prices could remain at or below $52/kgU through 2018, provided supply and demand relationships are similar to the middle demand case.

Since a great deal of information is known about Study RAR, they are accorded the highest confidence level of all of the resource categories and are projected to be among the first resources to be exploited as demand increases with time. Because of the level of detailed information available on Study RAR, they are very useful in modelling projected changes in the uranium production industry through 2026. Table II shows the role that different mining and extraction methods are projected to play in satisfying Market-based Production requirements throughout the next 25 years. In situ leach (ISL) output is expected to triple between 2000 and 2015, mostly at the expense of open pit mining. After 2020, however, resurgence in production from open pit operations is projected, as lower cost ISL-amenable resources are depleted. Production capacity limitations are clearly a factor in the growth pattern of ISL output. In 2008, for example, when the first increment of new projects will have to be added to meet Market-based Production requirements, ISL production centres will account for 56% of the total number of operations, but only 14% of annual production.

TABLE II. STUDY RAR MARKET-BASED PRODUCTION BY EXTRACTION METHOD - FIVE YEAR INCREMENTS

	2000	*2005*	*2010*	*2015*	*2020*	*2025*
Underground	53%	64%	61%	50%	43%	45%
ISL	7%	6%	11%	21%	20%	16%
Open Pit	18%	8%	3%	5%	20%	31%
By Product	4%	5%	5%	4%	6%	6%
Open Pit/Underground	18%	17%	20%	20%	11%	2%

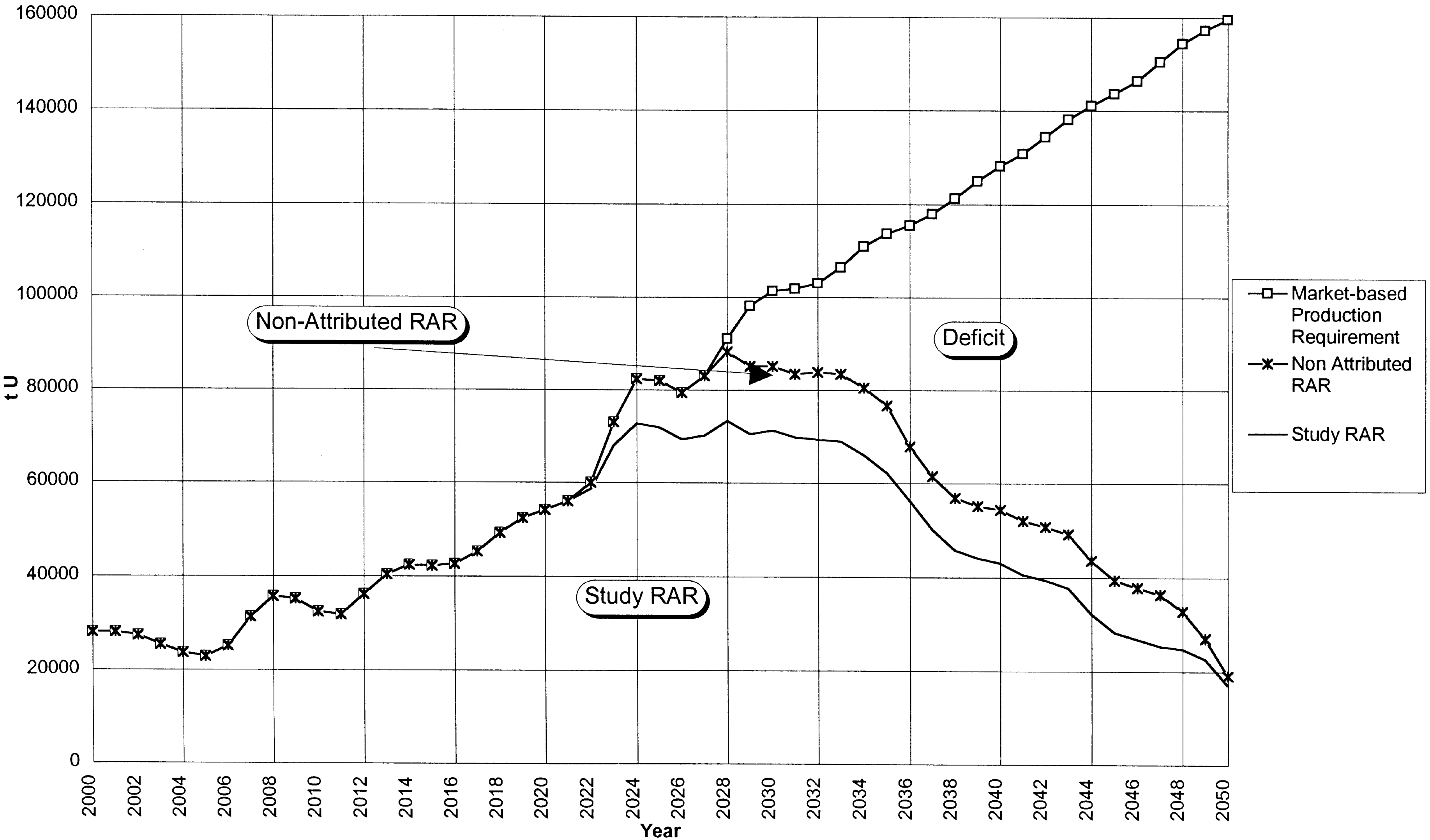


FIG. 10. Total RAR-derived production compared with market-based production requirement — middle demand case.

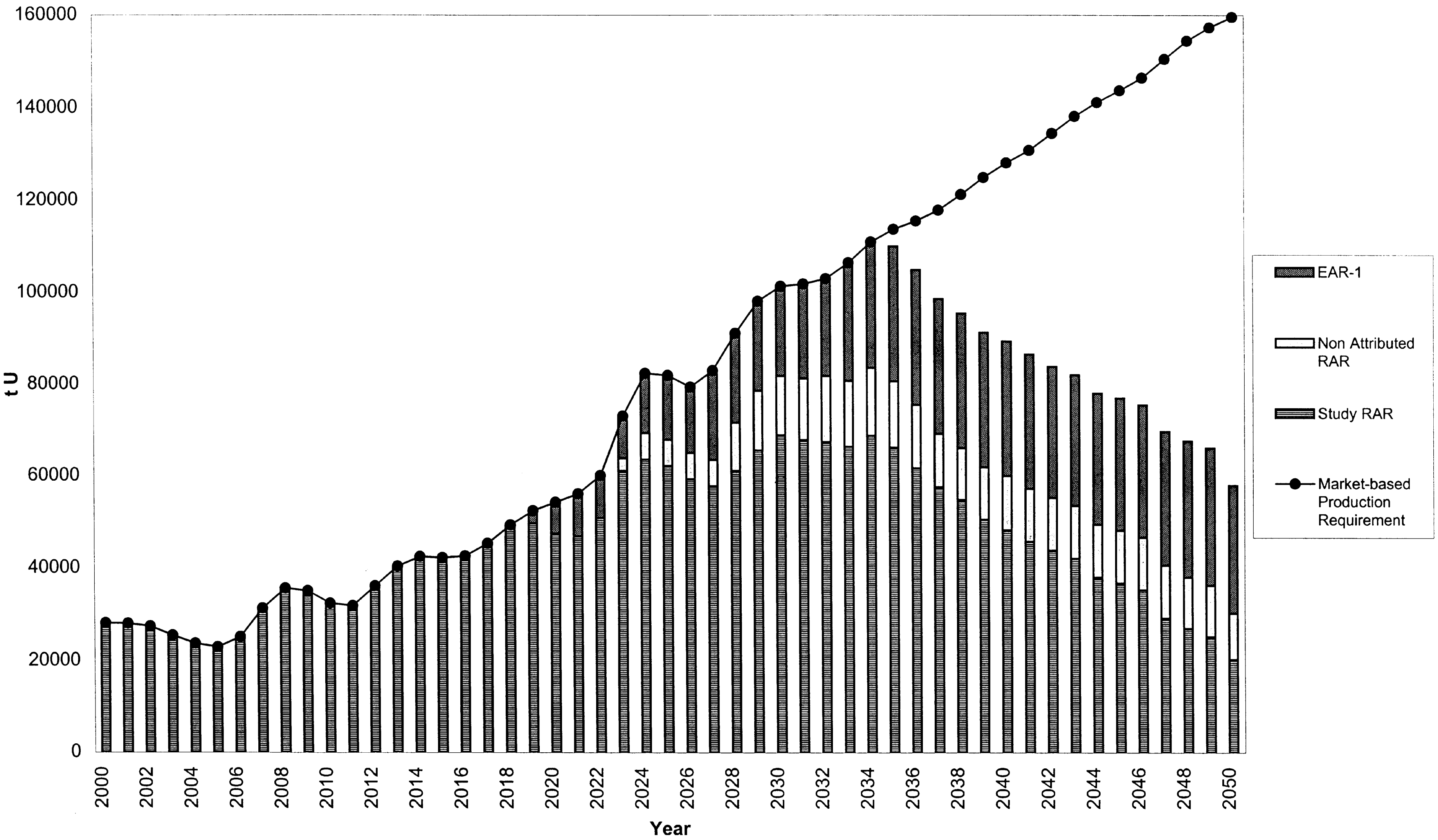


FIG. 11. Resource contribution by confidence level through EAR-I — middle demand case.

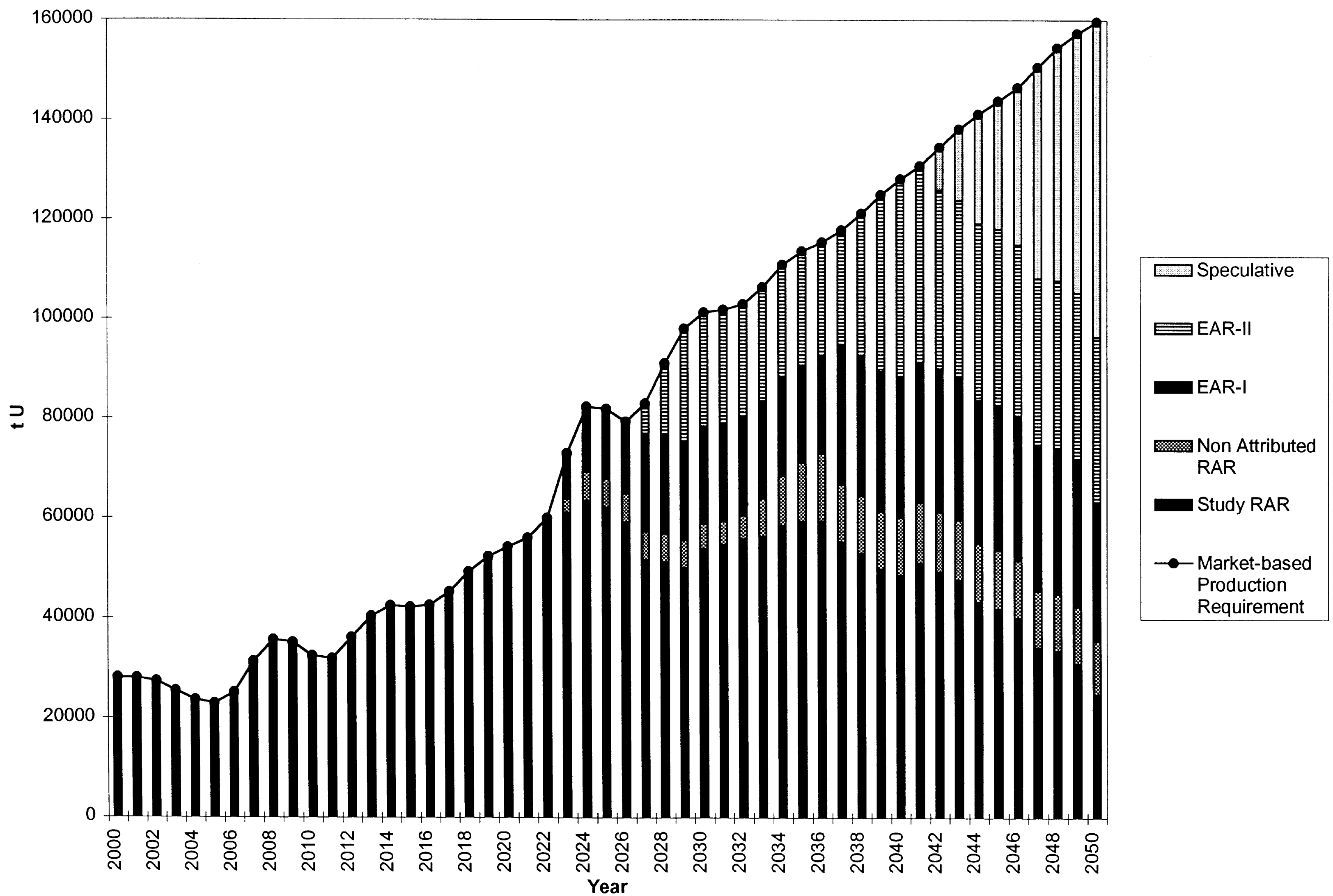


FIG. 12.Resource contribution by confidence level through EAR-II — middle demand case.

Table III is a summary of the changing contribution of different geologic deposit types over time. The unconformity-related deposits in Australia and Canada will clearly dominate production through 2015, with a significant contribution from the Olympic Dam breccia complex. Beyond 2015, other deposit types will have to be developed in greater numbers to satisfy Market-based Production requirements.

TABLE III. STUDY RAR MARKET-BASED PRODUCTION BY DEPOSIT TYPE - FIVE YEAR INCREMENTS

	2000	*2005*	*2010*	*2015*	*2020*	*2025*
Sandstone	19%	14%	17%	31%	27%	33%
Unconformity-related	49%	59%	66%	54%	39%	17%
Quartz-pebble conglomerate	4%	5%	5%	4%	3%	5%
Breccia complex	26%	21%	12%	9%	12%	9%
Vein	1%				3%	4%
Intrusive					7%	9%
Volcanic						8%
Calcrete/surficial					4%	6%
Phosphate					2%	4%
Metasomatic						2%
Collapse breccia pipe				2%	2%	2%
Metamorphic						1%
By Product	1%	1%	0.5%	0.5%	1%	0.5%

RAR not directly attributed by the study consultants to known deposits are termed Non-attributed RAR. As shown in Fig.10, adding Non-attributed RAR to the production stream only satisfies Market-based Production requirements through 2027 compared to 2026 when limited to Study RAR.

3.4.2. Estimated additional resources – category I (EAR-I) – middle demand case

EAR-I constitutes the next lower confidence level of resources below Non-attributed RAR. As defined in the Red Book, RAR plus EAR-I comprise total “known resources”. Fig.11 shows the relative contributions of Study and Non-attributed RAR and EAR-I (known resources). As shown in Fig.11, with the addition of EAR-I, known resources are adequate to satisfy Market-based Production requirements through 2034, or 7 years longer than the scenario restricted to RAR (Fig.9). Table IV compares the affect of successively adding lower confidence levels of resources to the production stream, starting with Study RAR and progressing through Non-attributed RAR and finally to EAR-1.

TABLE IV. COMPARISON OF THE AFFECT OF ADDING LOWER CONFIDENCE RESOURCES TO THE MARKET-BASED PRODUCTION STREAM – MIDDLE DEMAND CASE

	Study RAR	Total RAR	RAR+EAR-I
Market-based Production requirement (t U)	4 158 280	4 158 280	4 158 280
Cumulative production (t U)	2 319 210	2 617 860	3 313 780
Cumulative deficit*(t U)	1 839 070	1 540 410	844 500
Potential unutilized resources	476 390	515 820	698 440
First year high medium cost required	2019	2019	2021
First year high cost required	2023	2024	2027
First year EAR-I cost-justified	NA	NA	2019

*Deficit between Market-based Production requirements and cumulative production

As noted in Table IV, in the middle demand case, cumulative production derived from known resources is adequate to satisfy 80% of Market-based Production requirements through 2050. EAR-I are not projected to be cost-justified until about 2019 in the middle demand case. Therefore, their introduction into the production stream will not significantly change market price trends compared to the scenario limited to RAR. For example introduction of EAR-I only delays by two years (2021 compared to 2019) the point at which high medium-cost resources ($52 to $78/kgU) will be cost justified. Table IV includes the category "unutilized resources", which addresses the fact that 698 440 t U or 17% of known resources available to meet Market-based Production requirements will not have been utilized by 2050. Unutilized resources are typically associated with high-cost production centres with large resource bases that are cost-justified too late in the study period for their resources to be depleted by 2050 (assuming practical production capacities).

3.4.3. Estimated additional resources – category II (EAR-II) – middle demand case

Production derived from known resources is projected to satisfy only about 80% of Market-based Production requirements in the middle demand case. Therefore, lower confidence undiscovered resources will be needed to fill the gap between known resources and production requirements. *Having to rely on undiscovered resources to fill the projected supply gap substantially increases the uncertainties and risks. This cautionary note should be borne in mind throughout the remaining discussion of utilization of undiscovered resources*.

By definition, EAR-II, though part of the undiscovered resources category, are believed to occur in well-defined geological trends or areas of mineralization with known deposits, so they clearly carry less risk and uncertainty than Speculative Resources. Nevertheless, the true potential of EAR-II must still be proven by exploration and development programmes. Fig.12 shows the projected contribution of RAR through EAR-II between 2000 and 2050, and how the gap between Market-based Production requirements and production narrows with the addition of progressively lower confidence resources. Table V compares changes in production and cost parameters as lower confidence resources are added to the production stream.

TABLE V. COMPARISON OF PRODUCTION AND COST PARAMETERS – RAR THROUGH EAR-II- MIDDLE DEMAND CASE

	Total RAR	RAR + EAR-I	RAR + EAR-I+EAR-II
First year of deficit compared with Market-based Production requirement	2028	2035	2042
Cumulative production (t U)	2 617 860	3 313 780	3 851 530
Cumulative deficit*(t U)	1 540 420	844 500	306 740
Potential unutilized Resources	515 820	698 440	2 385 680
First year high medium cost required	2019	2021	2021
First year high cost required	2024	2027	2029
First year EAR-I cost-justified	NA	2019	2019
First year EAR-II cost-justified	NA	NA	2027

*Deficit between Market-based Production requirements and cumulative production.

As shown in this comparison and in Fig.11, the addition of EAR-II would cover Market-based Production requirements through 2041 and would reduce the deficit between production and requirements to 306 740 t U, assuming that their potential is confirmed by exploration. Also of significance is the fact that potentially unutilized resources are projected to total nearly 2.4 million t U, or eight times the projected deficit. More efficient use of only a portion of the unutilized resources could entirely eliminate the gap between supply and requirements in the middle demand case.

3.5. Adequacy Of Supply – Low And High Demand Cases

Up to this point we have considered the adequacy of supply in the middle demand case. The widely varying opinions concerning the future of nuclear power dictate that we also examine the adequacy of supply for the low and high demand cases. RAR are projected to be adequate to satisfy Market-based Production requirements in the low demand case, but, quite the opposite is true for the high demand case. Cumulative reactor requirements are projected to increase from 5.4 million t U in the middle demand case to nearly 7.6 million t U in the high case. Market-based Production would be expected to fill most of that increase. Since we are dealing with the same resource base in both demand cases, satisfying the accelerated demand schedule in the high case requires accelerated utilization of resources. Therefore, not surprisingly, the deficits between production and requirements that characterize the middle demand case increase substantially in the high case.

Table VI compares production and cost parameters for known resources in the middle and high demand cases. The deficit between cumulative Market-based Production requirements and production derived from known resources more than triples in the high demand case. Known resources are projected to be adequate to satisfy requirements through 2025 in the high case compared to 3034 in the middle case. And, production centres in the high medium-cost category will be cost-justified in 2015 in the high demand case compared to 2021 in the middle case, potentially advancing the projected increase in the uranium market price by six years.

TABLE VI. COMPARISON OF RESOURCE UTILIZATION PARAMETERS - MIDDLE AND HIGH DEMAND CASES, BASED ON PRODUCTION DERIVED FROM KNOWN RESOURCES

	Middle Demand Case	High Demand Case
Market-based Production requirement (t U)	4 158 280	6 406 190
First year of deficit compared with Market-based Production requirement	2035	2026
Cumulative production (t U)	3 313 780	3 455 840
Cumulative deficit*(t U)	844 500	2 950 350
Potential unutilized resources	698 440	556 710
First year high medium cost required	2021	2015
First year high cost required	2027	2022
First year EAR-I cost-justified	2019	2013

*Deficit between Market-based Production requirements and cumulative production

Fig.12 shows the contribution to annual production from different confidence level resources through EAR-II for the high demand case. With the addition of EAR-II to the production stream, there are actually sufficient resources available to nearly satisfy Market-based production requirements. However, about 1.9 million t U of the resources will not be utilized because they will not be cost-justified early enough to be fully depleted by 2050. Unutilized resources account for the gap between annual production and production requirements shown on Fig.12. With the inclusion of EAR-II, potentially unutilized resources are nearly equal to the deficit between cumulative production and Market-based Production requirements. In other words, resources are adequate to satisfy requirements *if* production capacity could be increased to fully utilize the resources.

3.6. Speculative And Unconventional Resources

As noted in Figs 11 and 12, in both the middle and high demand cases, even with the addition of lower confidence EAR-II, there remains a gap between production and Market-based Production

requirements. *However, it is important to emphasize that the gap does not result from a true shortage of supply potential*. Instead, it results mainly from unutilized resources, which in turn are attributable to the fact that there are relatively few large, low-cost deposits in the resource base that have not already been developed. Instead, the resource base is dominated by relatively small deposits with limited production capacity or by large, but high-cost deposits that are cost-justified too late in the study period to receive maximum benefit from their resources.

In addition to EAR-II, as noted in Table VII, contributors to the Red Book also report 8.67 million t U of Speculative Resources (SR) that are based on indirect evidence and geological extrapolation. Like EAR-II, however, SR are conceptual, undiscovered resources that will require extensive exploration that results in discoveries before they can be moved to higher confidence categories.

TABLE VII. LEADING COUNTRIES IN REPORTED SPECULATIVE RESOURCES

	<$130/kgU (1000 t U)	Total (1000 t U)
Canada	700	700
China	*	1770
Kazakhstan	500	500
Mongolia	1390	1390
Russia	544	1000
South Africa	*	1113
United States	858	2198
Total	3992	8671

* Not reported.

If exploration does not bear out the potential of the SR, unconventional resources offer a substantial, albeit very high-cost, supplement to undiscovered resources. Table VIII summarizes estimates of unconventional resources and the deposit types with which they are associated.

TABLE VIII. UNCONVENTIONAL RESOURCES – MINERAL INVENTORY

Deposit Type	Estimated Resources (1000 t U)
Phosphorite Deposits	9000
Black Shale Deposits	4000 – 5000
Lignite and Coal Deposits	70
Total	13 400 - 14 000

The message from Tables VII and VIII is that there is no shortage of potential uranium resources. The magnitude of projected SR listed in Table VII indicates that uranium experts throughout the world remain optimistic as to the potential for future discoveries. Translating that optimism into viable resources will, however, require extensive exploration and development expenditures, which in turn will require the incentive of sustainable higher market prices. Estimated SR are clearly adequate to cover the projected shortfall between production and Market-based Production requirements in both the middle and high demand cases. In addition, though they are high (or very high) cost and have potential environmental problems, the unconventional resources represent an enormous potential supply of uranium.

4. EXPLORATION REQUIREMENTS

In the middle demand case, we have established that known resources are adequate to satisfy 96% of Market-based Production requirements, and it is unutilized resources and not a true shortage of resources that accounts for the gap between production and requirements. The same is true in the high demand case if EAR-II are added to the resource base. As previously noted, unutilized resources are mainly attributable to high-cost deposits with large resource bases that are not cost-justified early

enough for their resources to be depleted by 2050. Production capacities could potentially be expanded for some of these projects, but expansion potential is limited and it is not the answer to the unutilized resources problem. Instead, the real challenge for the future will be to find large, relatively low-cost deposits that can be brought into production by at least 2025, so that their resources will be fully utilized within the remaining 25 years of the study period.

Historical discovery costs through 1998 in Australia and Canada, two areas with long-standing exploration programmes, ranged from $0.50 to $1.60/ kgU. Discovery costs between 1989 and 1999 increased to between $3.90 and $6.90/kgU, as exploration was forced to target deeper and/or more subtle prospects. All it would take would be the discovery of another deposit similar to McArthur River or Jabiluka to substantially reduce the recent costs, but the message is clear - the easy discoveries have been made. While it is not practical to broadly apply historical discovery costs to future exploration programmes, we can project a range of expenditures needed to meet future resource requirements. For example, there is a projected shortfall of 2.39 million t U between Market-based Production requirements and available *known resources* in the *high demand case*. Table IX shows order of magnitude exploration expenditures at a range of discovery costs that could be required to ensure discovery of sufficient resources to offset the projected high demand case deficit.

TABLE IX. EXPLORATION EXPENDITURES REQUIRED TO FILL PROJECTED DEFICIT IN HIGH DEMAND CASE: ASSUMES PRODUCTION FROM KNOWN RESOURCES

Discovery Cost ($/kg U)	Required Exploration Expenditure (billion $)
0.50	1.20
1.00	2.39
2.00	4.78
3.00	7.18
4.00	9.57

To meet the challenge of overcoming resource deficits, exploration expenditures will have to begin to increase significantly within the next five years to ensure that discoveries are made early enough to accommodate the long lead time between discovery and production. Otherwise, there is the probability that the resources will not be fully utilized by 2050. The McArthur River project in Canada is a good example of the time requirements to bring a deposit into production. Exploration in the McArthur River area, which dates back to the 1970s, was intensified in the early 1980s when a new generation of geophysical surveys was developed that could detect conductive zones at depth. Exploration drilling focused on one such conductive zone encountered encouraging, but sub-economic mineralization, in 1985. Discovery of ore grade mineralization occurred in 1988, nearly eight years after the start of systematic exploration. Eleven years lapsed between the discovery of ore grade mineralization and the start of production in late 1999.

Future discoveries can be expected to experience lead times comparable to those experienced by McArthur River. The message is clear - long lead times will be the rule rather than the exception, and exploration will have to accelerate to ensure a stable supply of relatively low cost uranium. In other words, the exploration expenditure requirements shown in Table IX cannot be evenly spread throughout the 50-year study period. Instead, they need to come early enough that the resulting discoveries can contribute to production requirements in a timely manner.

5. RISK AND UNCERTAINTY

Up to this point, a resource base has been projected at each confidence level, and the adequacy of those resources to meet Market-based Production requirements has been assessed. There is, however, no absolute certainty that all of the resources will be available, and there is equal uncertainty as to the

availability of secondary supply. Therefore, sensitivity studies have been completed that evaluate the impact of increases or decreases in the various supply components.

5.1. HEU

The HEU base case includes 250 t Russian HEU that are not included in the current Russian-US Agreement. This additional material extends by 10 years the availability of uranium derived from Russian HEU. There is every reason to believe that the two superpowers will extend the current agreement, and there is the potential that even more HEU could become available for commercialization with further bilateral reductions in nuclear weapons. However, there is also the possibility that HEU availability will be limited to the current Agreement which ends in 2013.

Therefore, in addition to the base case, high and low HEU scenarios are considered in order to evaluate the impact of limiting or increasing HEU availability. The low case conforms to the existing Agreement and ends HEU availability in 2013, while the high case extends availability through 2040 compared to 2023 for the base case**.** Table X shows the impact that changes in HEU availability will have in the middle demand case assuming that production is limited to known resources.

TABLE X. COMPARISON OF PRODUCTION AND COST PARAMETERS - LOW AND HIGH HEU CASE: ASSUMES PRODUCTION BASED ON MIDDLE DEMAND CASE, KNOWN RESOURCES

	Base Case HEU	Low HEU Case	High HEU Case
First year of deficit compared with Market-based Production requirement	2035	2034	2036
Market-based Production requirement	4 158 280	4 256 210	4 048 230
Cumulative production (t U)	3 313 780	3 340 370	3 246 230
Cumulative deficit* (t U)	844 500	915 840	801 990
Potential unutilized Resources	698 440	672 870	764 410
First year high medium cost required	2021	2019	2021

*Deficit between Market-based Production requirements and cumulative production

As noted in Table X, varying HEU availability has limited impact on the middle demand case. Adequacy of known resources to satisfy requirements only changes by one year on either side of the base case. The deficit between production and requirements varies by only 2 to 3% from the base case. Increasing HEU availability will not change the cost/price projection, while limiting it to the current Agreement will only advance by two years the need for high medium-cost projects to begin filling requirements.

5.2. MOX, REPU and re-enrichment of depleted uranium

Technical and political considerations could limit availability of secondary supply from MOX, RepU and re-enrichment of depleted uranium (tails). Anti-plutonium sentiment could end MOX use as early as 2005. The current trend towards higher burnup could decrease availability of economically attractive spent fuel by 2010, which is the basis for the low RepU case. Uncertainty as to availability of US tails for re-enrichment could reduce the overall contribution from tails re-enrichment by nearly half. Therefore, in addition to the base case, low case projections were made for each of these supply sources, the combined results of which are summarized in Table XI.

TABLE XI. COMPARISON OF PRODUCTION AND COST PARAMETERS – COMBINED BASE CASE AND LOW CASES FOR MOX, REPU AND TAILS: ASSUMES PRODUCTION BASED ON MIDDLE DEMAND CASE, KNOWN RESOURCES

	Base Case	Low Case
First year of deficit compared with Market-based Production requirement	2035	2033
Market-based Production requirement	4 158 280	4 432 550
Cumulative production (t U)	3 313 780	3 364 400
Cumulative deficit* (t U)	844 500	1 068 150
First year high medium cost required	2021	2019

*Deficit between production and requirements

The combined low cases result in a potential cumulative reduction in supply from MOX, RepU and tails of 270 200 t U compared to the total of their base cases. Even so, the potential reductions have limited impact on supply-demand relationships. For example, though the deficit between Market-based Production requirements and cumulative production from known resources increases by about 25% in the low case, cost-justified high medium-cost projects will be needed only two years earlier. Accordingly, the impact on market price trends of going to the low case will be minimal.

5.3. Impact of environmental and political opposition

Opposition to uranium mining from environmental or political groups presents a potentially serious obstacle to resource development and utilization. It is estimated that environmental and/or political opposition could result in deferral or even abandonment of up to 10% of RAR. As we look ahead 50 years, there is no way to forecast potential changes in public or governmental attitudes toward uranium mining. As shown in Table XII, we can, however, evaluate the impact on supply-demand relationships if projects that currently have the *potential* for environmental or political opposition are removed from the resource base.

TABLE XII. COMPARISON OF PRODUCTION AND COST PARAMETERS WITH AND WITHOUT RESOURCES SUBJECT TO ENVIRONMENTAL AND POLITICAL OPPOSITION: ASSUMES PRODUCTION BASED ON KNOWN RESOURCES, MIDDLE DEMAND CASE

	With Projects Subject to Opposition	Without Projects Subject to Opposition
Market-based Production requirement	4 158 280	4 158 280
Available resources	4 012 220	3 597 550
First year of deficit compared with Market-based Production requirement	2035	2029
Cumulative production (t U)	3 313 780	2 981 160
Cumulative deficit*(t U)	844 500	1 177 120
First year high medium cost required	2021	2019

*Deficit between Market-based Production requirement and cumulative production

As shown in Table XII without the resources subject to environmental or political opposition, known resources are only adequate to cover Market-based Production requirements until 2029 compared to 2035 if these resources are assumed to be available. Cumulative production is reduced by 10%, and the deficit between production and requirements is increased by nearly 40%. The projected change in the cost structure is, however, relatively minor. The potential impact of environmental or political opposition on the overall resource base is included as a cautionary note. It is, however, not intended to prejudge whether such opposition will have any permanent impact on the resource base.

However, it must be concluded that uranium production may only be successfully conducted when the community is convinced that environmental impacts are reduced to acceptable level with properly planned, developed, operated and closed project.

6. PRODUCTION COSTS AND MARKET PRICE IMPLICATIONS

For each combination of supply and demand, we have noted the dates when high medium-cost production ($52-$78/kgU) is projected to be required to satisfy Market-based Production requirements. As the role of secondary supply is reduced, uranium market price trends will more and more begin to parallel production cost trends; prices will have to increase to support increasing production costs. Table XIII summarizes the years in which market prices are projected to increase to the next higher cost category to cover production costs for the middle and high demand cases assuming varying resource bases.

As noted in Table XIII, in the middle demand case, with production derived from known resources, high medium-cost projects will first be needed to fill requirements in 2021. It follows, therefore, that the spot market price will have to increase to >$52/kgU in 2021 to support the need for projects with higher production costs.

TABLE XIII. PROJECTIONS OF WHEN PROJECTS IN NEXT HIGHER COST CATEGORIES WILL BE REQUIRED TO FILL PRODUCTION REQUIREMENTS

	Middle Demand Case		High Demand Case	
	High Medium-Cost	High-Cost	High Medium-Cost	High-Cost
RAR	2019	2024	2013	2019
RAR + EAR-I	2021	2027	2015	2022
RAR + EAR-I + EAR-II	2021	2029	2015	2023

7. ENVIRONMENTAL IMPLICATIONS OF THE USE OF NUCLEAR POWER

The debate surrounding the future of nuclear power is not likely to be resolved in the very near future. However, as the debate on global warming continues, the advantage that nuclear power has in not directly producing greenhouse gases could become more widely recognized. If nothing else, it may help stabilize nuclear power’s role in the energy mix, and to offset the paradox in which those that purport to be the most concerned about the potential for human-induced global warming are the same as those most opposed to nuclear energy. Table XIV shows the projected cumulative reactor uranium demand for the three demand cases and the amount of carbon dioxide generation that would be saved relative to burning coal if any one of these cases is implemented.

TABLE XIV. CARBON DIOXIDE SAVINGS FROM USE OF URANIUM IN LIEU OF COAL: LOW, MIDDLE AND HIGH DEMAND CASES

	Reactor Demand (1000 t U)	Carbon Dioxide Saved (billion tonnes)
Low Demand Case	3390	135
Middle Demand Case	5394	216
High Demand Case	7577	303

8. CONCLUSIONS

In 2000, primary and secondary supply are projected to satisfy 58% and 42% of reactor uranium requirements, respectively in the middle demand case. By 2025, primary supply sources are expected to cover 94% of requirements, and the role of Market-based Production is projected to grow from satisfying 45% of requirements in 2000 to 86% in 2025. Known resources are adequate to cover about 96% of Market-based Production requirements in the middle demand case. However, because of resource distribution and production capacity limitations, not all resources will have been depleted by 2050, leaving a cumulative deficit between production and requirements of nearly 850 000 t U. This deficit expands 3.5-fold in the high demand case. Even with the addition of undiscovered EAR-II, there will still be a deficit between production and Market-based Production requirements of about 307 000 t U in the middle demand case.

The challenge for the uranium production industry will be to discover large, relatively low-cost deposits to fill the projected deficits. Plentiful secondary supply has depressed uranium market prices, which in turn has diminished incentive to undertake the exploration programmes needed to offset these deficits. Estimates of EAR-II + Speculative Resources are more than adequate to offset the projected deficits. In addition, unconventional resources such as uranium-bearing phosphorite and coal and lignite deposits offer a very high-cost supplement to undiscovered conventional resources.

Therefore, there is not a true shortage of potential resources. However, these undiscovered resources must be converted to discoveries, which must then be developed in a timely matter to ensure that their resources can be fully utilized to offset the projected deficits. Lead times between the beginning of exploration and production can range between 15 and 20 years. Therefore, the market price must increase sufficiently for producers to be willing to take the financial risks associated with exploring for and developing new uranium resources. The increase in market price should make it possible for industry to discover new low cost resources. It will also then be necessary for industry to continue to demonstrate that it can produce uranium in an environmentally acceptable manner.

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Do we approach a uranium supply crisis in the early 21st century?

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Abstract. Against the background of the global warming, the Kyoto Protocol and the foreseeable depletion of today's known oil and gas reserves, a renaissance of nuclear power is foreseen. At the present time the reliance on recycled plutonium as mixed oxide, the use of reprocessed uranium (RepU) and the high grade, low cost uranium mines in Canada, suggest that there will be no uranium supply gap before 2020. The intention of many US nuclear power plants owners to extend their licence period from 40 to 60 years, and the increasing use of nuclear power in China, India, Korea and Taiwan is creating an increase in nuclear generating capacity. The resulting increase in uranium demand between now and 2020, could lead to a supply gap between 2005 and 2020. This uranium shortfall could be eliminated or reduced by taking various actions. By reducing the enrichment tail assay from 0.3% ^{235}U to .25% ^{235}U the demand could be reduced by 10%. By utilizing recycled material at a maximum level, and especially by reducing the tails assay the enrichment of new tails, could contribute to overcoming the short fall. However more centrifuge and/or laser enrichment technologies would be needed. By opening new mines, the shortfall could also be solved. In view of these consideration the uranium supply situation could become critical in the next 10 years and beyond. It is therefore the responsibility of the policy makers to develop a long term strategy to assure a reliable fuel supply to meet the projected nuclear capacity.

1. HOW DID WE CONSIDER THE SUPPLY SITUATION IN THOSE YEARS? (Fig. 1)

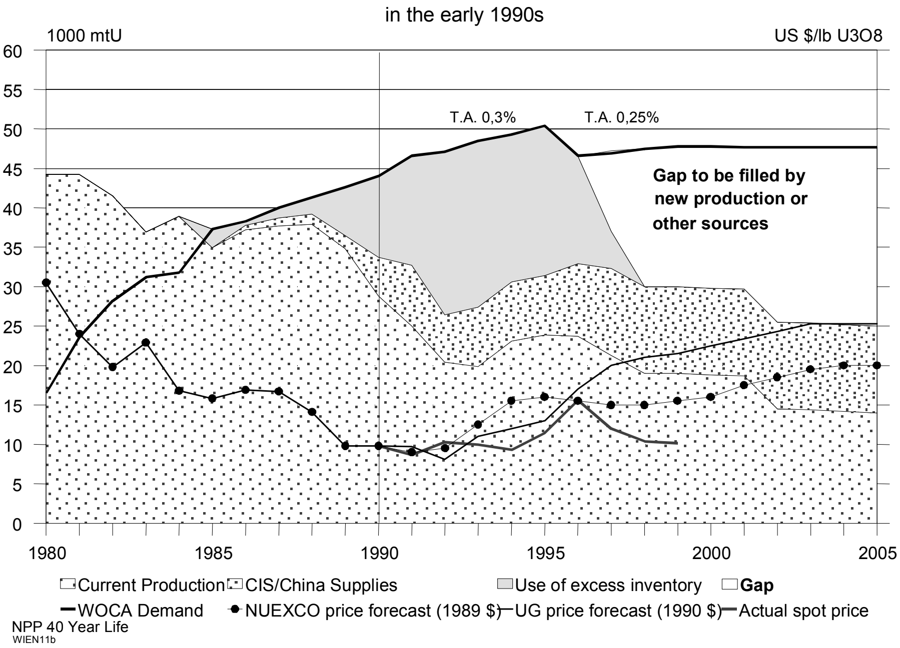

FIG. 1. WOCA uranium supply and demand forecast.

Before 1985 annual primary production in the Western World (WOCA) exceeded the annual demand resulting in a substantial inventory build up. Due to the oversupply market prices declined simultaneously. As a consequence more costly uranium mines have been shut down, especially in the US. This trend kept on while also low cost reserves were being depleted. Increased imports from former USSR and China were predicted as well as the use of excess inventories.

Commencing 1995 a huge supply gap was anticipated only to be filled by increased imports from CIS and new primary production. This gap could have been somewhat reduced by lowering the demand through a lower tails assay.

In any case new primary production would have been needed requiring higher prices than the prevailing ones in the early 90s. Comparing the price forecasts with the actual price development one can recognize a nice concurrence until 1996, however, an increasing divergence thereafter.

2. WHAT CAUSED THE DRAMATIC PRICE SLUMP? (Fig. 2)

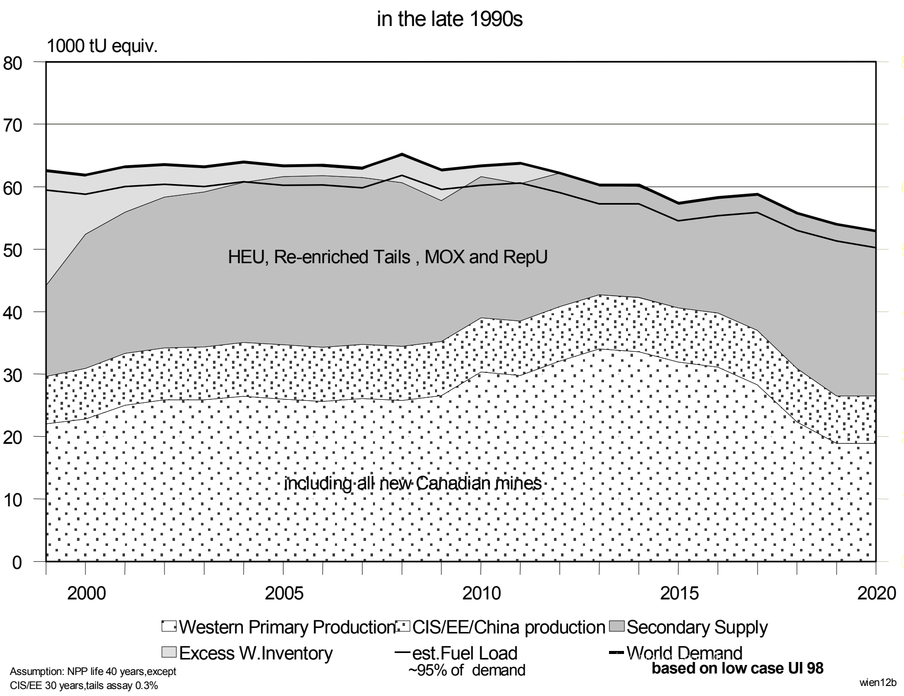

FIG. 2. World uranium supply and demand forecast in the late 1990s.

After the break up of the former USSR, more and more information about the capability of CIS to supply the Western markets with material from their production and military inventory became known. Especially the so-called Highly Enriched Uranium (HEU) deal between the US and Russia in 1993 and its implementation in 1994 changed the supply situation dramatically [1]. About 500 t of high-grade military uranium were to be diluted into commercial grade over a period of about 15 years. Suddenly large new import quotas from CIS penetrated the Western markets. The privatization of the US Enrichment Corporation (USEC) in 1998 added another source of supply from formerly governmental owned stockpile.

The use of recycled plutonium as mixed oxide (MOX), the use of reprocessed uranium (RepU) and re-enriched Western tails in Russia were the third area of secondary supply sources. In the meantime large new high grade/low cost uranium mines were developed in Canada and the existing ones in Australia extended. Against this background, no supply gap between the late 90s and 2020 was expected anymore.

The uranium market reacted with decreasing prices.

3. THE TODAY'S SUPPLY AND DEMAND PICTURE SEEMS TO BE CHANGING AGAIN (Fig. 3)

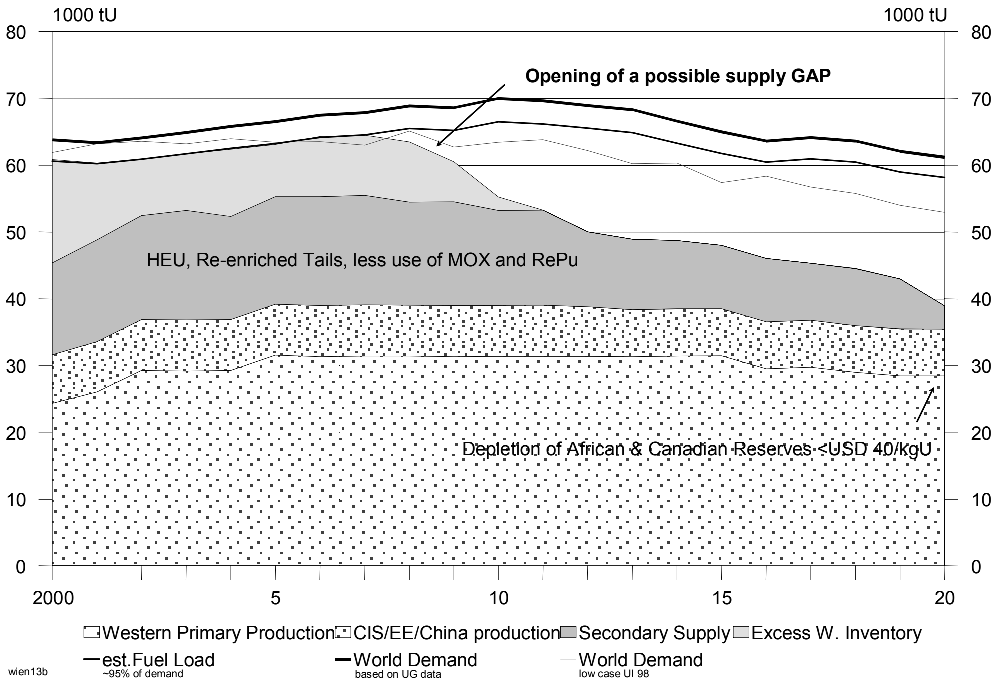

FIG. 3. World uranium supply and demand forecast at the beginning of the 21st century.

In the wake of the electricity market liberalization within the US and Europe there is a change in utilizing nuclear power. In the US more and more utilities are merging and keeping all operating Nuclear Power Plants (NPPs), with the intention to extend their licence period from 40 to 60 years. In contrary there exist a lower public acceptance of nuclear power in Europe. Consequently, Sweden and the Netherlands started to close nuclear power plants, Germany is following with a gradually phase out over the next 30 years. On the other hand there is an increasing use of nuclear power to be registered in countries like China, India, Japan, Korea and Taiwan. Even countries in Eastern Europe and in Russia are already installing or planning to install additional nuclear power plants.

As a result there will be a worldwide increase of nuclear generating capacity and the uranium demand accordingly between now and 2010.

The base load of supply will continue to come from primary production. The actual production capability in the Western World and the CIS countries will contribute with steady supply of about 60% of the cumulative consumption between now and 2020. At the end of this period, the reserves of Class I in the category < US $40.00/kg U [1] will be however nearly depleted in Canada and Africa while CIS countries and Australia could continue to produce in this cost category.

4. HOW IS THE IMPACT OF SECONDARY SUPPLY SOURCES DEVELOPING DURING THIS TIME?

Recent analysis of depleted uranium inventories indicated a reduced availability of high-grade tails of 0.3% ^{235}U and above, which could be economically utilized for re-enrichment.

The US is planning to convert their large stock of about 700 000 t DU (depleted uranium) [2] into a stable form instead of re-enriching due to the lack of economical enrichment facilities.

Likewise the maximum use of MOX and RepU might not happen as formerly forecasted (for example: Germany's new non-reprocessing strategy).

On the other hand, the excess inventories of utilities and USEC are larger than formerly anticipated. A draw down to zero is now seen after 2010.

Balancing the various components of the supply and demand picture leads to a supply gap opening between 2005 and 2010.

5. COULD THAT TAKE US TO A URANIUM SUPPLY CRISIS? (Fig. 4)

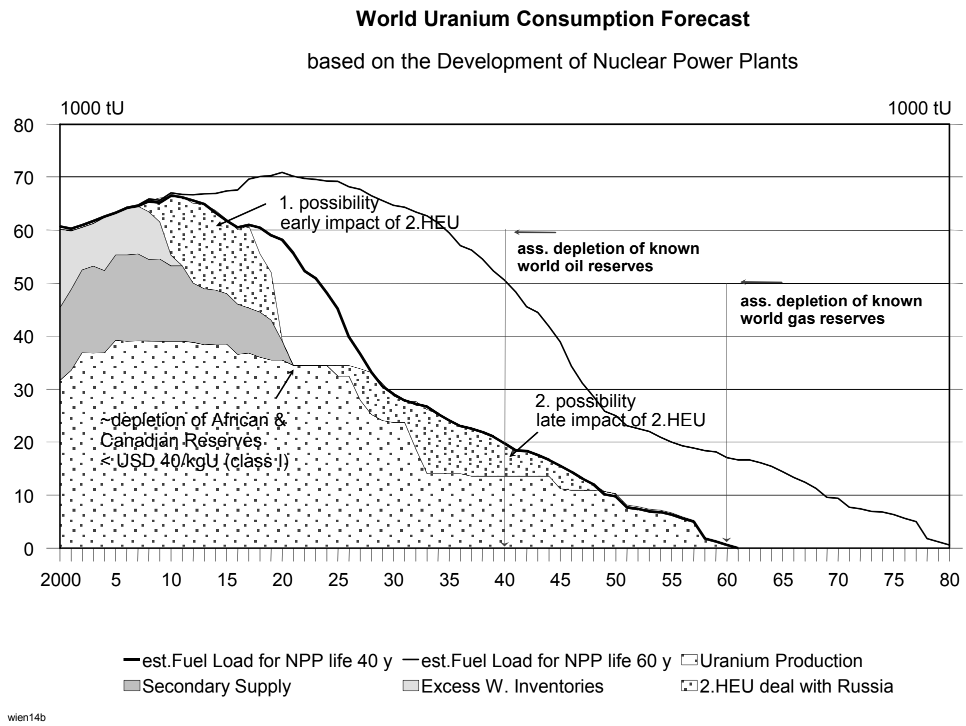

FIG. 4. World uranium consumption forecast based on the development of nuclear power plants.

Let us have a look at the following scenarios:

From today's point of view world nuclear generating capacities could theoretically disappear by 2060 based on a 40 years reactor life.

In this scenario all new planned nuclear power plants are already included. Capacity growth is peaking around 2010 and decreasing thereafter rapidly.

Provided that the use of nuclear generating electricity will continue at the same pace as 2010, about 37 GWe per year would have to be installed commencing 2010. This would call for annual investments of about US $75 billion.

In an alternative scenario reactor life could be extended from 40 years to 60 years as recently seen in the US. A number of US utilities successfully applied for licence extensions of five selected nuclear power plants. If theoretically the life of all world nuclear power plants is extended, they would phase out in 2080.

In those scenarios a supply gap could appear around 2007.

6. WHICH ARE THE POSSIBILITIES TO FILL THIS GAP UNDER TODAY'S POINT OF VIEW? (Fig. 5)

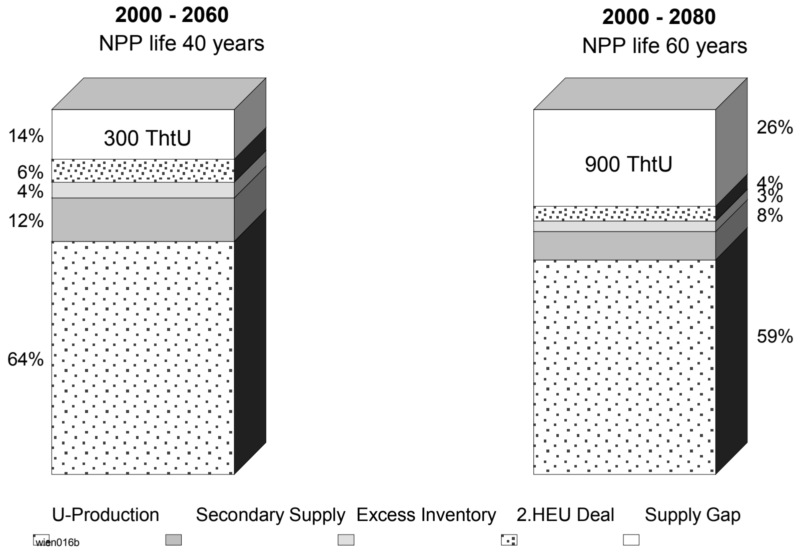

FIG. 5. Uranium supply and consumption forecast.

6.1. Changing the tails assay from 0.3% ^{235}U to 0.25% or even lower would reduce the demand by 10% or more. But this step depends upon the economics of uranium and SWU prices and it is very unlikely that it happens on a world-wide base in the foreseeable future.

Only Russia is operating with tails at or below 0.2% ^{235}U since many years, and will continue to do so.

6.2. By utilizing recycled material at a maximum level, especially the re-enrichment of new tails arisings. For this purpose, more centrifuge and/or laser enrichment capacities would be needed, warranting additional investments. Besides, the use of military plutonium as MOX and a second Russian HEU deal generating possible about 140 000 t U equivalent, could contribute to overcome the shortfall of supply.

6.3. By mobilizing all reserves of the Classes I and II in the cost categories of US $40-60/kg U amount to an estimated total of 3 million t U [1]. In the above scenario forecasts already 45-65% of these reserves have been incorporated. Additional new deposits and mines have to be developed with investments of hundreds of millions of US dollars.

7. CONCLUSION

Against the background of the global warming (Kyoto protocol) and the foreseeable depletion of the today's known oil and gas reserves in 40-60 years (see Fig. 4), a renaissance of nuclear power is foreseen.

No matter which scenario for the life of nuclear reactors we consider in the long term, either a 40 years reactor life, a 60 years reactor life, or the instalment of additional technologically improved nuclear generating capacity, the uranium supply might become critical in the next 10 years and beyond.

It is up to the policy makers to develop a long term energy strategy including nuclear power.

The nuclear industry needs political and legal guarantees as well as secured economical environments in order to maintain the existing nuclear capacities and more so to undertake any future nuclear growth and its investments.

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The Joint NEA/IAEA Uranium Group — its role in assessing world uranium resources, production, demand and environmental activities and issues[1]

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Abstract. In 1965 a 20-page report entitled *World Uranium and Thorium Resources* was published by the OECD-European Nuclear Energy Agency. Today, 35 years later, the report is jointly prepared by the OECD/Nuclear Energy Agency and the IAEA and published by the OECD. The report: *Uranium Resources, Production and Demand* also known as the *Red Book* is in its 18th edition. It is the only official publication on world uranium statistics and provides information from 45 or more countries. One aim of the Red Book is to obtain a uniform, worldwide acceptable classification of uranium resources. The Red Book provides statistics and analyses for resources, exploration, production, demand, secondary sources, surplus defence material and the supply and demand relationship. The sales records indicate that it is used as reference material for various purposes including public and private libraries, energy companies, uranium production companies, national and international organisation, universities and other research and business institutions. In 1996 a study was started which led to the 1999 report: *Environmental Activities in Uranium Mining and Milling,* a companion to the *Red Book.* This complementary report provides information on the site characterization, dismantling and decommissioning, waste management, water remediation, long term monitoring policies and regulations for 29 countries. A second report entitled "*Environmental Remediation of Uranium Production Facilities*" is being prepared.

In 1965 a 20-page report entitled *World Uranium and Thorium Resources* was published by the OECD-European Nuclear Energy Agency as a result of an assessment performed by 11 experts from six countries. The report, which included information from 16 countries, was intended to be the first of a series that expanded country coverage to include a worldwide review. Just two years later (1967), the effort was improved when the IAEA was included in the exercise. Today, 35 years later, the report published jointly by the NEA and IAEA as *Uranium Resources, Production and Demand* is in its 18th edition. The report, also known as the Red Book, represents the only official publication on world uranium statistics. The report is published every two years simultaneously in English and French by the NEA and the IAEA and is translated into Japanese for circulation in Japan. The last four editions contained information from over 45 countries, including for the first time, official reports from the Russian Federation, Kazakhstan, Ukraine, China, the Czech Republic and Uzbekistan among others.

The Uranium Group is the body responsible for preparation of the report. The Group was formally established as the Joint NEA/IAEA Uranium Group in 1996 when delegates from non-OECD countries became official members of the Group. Before that date, however, non-OECD countries had been actively contributing to the Red Book via their status as invited experts. Participation in the Uranium Group activities and in particular in the preparation of the Red Book has grown each year since 1991.

The publication is derived from responses to questionnaires designed by the Uranium Group and distributed by the OECD/NEA and IAEA to national organisations worldwide. Between 25 and 40 experts and members of the Uranium Group nominated by the corresponding Member countries assess the responses to the questionnaires. These contributions provide the basis for the descriptive components in the supply and demand sections of the Red Book and also its individual country reports.

[1] Paper dedicated to the late Dr. Ingemar Lindholm, long term Swedish delegate to the Joint Uranium Group and promoter of environmental activities.

One of the aims of the Red Book is to obtain a uniform and worldwide acceptable categorisation of the uranium resources. Resource estimates are divided into separate categories reflecting different levels of confidence in the quantities reported. Resources with a high degree of assurance are defined as *Reasonably Assured Resources (RAR)*. This category refers to uranium that occurs in known deposits of delineated size, grade and configuration. The quantities estimated are recoverable at specified production costs when using currently proven mining and processing technology. RAR can be correlated with the terms "measured and indicated resources" or "proven and probable" resources used by the mining industry in many countries.

The *Estimated Additional Resources Category I (EAR I)* is defined as the amount that occurs in addition to RAR mostly in the extensions of well explored deposits where the knowledge of the deposits characteristics is considered to be inadequate to classify the resource as RAR. EAR I could be correlated with the terms "inferred" or "possible".

In both the RAR and EAR I the degree of assurance of the uranium quantities is such that RAR + EAR I are identified as *Known Resources*.

In addition, *Estimated Additional Resources Category II (EAR II)* and *Speculative Resources* are defined as categories with decreasing confidence in the estimates. Both are therefore combined under *Undiscovered Resources*.

In contrast to other mineral commodities, uranium resources are classified according to their costs of production. The cost classes have been modified and adjusted to the changing market conditions.

Recently the cost ranges for the resource estimates are:

< \$40/kgU	-	< \$15/lbU_3O_8
\$40 - \$80/kgU	-	\$15 - \$30 /lbU_3O_8
\$80 - \$130/kgU	-	\$30 - \$50 /lbU_3O_8

The very high cost category of < \$260/kgU has not been assessed in recent editions.

Until 1990 the assessment of the world uranium situation, its resources, production, exploration and demand was mainly restricted to the so called WOCA area which excluded the Soviet Union, China and Central/Eastern Europe (CAMECON area). Owing to this exclusion, assessments for the entire world were incomplete. However, before 1990, uranium trading between the WOCA and COMECON areas was minimal.

The amount of uranium resources in the COMECON area was not known since the annual uranium production was considered confidential in several countries of this region. Starting in 1990 the worldwide uranium situation gradually opened when representatives from Central and Eastern European countries, the Soviet Union and the CIS reported to the IAEA their corresponding uranium resources and production and consequently joined the Uranium Group as visiting experts. The 1991 edition of the Red Book was the last one covering only countries of the WOCA region. At that time, the reported reasonably assured uranium resources recoverable at costs below \$ 80/kgU were about 1.5 million tU. These resources for 1999 are about 2.3 million tU covering now the entire world. Official figures of the annual uranium production are now available on a worldwide basis as well as the cumulative total uranium production since 1945. This enables analytical exercises on uranium availability, e.g. in inventories and various stockpiles. The year 1991 thus represents a turning point in the assessment of the worldwide uranium situation. Another change occurred in 1996 when the Uranium Group was reconstituted forming, the Joint NEA/IAEA Uranium Group with official membership of all non-OECD countries. As a consequence, two new Vice Chairmen were elected (one from the Czech Republic and the other from the Russian Federation). These additions extended support for activities already being conducted by the existing Vice Chairmen from France and the USA and the Chairman from Germany.

The data collection contained in the Red Book is used as reference material for various purposes. Customers of the Red Book include public and private libraries, energy companies, uranium companies, national and international organizations, universities and other research and business institutions. The Red Book is valued by its customers for the reporting of worldwide official data and for its unbiased and non-promotional analysis of the uranium market. The World Energy Council, the leading non-commercial global multi-energy organisation of about 100 countries, relies on the uranium resource and production data of the Red Book for its regular report *Survey of Energy Resources*. Commercial organizations such as the Uranium Institute in London reviews the Red Book data while preparing its own resource assessment based on information collected from the industry.

In summary the Red Book provides statistics and analysis for resources, exploration, production, demand, secondary sources, surplus defence material and the supply and demand relationship.

Since 1995, the Red Book has included a section on "Radiation Safety and Environmental Aspects". This section, which has been included in the last three editions of the Red Book, reflects the increasing awareness in all countries of the need for environmental protection. For several years large programmes have been underway in several countries to clean up wastes from closed mines and mills. Many of these sites, particularly the older ones, were brought into production, operated and closed when little was known about environmental effects. At the time, little concern was given to the resulting environmental impacts. Currently, planning for and conducting uranium mine and mill decommissioning, together with site cleanup and restoration, are of almost universal concern. Mine and mill closure activities have been or are being conducted in most of the countries with a history of uranium production. A summary of environmentally related activities reported by countries is presented in this section of the Red Book.

In 1996, the Uranium Group started a study on environmental aspects in uranium mining and milling. This issue became a major priority for the Group in response to an initiative by the Swedish Government. Under the leadership of Mr. Lindholm from Sweden a subgroup investigated the current world status. The results were published in 1999 in the joint NEA/IAEA report *Environmental Activities in Uranium Mining and Milling*. The report presents an overview of environmental activities related to uranium production. This profile of activities and concerns is based on survey responses from 29 countries and also includes a review of relevant activities of the International Atomic Energy Agency and the Nuclear Energy Agency of the OECD. The report also provides an overview of the reported interests of specialists working in the field. These areas of interest include: environmental impact assessment, emissions to air and water, work environment, radiation safety, waste handling and disposal, mine and mill decommissioning, site restoration and the regulation of these activities.

In 1999, the Joint NEA-IAEA Uranium Group established a "Working Group on Environmental Restoration of World Uranium Production Facilities". This was done in response to the broadened mandate of the Group to foster the exchange of information on environmental effects and environmental technologies associated with uranium mining and ore processing. The Working Group conducted a study on remediation activities and is preparing a report for publication in early 2001. To obtain an overview of this theme, the Working Group sent questionnaires to Member Countries / States requesting information about remediation activities. The results of this survey were analysed by the Group and summarized in sections describing the most relevant issues involved in the remediation of uranium production facilities. The report will provide a synopsis of the most relevant issues in remediation programmes for uranium production facilities and an overview of activities and plans in the reporting countries. Relevant issues discussed include: site characterisation, dismantling and decommissioning, waste management facilities, water remediation, long term monitoring, policies and regulations, and costs. The country profiles of remediation activities and plans include information provided by 22 countries (12 OECD and 10 non-OECD countries).

Sustainable development and energy resources

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Abstract. (a) The paper describes the substance and content of sustainability as well as the elements, which determine the objective. Sustainability is high on national and international political agendas. The objective is of a long term nature. The focus of the paper is on hydrocarbon emissions (CO_2); (b) International approaches and policies are addressed such as the climate change convention and the Kyoto protocol. The burden for change on the energy sector to achieve sustainability is very large in particular for OECD countries and those of central and Eastern Europe. Scepticism is expresses whether the goals of the protocol and be reached within the foreseen timeframe although governments and industry are active in improving sustainability; (c) Future trends of demand and supply examines briefly the growth in primary energy demand as well as the reserve situation for oil, gas and coal. Renewable energy resources are also assessed in regard to their future potential, which is not sufficient to replace hydrocarbons soon. Nuclear power although not emitting CO_2 is faced with grave acceptability reactions. Nevertheless sustainability is not threatened by lack of resources; (d) Energy efficiency and new technologies are examined vis-à-vis their contribution to sustainability as well as a warning to overestimate soon results for market penetration; (e) The impact of liberalization of energy sectors play an important role. The message is not to revert back to command and control economies but rather use the driving force of competition. It does not mean to renounce government energy policies but to change their radius to more market oriented approaches; (f) Conclusions centre on the plea that all options should be available without emotional and politicized prejudices.

1. CONCEPT OF SUSTAINABILITY

Sustainability linked to protection of nature and the environment has come to the forefront of the political agenda worldwide. Its concept is not clearly defined. It addresses societal, political, economical national as well as international aspects. The concept or rather the objective is, however, accepted internationally since the Rio Earth Summit 1992, the Kyoto Conference 1996 and the Conferences of the World Trade Organisation (WTO). Rio and Tokyo produced two important agreements the United Nations Framework Convention on Climate Change (UNFCC) and the Kyoto Protocol (Protocol) with detailed targets and efforts for implementation. Sustainability embraces: saving natural resources, building and using long lasting economic capacities for economic growth, continued societal progress. The interrelationship of these elements and the priorities amongst them continue to be controversial. It is obvious that no across the board solution has been found yet nor will one be achievable in the future. Economic, social and political as well as historic and cultural differences between countries and regions exist and will continue in the future. Nevertheless, sustainability requires changes in today's world. The time frames and capacities for change, and political constraints or perceptions, will influence greatly the implementation of international agreements.

Sustainability is of a local, regional, national and global nature and so are different kinds of emissions. In the context of this conference agenda I shall limit myself to the climate change issues connected with greenhouse emissions treated in the UNFCC and the Protocol. The focus of this paper is on global hydrocarbon –CO_2– emissions, and the related role of energy. The energy sector from primary extraction to energy use is the major source of CO_2 build up and is being requested to make a major contribution to address the climate change problem in reducing these emissions in order to mitigate climate change over time.

Energy is an essential factor and engine for economic development and growth. Energy security has always been a high priority task for policy makers because it contributes directly to meeting both basic and more sophisticated human needs. It has also been at the heart of political clashes and wars leading to economic disruptions. Since CO_2 emissions do not stop at national borders, the climate change issue is of a global nature. Two considerations have to be taken into account. First: energy is

not only a sectoral issue; its strategic nature, while changing over time, must not be neglected. Second: sustainability requires responsibilities and actions for global and comprehensive but at the same time differentiated energy solutions. The World Energy Council (WEC) defines three energy goals: accessibility, availability and acceptability, and deems them fundamental for political stability worldwide. Achieving sustainable energy is of a long term nature, which means setting the necessary and appropriate policy frameworks and conditions now. The fact that the climate change issue receives the attention at the highest political level and is subject of intense international activities and negotiations asks for serious consideration worldwide.

2. INTERNATIONAL APPROACHES AND POLICIES

While the UNFCC sets out political objectives to stabilize CO_2 emissions the Protocol establishes legally binding commitments on their implementation. Notwithstanding the fact that the Protocol has not entered into force yet – it has not even been ratified by all members of the Organisation of Economic Co-operation and Development (OECD) – efforts on how to translate the commitments into practical policies and practices are manifold. The latest event of this kind was a meeting in Bonn, the location of the UN Climate Secretariat, in the run up to the next ministerial meeting in November in The Hague and the UN Conference on Sustainable Development in 2001.

The commitments of the Protocol differ between OECD Countries and those of Central and Eastern Europe on the one hand and the rest of the world on the other. The first group – Annex B Countries – is committed to reducing emissions between 2008 and 2010 by 5% on average on the basis of the emissions level of 1990. The scale differs e.g. EU minus 8%, USA minus 7%, Japan minus 6%, Russia 0%. For the rest of the world no commitments have been negotiated. However, this is still being debated. Several mechanisms are enumerated in the Protocol of how to assist developing countries to reduce their emissions and beyond that how international co-operation can enhance a more global oriented approach.

The protocol enumerates a list of measures how to reach its targets. Amongst them are: energy efficiency enhancements, research and development of new and renewable forms of energy, reduction and phasing out of imperfections in the energy markets, e.g. subsidies for CO_2 emitting sectors. Market-based instruments are recommended. The Protocol encourages co-operating across national borders for instance through the Clean Development Mechanism and emissions trading. Fossil fuels are acknowledged as well as nuclear power. The big issue still controversial is how to follow up the fulfilment of the commitments in international fora. The summer meeting in Bonn could not find solutions.

On substance there is no disagreement that fossil fuels in the following order – coal, oil and gas – emit the largest amounts of CO_2, though progress in the relevant combustion techniques has produced large efficiency improvements, especially in electricity and space heating.

The most important problem is whether Annex B countries will be able to live up to their obligations within the time frame of the Protocol. The answer in my judgement ranges from sceptical to no. Governments are surely intensively debating their policy mixes and have taken some measures already such as taxes, regulations, and reducing or phasing out counterproductive subsidies. One must also mention voluntary commitments by industry which show a wide range of efforts. There will be reductions of CO_2 emissions in some energy sub-sectors, but doubts remain whether the necessary turnaround of the energy sector will be achieved on the present basis of the planned policies. This is not a surprising situation because the fundamental change of the sectors′ structures in all its branches and fields, the economic and fiscal implications, the impact on the employment situation and last but not least consumer behaviour, do not lend themselves easily to an integrated solution. Furthermore, security of supply at affordable prices must be taken into account, as must the trends and achievements of liberalization and deregulation in the energy sector world wide, with the objective of making them more efficient and less State-controlled. Finally national policies must not regress into

trade barriers because of lack of comparability of environmental protection policies, sometimes envisaged as means for limiting trade in energy.

The burden on the energy sector is very large. The envisaged time frame seems long but it is indeed short for the immense task to achieve the foreseen changes in the sector. Nevertheless, belittling the need for change would lack political responsibility. In my view both the substance and the time frames for change should be reassessed with realism and differentiation. Examples of needed and potential change could include resource and production efficiency improvements, potential of cost-effective technologies including nuclear power, and the capacity for consumer response. Also needed is an assessment of which instruments contribute to accountable and foreseeable success without falling back into a command and control policy. The energy industry must also be taken on board as an integral part of this process. A mix of policies, and an integration of policies and practices will be needed to achieve the objective.

It follows from the above description, which can only be a brief summary, that sustainability in the energy sector is an ongoing process that carries a heavy burden at present mostly for Annex B countries. But changes in other countries over time are vital in order to cope with the global aspect. Intimately linked to the achievement of sustainability is the present and future energy demand and supply situation.

3. FUTURE TRENDS OF DEMAND AND SUPPLY OF ENERGY RESOURCES

There is no lack of forecasts and outlooks. They must not be taken as predictions for the future. Developments are constantly changing worldwide. Governments, international organizations such as the International Energy Agency (IEA) and the WEC, scientific and other institutions as well as energy companies all engage in assessments of possible future developments and their uncertainties. These outlooks are based on scenarios in order to take into account possible different developments. They are also adjusted regularly.

Elements of these outlooks are population growth, economic growth, financial markets and their role of providing the necessary resources for new investments, speed of capital turnover and national and international environmental policies and prospects. The end results differ in terms of timeframes, possible price scenarios, technology advancements etc. However, there are certain fundamental outcomes which are common to the main outlooks of world energy demand growth and availability of supplies. The following brief overview is mainly based on the work of IEA and WEC. Time horizons are until 2020. The WEC has, however, just recently stated again that this timeframe is too short for radical changes in energy trends. The IEA expressed the opinion repeatedly that their analysis discusses the main issues and uncertainties that lie ahead.

3.1. Demand

The IEA estimates primary energy demand growth by 65 % worldwide until 2020 unless new policies to cope with the reduction of CO_2 emissions are enacted and gain results. Within this range OECD countries account for annual growth of ca 1% p.a , the rest of the world by more than 4% p.a. Growth will be particularly strong in Asia and Latin America. China and India with their very large populations, are leading in demand growth.

The more modest demand growth in OECD countries is largely attributable to achievements in reducing the energy content in production and consumption. A considerable number of energy intensive industries of these countries were shifted to developing countries whereby the overall energy intensity of OECD countries was reduced. In addition, consumption in some countries shifted from coal to gas. Several environmental oriented policies and regulations were introduced.

The developing countries, on the other hand, will need strong economic growth and a switch from non-commercial technologies to commercial ones in order to raise the living standard of their population. This will have the effect of increasing emissions. Therefore, radical changes cannot be expected quickly.

Sectors which will influence energy growth are transport, electricity, space heating, industry, services and households. Increasing urbanization in developing countries has an important impact, wherein lies the potential for achieving energy efficiency gains. In Central, Eastern Europe and in developing countries the potential is high, although technologies at affordable cost are not sufficiently available or other economic priorities have been set. Long lead times will be unavoidable. They could be shortened through mechanisms of international co-operation foreseen in the Protocol.

3.2. Supply

There is general agreement that hydrocarbon resources might have to cover up to 90% of world demand during the timeframe of the Protocol. The question to be answered therefore is, will there be sufficient supplies of these fuel resources? What can be the role of renewable energies and nuclear power? Answers depend on reserve capabilities including their geographic distribution, timeliness of necessary new investments, sufficient and available infrastructure for transportation and transmission facilities, affordable prices and the functioning of national and international markets. Government policies in liberalized and global markets can influence the situation, including actions against abuse of market power of large industry mergers.

Forecasts of oil and gas supply vary and to a lesser for coal. Renewable energies have difficulties still to gain market penetration. They must cope with maturity of technology, energy intensity, reliability and commercial competitiveness. Nuclear is above all confronted with acceptability in many – especially western – societies.

OIL will contribute the largest share of supply in spite of its decreasing demand. As to reserves, one has to distinguish between conventional and non-conventional ones such as oil shales, oil sand-based synthetic crudes and derivative products, coal based liquid fuels, biomass liquid fuels and gas bases liquid supplies. While conventional reserves are plentiful beyond 2010, North Sea and other production areas may peak. The largest estimated conventional reservesare to be found in the Gulf Region, with Saudi Arabia as the largest reserve country, and in Venezuela. Those reserves are plentiful for much of this century. Another area which is subject to various estimates are the Caspian Sea countries. The most realistic assessment is that these reserves can be compared to those of the North Sea, but the problem is transport to consuming areas. Non-conventional reserves require technological advances to extract them, as well as increased investments and financing. According to the July *Monthly Oil Market Report* of the IEA the production ratio between that of the Organisation of Oil Exporting Countries (OPEC) and that of Non-OPEC countries is ca 45 million barrels per day (mbd) and ca 29 mbd. Opinions differ whether in the years to come, more new production areas, outside OPEC will be opened up. Price and technologies will have an important role to play. In any event, there will be no lack of reserves through 2010. The start of on-stream production for additional resources will depend on technologies, costs, prices and industrial cross-border co-operation.

Given the regional distribution of oil reserves the risk of political disturbances cannot be ruled out. It is true that past confrontation between OPEC and the rest of the world has to a very large extent lapsed. A variety of bilateral and multilateral dialogues, for instance, between OPEC and IEA take place. However, if one major producing country would decide to completely stop oil exports it would disturb the market. Oil is still part of the political agenda. The recent actions of OPEC of curbing production and thereby causing large price increases has a number of reasons which I would not call foreign policy oriented. The very low price of $10 per barrel was the starting point for OPEC decisions. Other elements which contribute have been the very low level of industrial oil stocks and some environmental regulations for oil refineries. It should also be mentioned that within OPEC there

are different opinions whether a high price negatively affects world economic growth and market shares of their countries vis-à-vis other energy resources in the long run. The present situation is a fluid one. Which role OPEC will play over time is open to speculation, in which I will not participate. Without doubt there is more understanding today of the role of oil markets and their functioning than there was in the past.

As to transportation and transmission facilities, access is vital. This is particularly the case in regard to the Caspian Oil. Within the framework of the Energy Charter Treaty (ECT) its 51 member countries have embarked on negotiations to establish a framework – including a legally binding protocol – for unimpeded transit in order to bring exports to consumers and diversify transport facilities through several third-party and intermediary countries.

GAS will probably enjoy the highest demand growth rates. One important reason is that it emits less pollution, including less CO_2 than oil and coal. Reserves are more widely located than oil. They are in North America, the North Sea, Russia, Caspian States, in several Gulf countries, Asia, Latin America. and some African countries. Reserves are also plentiful for the next 20 to 30 years, though gas imports will be necessary for a number of countries, especially in Europe and Asia. Wherever possible, pipeline deliveries will be preferable, as this is less costly than liquefied natural gas (LNG). New investments and financing for pipelines and harbour facilities will be needed as well as an open investment climate for foreign partners. Reassessments for upgrading reserves are being discussed. One word of caution is in order here. With the exception of North America too heavy a reliance on gas imports should be avoided in order not to repeat the mistakes of the past, when importing countries relied too heavily on one dominant energy source. To avoid misunderstanding, imports are not dangerous per se. On the contrary, this is what is needed in global markets. But over dependence on one single commodity is an unsound business practice.

COAL reserves have the longest lasting potential; estimates range between 100 and 200 years. Coal is also competitive on a world basis, but not in some traditional coal producing countries, where subsidies must be phased or at least cut to a minimum level required for supply security. The problem with coal is its pollution potential, which can be decreased through a number of efficiency and pollution control technologies. Coal also an energy resource which is available in several large developing countries e.g. China, India, Columbia. These countries will not and cannot forego this energy source.

RENEWABLE ENERGY SOURCES are at the centre of the sustainability discussion, combined with focus and hope in regard to their future potential. Renewable energies comprise a large number of new technologies e.g. solar, wind, photovoltaics, biomass, fuel cells, hot dry rock, hydropower. Their contribution, except for hydropower, is still small (far below 10%). Obstacles to gaining a higher market share are still manifold. They include their energy density, reliability and economic competitiveness. Market penetration and how to achieve it is the main issue. In spite of many efforts through government assistance and pilot projects of industry their overall contribution to replace hydrocarbons until 2020 will grow relatively fast but remains small overall. That is not to say that individual renewables such as wind power or solar cannot make a proportionally larger contribution. Niche projects can be counted upon here. In the transportation sector a number of pilot projects to replace oil based gasoline (e.g. gas, fuel cells) are being developed.

All in all the contribution of renewables will not change the scene dramatically within the timeframe of the Protocol. But all efforts must continue. It seems reasonable to expect larger contributions later in this century. Again one word of caution. Financial assistance and subsidies do not by themselves produce necessary technological breakthroughs. But without strengthened Research and Development efforts the potential of these energies will not come to market. Encouraging market access and penetration of these technologies should take into account competition in order to stimulate creativity, rather than suppressing competition through too generous public funds.

NUCLEAR POWER is important in power production. It has contributed considerably to a diversified energy supply. But the question of societal acceptability has not yet been resolved. It has grown more acute in a majority of OECD countries. The perceived relationship with nuclear arms was the first element of societal resistance to this energy source. After the Chernobyil accident the resistance against it has increased. There is no doubt that nuclear power has risks. But the national and international efforts to master them have been upgraded and improved greatly, as has the co-operation within the IAEA. Nevertheless certain very important issues remain to be unresolved such as waste disposal and decommissioning. In spite of various technological improvements the fact remains that this power source faces the above mentioned impediments. The recent decision to phase out nuclear power in Germany – admittedly over a period of 32 years – is a point in fact.

To demonstrate the sustainability of nuclear power, two approaches are necessary. First, it is important to educate the public on the fact that nuclear power does not emit CO_2 and that replacing nuclear power by coal, as suggested by some countries, will result in higher emissions. Second, the nuclear power industry must face the fact (and act accordingly) that nuclear power must be competitive and no longer dependent on public funds. This may mean a reduction in the number of plants but not a disappearance. There are many cases in the US and the UK where plants are competitive. It is clear that it is easier for existing plants for which the capital costs have already been amortized. Nevertheless, in any appropriate evaluation of capital and working costs for the anticipated life of the plant, the cost of nuclear power must be competitive with other energy sources.

3.3. Energy Efficiency

Energy efficiency means reducing energy intensity per unit of production and consumption as well as GDP. Energy efficiency policies and activities are indispensable for stable energy sectors, economic growth and environmental sustainability. Since the oil shocks of the seventies energy efficiency has improved considerably especially in IEA countries. At the beginning, efficiency was a response to price increases, supply uncertainties and government policies The objective of efficiency improvements has undergone changes. In the seventies, it was mainly driven by energy disturbances; in the eighties, this factor lost its importance because of the comfortable supply situation and low oil prices. Under the auspices of sustainable development and reflecting the overall trend of liberalising economies, efficiency has regained great attention and is the basis for new government policies and industrial efforts.

Efficiency improvements span the entire energy system – production, transport and distribution as well as consumption. Efficiency efforts and gains can be seen in industry, power production, building and space heating, transport, household appliances, oil, gas and coal extraction and refining to mention the main areas. The greatest savings so far have been in the industry and power sectors. Government policies have been manifold ranging from regulations to incentives –fiscal and others. Economic growth with capital turnover has fostered efficiency gains aided more recently by liberalising the sector and introducing competition. There is still large potential worldwide. Opinions differ on how, where and when the remaining potential can be realized. The situation differs not only between countries – IEA, Central and Eastern Europe and the developing countries – but also between sectors. Some analysts speak of shorter time horizons, others of decades. The IEA has stated that large scale energy efficiency improvements can be obtained neither easily nor quickly. The WEC has found its own previous forecast of efficiency gains was too optimistic, and that change has been slower than projected.

Irrespective of these outlooks it is important to give great attention to energy efficiency efforts and activities. How to encourage and foster them depends on technology breakthroughs, their competitiveness, economic and financial capacities as well as co-operation and dissemination across national borders.

3.4. Energy Technologies

Energy technology objectives have changed. Whereas in the seventies the emphasis was on developing alternatives to oil, in the eighties energy companies focused their attention on reducing costs and streamline management in order to stay competitive with very low cost OPEC oil. To achieve environmental goals, new emphasis has been placed on technology improvements and new developments. In the IEA, for example, there is a whole network of international co-operation via so called implementing agreements.

Fields of technology activities are production and sources of energy; energy end-use efficiency; supporting technologies e.g. high temperature material, storage systems, fuel cells, complex power systems, biotechnology, hydrogen as an energy carrier; and life cycle energy modelling and analysis. There are many more. As noted above, technology developments have occurred throughout the energy sector which have contributed to manifold improvements. The list of successes is long and constantly growing. There have also been disappointments and failures. Conditions for market penetration have also changed. For instance fuel prices can be increasingly important in competitive electricity markets so that even the gas turbine could be faced with cost disadvantages in spite of its low capital costs and low CO_2 emissions.

This leads to the assessment that efforts by governments and industry must continue vigorously taking into account, however, that neither large amounts of public funds nor continued research and development by themselves can guarantee when and at what cost new technology breakthroughs would be economically competitive. New energy technologies to endure they must be economically competitive. It is appropriate to mention at this juncture the enormous impact new technologies can make to the changing environmental outlook of the energy sector. Last but not least it is appropriate to mention here the influence modern communication technologies have on the energy sector.

The message is that all efforts in the technology field must continue. In my opinion, it is perhaps the most important way to achieve cleaner environmental energy, without belittling the importance of other approaches. Lastly it must also not be underestimated that dissemination and transfer of competitive energy technologies can assist Non-OECD countries to clean up their environment and contribute to the global reduction of CO_2.

4. LIBERALIZATION OF ENERGY SECTORS AND SUSTAINABILITY

The deregulation and liberalization process – although still evolving – originates in the fundamental policy change of the role of governments vis-à-vis the market and its actors. The traditional governmental role of intervention in the energy sector arose from perceived public and social responsibilities e.g. common good, service public. The need for change arose from increased global competition. Recognition and awareness in economies as a whole and the energy sector, in particular, identified a need for increased efficiency, separation of commercial, social and political objectives, higher capital and labour productivity, mobilising financial resources for new investments, worldwide competition between countries and their economies.

The shift from government intervention to markets and to corporate responsibility has created more freedom for suppliers, and for consumers to choose their supplier. The degree of integration of different company activities has been reduced, mostly by law. Because of the strategic nature of the energy sector governmental responsibility to guard against market failures remains. Liberalization does not eliminate energy policies but the degree and nature of intervention has changed. Political framework conditions which are stable and predictable are the imperative of modern economic and energy policy.

Consequences of deregulation and liberalization differ between energy sub-sectors. There are benefits and risks related to this process. However, competition as the driving force will remain and offers

more benefits than disadvantages, but these cannot be described in detail in this context. Governmental responsibility remains especially in two areas: security of supply and environmental protection. But these policies must be of a general nature to set stable framework conditions and governments must not act in place of companies. Heavy handed policies which discourage rather than encourage structural change towards diversity of supply or change to sustainability would not achieve the desired results. If regulation in environmental protection would grant pubic funds for assisting efficiency or development of renewables without prescribing competition, it would forego the option to focus on the most creative developments.

It is clear that deregulation and liberalization has to take into account the different maturity of countries. In many developing countries it is in the first instance necessary to bring these economies into a situation where the necessary conditions for markets and competition can be created. In this process, however, mistakes experienced in the most industrialized countries should to the extent possible be avoided. Therefore economic efficiency is an important objective in the present changing world.

5. CONCLUSIONS

This overview of the relationship between sustainable energy and energy resources can only be brief. It cannot explain in detail all aspects of this complex subject. With this explanation the following conclusions are proposed.

(1) Sustainable development has a high priority on the international agenda. The transformation from the present situation is of a long term nature.

(2) Sustainable development embraces saving natural resources, economic growth, continued societal progress and security of supply

(3) Achieving this goal places a high burden on the energy sector.

(4) Sustainable development is not threatened by lack of energy resources, although disturbances cannot be ruled out if the development of the necessary resources fails or political disturbances lead to supply disruptions.

(5) All energy resources will be needed to respond to the forecast increases in demands, especially for the developing world. This includes hydrocarbons, renewables and nuclear power.

(6) Sustainable development means supporting economic development and growth while protecting the environment. It means realism, flexibility, appropriate contributions from governments and industry according to their roles in the ongoing liberalization of the energy sector.

(7) A mix of policies will be needed, targeted to the characteristics and differences of the various sub- sectors; one policy focus must be to achieve acceptability of energy technologies.

(8) Key elements for integrating sustainable energy development goals are energy efficiency, development of new competitive energy technologies and using the adequate public incentives.

(9) Efforts should be concentrated on all options available without emotional and politicized prejudices.

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The potential role of nuclear energy in greenhouse gas abatement strategies[1]

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Abstract. Nuclear energy plays an essential role in avoiding greenhouse gas emissions. The contribution of nuclear power to electricity supplies has grown rapidly since the 1970's. As of July 2000, 432 power reactors were in operation in 31 countries. Nuclear power provided some 2300 TWh. This is about 17% of the world's total electricity, or 7% of total primary energy. This contribution avoids the emissions of about 2300 million tonnes of carbon dioxide annually, assuming that it would otherwise be provided mainly by coal-fired plants. This represents nearly one-third of the carbon dioxide presently emitted by power generation. Since electricity generation accounts for about 30% of all anthropogenic carbon dioxide emissions, total emissions would be about 10% higher if it were not for nuclear power. In contrast, the objective of the Kyoto Protocol is to reduce greenhouse gas emissions in industrialized nations by 5% by 2008-12 compared to a 1990 baseline. In order for atmospheric greenhouse gas concentrations to be stabilized at a sustainable level, it will be necessary to reduce emissions by around 60% from the 1990 level. Advocates of a policy of "convergence and contraction", where developed and developing countries are to be allowed similar levels of emissions on a per capita basis, state that developed countries may have to reduce emissions by as much as 80%. Nuclear energy will make a significant contribution to meeting the world's future electricity demand while helping reduce greenhouse gas emissions. However, the scale of that contribution will be strongly influenced by the way in which this contribution is recognized in national and international policies designed to tackle climate change. The debate continues to rage over the science of climate change: is climate change the result of human intervention or is it a naturally occurring phenomenon? The majority of scientists involved in this debate would agree that enhanced global warming, as witnessed in recent years, has come about as a result of the massive explosion in greenhouse gas emissions since the beginning of the industrial era. This paper will give an overview of the institutions and organizations involved in the international climate change negotiations. It will describe the political positions of different countries on their perceived role of nuclear power in mechanisms designed to reduce greenhouse gas emissions. The paper will also give an insight into the financial impact of assigning a value to carbon emissions and how that might change the relative economics of nuclear power in comparison to fossil fuel generation.

1. THE DEVELOPMENT OF INTERNATIONAL POLICIES ON CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 by the World Meteorological Organisation and the UN Environment Programme (UNEP) to produce scientific information on climate change to assist policy makers in addressing the growing concerns about climate change. The IPCC published its First Assessment Report in 1990. The report confirmed that climate change was a threat and called for a global treaty to address the problem. The UN General Assembly established an Intergovernmental Negotiating Committee (INC) to negotiate such a treaty.

In 1992, the INC adopted the United Nations Framework Convention on Climate Change (UNFCCC). The Parties to the UNFCCC have adopted the long term aim of stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous changes in the climate. This has been done in a way that is consistent with continued economic and social development. The challenge for energy supply over the next 50 years, therefore, is how to meet the rapidly growing demand for energy services from a growing population whilst limiting greenhouse gas emissions. Some 180 governments and the European Union (EU) are Parties to the Convention. Parties meet at

[1] This paper is based on "The Influence of Climate Change Policy on the Future of Nuclear Power", Jonathan Cobb, The Uranium Institute 25th Annual Symposium, 30 August-1 September 2000: London.

an annual Conference of the Parties (COP) to review the implementation of the Convention. Additional intergovernmental meetings of various subsidiary bodies are also held each year.

The Convention divides countries into Annex I and non-Annex I Parties. Annex I Parties are industrialized countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992 and countries with "economies in transition" (EIT). The EIT countries include the Russian Federation, the other former Soviet Republics, and certain other Central and Eastern European countries. Non-Annex I Parties are the developing nations.

Annex I Parties were committed to adopting national polices that would stabilize greenhouse gas emissions at 1990 levels by 2000. However, this was a non-legally binding aim and few countries have actually achieved this target.

The Annex I Parties that were members of the OECD in 1992 are also Annex II Parties. These Parties have an obligation to provide "new and additional financial resources" to developing countries to help them tackle climate change. Annex II Parties are also required to facilitate the transfer of technologies that can help tackle climate change to both non-Annex I Parties and the EIT countries.

At the first Conference of the Parties (COP 1), held in Berlin in 1995, Parties decided that the commitments taken on by Annex I Parties in the Convention were not sufficient, and they agreed to develop further commitments. The culmination of the negotiations that followed was the Kyoto Protocol, which was adopted at COP 3 in Kyoto at the end of 1997.

The Kyoto Protocol commits Annex I Parties to legally binding targets to limit greenhouse gas emissions. The overall effect of these limits would be to reduce these emissions by 5% by the period 2008-12, compared to 1990 levels. Individual countries have been set specific targets, ranging from an 8% cut to a 10% increase in emissions. The one exception to this allocation system is the EU, which has been given an overall target of an 8% reduction in emissions. EU member countries have reached an internal agreement on the allocation of individual country targets to achieve the overall EU target, thus forming the EU bubble.

Over 80 countries have signed up to the Kyoto Protocol. However, few of the major emitters have ratified it. Therefore the Protocol has not entered into force and the emissions targets are not legally binding. For the Protocol to enter into force, it must be ratified by 55 Parties to the Convention, including Annex I Parties accounting for at least 55% of 1990 carbon dioxide emissions.

Many countries are waiting to agree the operational details of the Protocol before they ratify the Protocol. Considerable progress on the negotiations to develop these operational details is hoped to be achieved at COP 6 in The Hague in November 2000.

2. THE KYOTO MECHANISMS

The Kyoto Protocol established three "Mechanisms" to help Annex I Parties reduce emissions. The three mechanisms are known as emissions trading, joint implementation (JI), and the clean development mechanism (CDM).

Emissions trading would involve the purchase of a proportion of one Party's quota of emissions by a second Party. The Protocol states that the COP will develop the rules and guidelines that will allow Parties to carry out emissions trading. At present the Protocol only deals with emissions trading between Parties. However, it is likely that systems will be put in place to allow legal entities (e.g. companies) to participate. It is assumed that the legal entities will be emitters: the nuclear industry 'avoids' GHG emissions hence the industries' participation in emissions trading is not immediately clear and will, in many cases, be dependent upon national climate change strategies.

While an international emissions' trading scheme operating under rules set out by the COP may be some years off, some national emissions trading schemes are currently being developed. Some of these schemes are being developed in co-operation with business and industry. It is important that companies in the nuclear sector participate, where possible, in the development of these national schemes to ensure that the nuclear industry is treated on a level playing field with the other electricity generators.

The two remaining mechanisms, JI and CDM, share some similarities. They are concerned with the execution of "projects" that lead to emissions reductions that would otherwise not occur in the absence of the project. The JI mechanism applies to projects carried out in an Annex I country whereas the CDM is for projects carried out in a non-Annex I country.

JI allows one Party to transfer emissions reduction units to another Party in return for projects carried out by the second Party in the first Party country. The projects must result in emissions reductions additional to any that would otherwise occur. The exact meaning of this "additionality" has yet to be defined, but, in principle, it requires some activity over the business as usual case.

Parties may authorize legal entities to carry out projects. An example of a JI could be if Company X carried out an upgrade to a nuclear reactor in Country A on behalf of Country B (where both Country A and B are Annex I Parties) which resulted in additional output, either through improved performance or extension to the operating lifetime. If it could be demonstrated that this additional output displaced electricity generation from greenhouse gas emitting sources then the project would be eligible for credit for the emissions avoided.

The CDM operates in a similar way to the JI mechanism in that credit would be given for projects carried out that resulted in lower greenhouse gas emissions than would have otherwise occurred. However, the CDM applies to projects carried out in countries that are non-Annex I Parties (i.e. developing countries). The non-Annex I Parties represents a very important group in the climate change debate as their future emissions are predicted to escalate as populations in these areas grow and industry develops.

As the non-Annex I countries do not have an assigned emissions reduction target under the Kyoto Protocol, they can not transfer emissions credits to an Annex I Party seeking to carry out a project. Instead, it is expected that an Executive Board will be set up to evaluate CDM projects and award Certified Emissions Reduction credits based on the emissions avoided. Credits may be used by an Annex I Party towards meeting its emissions target. A sponsoring Party may authorize legal entities to carry out projects on its behalf.

The CDM mechanism has another objective, namely to assist developing countries in achieving sustainable development. It is this second objective that provoked considerable debate on the eligibility of nuclear power projects. Whether or not nuclear power projects will be eligible for the CDM is one of the issues that will be discussed at COP 6. Nuclear power projects are not the only type of project facing objections against inclusion in the CDM. The use of sinks (e.g. forestry projects and land use management); cleaner fossil fuel and large scale hydro technologies are also facing objections.

3. HOW NUCLEAR FARES UNDER THE MECHANISMS

Over the last year Parties have assimilated a text establishing the principles, modalities, rules and guidelines for the Kyoto Mechanisms. The text, [2]*Summary of notes to Mechanisms Pursuant to*

[2] Statement by the international nuclear power industry to the Third Conference of the Parties to the UNFCCC in Kyoto (Available at http://www.uilondon.org/uifostat.htm).

Articles 6,12 and 17 of the Kyoto Protocol – text for further negotiation on principles, modalities, rules and guidelines can be accessed in its entirety via the World Wide Web.

Perhaps the issue most pertinent to the industry is the question regarding the CDM. It has been through the CDM that nuclear has really come to the attention of the delegates of the FCCC meetings. Bids to exclude nuclear technologies from the project-based mechanisms have come from the Association of Small Island States (AOSIS), the oil producing nations, as well as the environmental NGOs. Other Parties share their views though have not made their position part of the negotiating text. Parties supporting nuclear as a suitable CDM technology are less vocal but statements from the Umbrella Group (a group of countries including the US, Canada, Australia, Iceland, Japan and the Russian Federation) oppose the exclusion of any technology from the project-based mechanisms. Developing countries have underlined the role of the host country in determining project eligibility, defending their sovereign rights in choosing sustainable development practices.

At the meeting of the Subsidiary Bodies to the FCCC in Bonn, June 2000, the same requirements proposed for the CDM, to exclude nuclear from this mechanism, were also proposed as an optional requirement for JI projects. Some developing nations want to place the CDM criteria on JI projects because of fears that the additional cost of the CDM criteria could lead Parties to invest in JI projects between developed countries instead of CDM projects with developing countries.

Whilst the adoption of such a policy could potentially exclude the nuclear industry from any resulting GHG market at an international level, countries could still establish national policies to tackle climate change that could recognize the climate change benefits of nuclear power. However, exclusion at an international level would add considerable political leverage to those who would oppose national measures that treated nuclear power in this way and ultimately favour other technologies that do not provide the base-load, emissions free, electricity generation that is inherent with nuclear.

4. THE POSITION OF PARTIES ON NUCLEAR POWER AND THE KYOTO MECHANISMS

Opposition to the inclusion of nuclear power within the Kyoto Mechanisms was always likely to be an issue of contention because of the varying positions taken on the use of nuclear power by individual Parties.

Objections to the inclusion of nuclear power in the Kyoto Mechanisms were made by the AOSIS at COP 5 and by Saudi Arabia during the June 2000 subsidiary body meeting. During the same meeting, Canada objected to the exclusion of any options from the CDM. Thus, an objection to the exclusion of nuclear power projects has been noted in the negotiating text.

AOSIS is one of several groupings of Parties, each with a different stance on the inclusion of nuclear power in the Kyoto Mechanisms. Other groupings of Parties include the “Umbrella Group”, the G77 and China, and the European Union.

The Umbrella Group consists of Australia, Canada, Iceland, New Zealand, Norway, the Russian Federation, Ukraine and the United States. On the whole this group opposes the exclusion of non-emitting technologies from the CDM. It includes some Parties that have high energy consumption and wish to maximize the use of the Kyoto Mechanisms in order to meet their targets. Other Parties, such as the Russian Federation and Ukraine, are likely to have much lower emissions than their Kyoto Protocol targets and therefore will be opposing any arbitrary limit on the trading of assigned amounts.

The G77 and China consists of the developing countries. On the whole this group opposes any restrictions on the CDM that may restrict the flexibility of individual Parties in determining their future technology options. At present, few countries in this group have plans to use nuclear power to meet their energy needs. However, some parties will face increasing pressures to increase their energy

supply infrastructure and the use of nuclear power plants could make a major contribution to the avoidance of greenhouse gas emissions. Not all members of the G77 and China take this view. The exceptions are namely the oil producing nations that feel economic threat from any restrictions on the future use of fossil fuels.

The majority of countries in the European Union are opposed to the inclusion of nuclear power in the CDM. However, France and the UK have opposed an outright exclusion of nuclear power. A compromise position has emerged where the European Union will support the concept of a "positive list" that would include technologies such as renewables and energy efficiency. This positive list would not exclude other technologies, such as nuclear power, from the CDM.

A key issue raised in opposition to including nuclear technology in the project based mechanisms is the accusation that nuclear energy does not fulfil the objectives of sustainable development and therefore does not comply with the criteria of the CDM.

It could be argued that as uranium reserves are finite nuclear power is not infinitely sustainable. It should be noted, however, that the potentially exploitable reserves of uranium are very large, particularly if one includes the uranium resource in seawater and the use of fast reactors. It is also worth remarking that many renewable energy sources are not infinitely exploitable because they are constrained by a finite number of suitable sites.

Further more, the climate change debate is proposing the allocation of a cost to carbon, as this is the environmental externality considered. Historically, the nuclear industry has accounted for its environmental external costs in waste management (including the decommissioning of nuclear facilities) and air-borne pollutants, which include greenhouse gases, oxides of sulphur, nitrogen and particulates.

An additional concern is the apparent lack of understanding regarding the international regulations and requirements with which the nuclear industry must comply during normal operation and new nuclear build. Some Parties have expressed concern that nuclear projects under CDM or JI may have safeguard implications especially if the proposed projects involve countries that have not signed the NPT. Clearly any nuclear project proposed under the CDM or JI would have to comply with all international safeguard regulations as well as satisfying the objectives of the Kyoto Protocol.

In the short term, the objection of new nuclear build projects under the CDM is not likely to be valid because of the current long lead times. However, there exists greater potential in projects that might result in capacity upgrades or life extensions of existing reactors.

In the longer term, significant growth in energy demand is expected globally. If this demand is met with conventional fossil fuels then the resultant greenhouse gas emissions could pose a serious threat to the environment. Therefore, it should not be surprising if a significant proportion of CDM projects are related to the energy sector. It is also worth noting that CDM projects will earn emission credits only where it can be demonstrated that emissions are being avoided. In general, this would mean, for example, a nuclear power plant being built in place of a large fossil fuel power plant. It is likely that large fossil fuel power plants will be built where there is the existing infrastructure to support the transmission of electricity through electricity grids. In comparison, many renewable energy projects will be better suited to where there is a lower level of energy demand and the energy supply infrastructure is not suited to large power plant.

Obviously some countries have made the decision not to use nuclear power. However, the 31 countries with nuclear capacity are using nuclear power to meet their greenhouse gas emissions reduction targets and some developing countries want the option of using nuclear power as part of their specific sustainable development programme. Individual developing countries are best placed to determine their own sustainable development needs.

5. THE POTENTIAL EFFECT OF ECONOMIC INSTRUMENTS ON NUCLEAR ENERGY

As has been described in this paper there is considerable debate over whether nuclear power projects should be included or excluded from participation in the Kyoto Mechanisms. One important issue to consider is whether the inclusion or exclusion of nuclear power from the mechanisms will have any impact on the prospects for new nuclear build.

Answering this question is difficult, if, for no other reason, that the strong influence of fuel costs on the overall generation costs of fossil fuel plant are such that it is difficult to make a valid assessment of the future costs of different generation techniques. However, the potential credit for the avoidance of greenhouse gas emissions can be illustrated by converting the value of carbon from the price per tonne of carbon to the price per kW·h for different generation technologies.

This conversion is shown for coal-fired generation in Tables I and II, and for gas-fired generation in Tables III and IV. Values are shown for permits with units of tonnes of carbon dioxide (tCO_2) and tonnes of carbon[3] (tC). This is because both these units are used regularly when defining quantities of greenhouse gas emissions and it is important to be certain as to what units are being used. As can be seen in the tables, the difference between the two units in terms of the equivalent value is large, therefore care is needed to ensure the correct conversion is used.

TABLE I. EMISSION PERMIT VALUES IN TERMS OF US$/$tCO_2$ AND THEIR EQUIVALENTS IN TERMS OF MILLS/kWh WHEN COMPARING COAL-FIRED GENERATION TO NUCLEAR POWER (1 MILL = US$0.001)

Emissions permit values (US$/$tCO_2$)	Value (mills/kWh)
5	4.8
10	9.6
15	14.3
20	19.1
25	23.9
30	28.7
40	38.2
50	47.8
100	95.5

TABLE II. EMISSION PERMIT VALUES IN TERMS OF US$/tC AND THEIR EQUIVALENTS IN TERMS OF MILLS/kWh WHEN COMPARING COAL-FIRED GENERATION TO NUCLEAR POWER

Emissions permit values (US$/tC)	Value (mills/kWh)
5	1.3
10	2.6
15	3.9
20	5.2
25	6.5
30	7.8
40	10.4
50	13.0
100	26.0

[3] Tonnes of carbon (tC) may be converted to tonnes of carbon dioxide (tCO_2) by multiplying by 44 (the molecular weight of CO_2) and dividing by 12 (the atomic weight of carbon).

TABLE III. EMISSION PERMIT VALUES IN TERMS OF US\$/tCO_2 AND THEIR EQUIVALENTS IN TERMS OF MILLS/kWh WHEN COMPARING GAS-FIRED GENERATION TO NUCLEAR POWER.

Emissions permit values (US\$/tCO_2)	Value (mills/kWh)
5	2.2
10	4.5
15	6.7
20	8.9
25	11.2
30	13.4
40	17.8
50	22.3
100	44.6

TABLE IV. EMISSION PERMIT VALUES IN TERMS OF US\$/tC AND THEIR EQUIVALENTS IN TERMS OF MILLS/kWh WHEN COMPARING GAS-FIRED GENERATION TO NUCLEAR POWER.

Emissions permit values (US\$/tC)	Value (mills/kWh)
5	0.6
10	1.2
15	1.8
20	2.4
25	3.0
30	3.6
40	4.9
50	6.1
100	12.1

The future trading price of emissions permits is a much-debated issue. However it is not unreasonable to assume a trading price of around US \$25/tC as a possible price over the first compliance period. At this level the value of carbon emission reduction credits for a nuclear generator would be worth around 6.5 mills/kW·h in comparison to a coal plant and 3.0 mills/kW·h in comparison to a gas plant (1 mill = US \$0.001).

The impact of carbon emission credits valued at this level would depend on the individual circumstances which would vary from country to country. In the future more demanding emissions reduction targets may drive the value of carbon emission reduction credits higher.

Another way of considering the impact of assigning a value to the avoidance of carbon emissions is to off-set the capital costs of reactor construction by trading in futures for the carbon permits that would be earned from the project. Greenpeace has used such a scenario in its briefing: "The Clean Development Mechanism: An Instrument for Sustainable Development or a New Nuclear Subsidy." The Greenpeace data considers replacing a 700 MW(e) coal fired power station with a similarly sized nuclear reactor.

According to Greenpeace, the 700 MW(e) coal fired power station would emit around 4.5 million tonnes of carbon dioxide every year. If, instead, a nuclear power station was built the carbon offset could be traded. Likely carbon dioxide permit levels are estimated to be US \$10–30 per tonne of carbon dioxide. The carbon offset earned by the nuclear power station would be worth between US \$450 million and US \$1.35 billion (ignoring the discounting of future credits). Greenpeace

suggests a new 700 MW(e) nuclear power station would cost between US $2.5–3.0 billion[4]. On this basis, the value of the trade in emission credits futures would reduce the capital cost by between 15–40%.

The nuclear industry is seeking ways to improve the economics of electricity generation from nuclear energy, including reductions in capital costs. Therefore, it is possible that trading in emission credit futures will be able to cover a higher proportion of the capital costs than suggested by the Greenpeace calculation.

6. THE COST OF EXCLUDING NUCLEAR ENERGY

To conclude, it is perhaps worth considering what would be the effect of excluding nuclear power from climate change policies and measures, both nationally and internationally.

It is a mistake to consider taxes and emissions trading permits as subsidies for nuclear energy, renewable energy, or any projects that can help reduce greenhouse gas emissions. Under the current situation electricity generation from fossil fuels is being subsidized. We will all pay for the cost of dealing with economic, social and environmental damage caused by climate change. Perversely, it is some of the poorest countries that are most at threat from climate change, whilst it is the developed countries who are primarily responsible for causing climate change through their use of fossil fuels.

Using nuclear power instead of fossil fuels is one way of combating climate change. In some cases, it will be the best option. If that option is denied then the cost of either avoiding climate change or adapting to it will be raised. For developed countries this may slow their progress in reducing emissions. Developing countries may find it harder to avoid the temptation of using fossil fuel generation to meet their energy needs in the absence of foreign investment.

The exclusion of nuclear energy will not stop the nuclear industry in its tracks. In some countries nuclear power remains a valued component of energy supply. New nuclear power stations are still being built. Those entering service over the next decade can be expected to be operating well into the middle of the twenty first century. These new stations will require fuel supply, spent fuel management, and waste management and decommissioning services.

Even if nuclear energy is eligible for Kyoto Mechanism projects there will be considerable challenges to be resolved. Some governmental representatives and members of the public will still have the same concerns in relation to perceived risks from proliferation and safety as they do today. The nuclear industry will have to continue to engage in the debate on these issues.

Nevertheless, the treatment of nuclear energy in climate change policies is important to the nuclear industry. If nuclear energy were excluded it would not be because of doubts over its contribution to avoiding climate change. Instead, it would be excluded because of other environmental and political issues. Any exclusion would send out a signal that Parties that may support the use of nuclear power in combating climate change, who support the right of developing nations to determine their own sustainable development needs, and who recognize that nuclear power makes a valuable contribution to securing a safe and diverse supply of energy, are willing to yield to those who take an opposing view.

7. SUMMARY

The ultimate objective of the international action on climate change is to stabilize atmospheric greenhouse gas emissions at a "safe level". Climatologists suggest that this will require a 60% reduction in global greenhouse gas emissions. The implications for global economic development and

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[4] 1 billion = 10^9.

energy supply are huge. The world will change dramatically over the next one hundred years, either as a result of the programmes put in place, if we are successful in reducing greenhouse gas emissions, or as a result of the environmental damage caused by climate change if we fail.

Nuclear energy can make an important contribution to meeting the increasing global demand for energy and assisting in the sustainable development of developing countries. However, the scale of that contribution will depend on how nuclear energy is treated in the emerging environmental legislation.

If the climate change benefits of nuclear energy are not reflected in national and international climate change policies then the existing inequities in the treatment of different electricity generation technologies will be made worse.

Economic impact of world mining

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Abstract. Mining plays a vital role in the economic development of many countries. The emerging economies are now major players in the production and availability of key commodities such as copper (70%), bauxite (40%), iron ore and precious metals. Mining also has a positive impact on the economy of many countries. Another impact of mining can be measured in terms of employment opportunities and income generation. Commercial scale mining provides employment and skills transfer to more than 2 million workers. The multiplier effect increases this benefit by a factor of between 2 and 5. The World Bank Mining Department has carried out an in-depth study on economic and social impact of mining at the community level in Chile, Peru, Bolivia, Papua New Guinea and Mali. This study demonstrates that there are substantial social and economic benefits to the community. The most positive cases are related to the growth of local small- and micro-enterprise activities. However, mining remains controversial, as true sustainable development is not only a matter of financial flows. Mining has also been associated with a number of economic and social problems. As a result there are questions about the sustainability of the economic outcome of mining. The contribution of mining to sustainable development needs to be considered in terms of economic and technical viability, ecological sustainability and social equity. To achieve this, governments, mining companies and local communities must work together to address these issues.

Mining plays a vital role in the economic development of many countries. Historically this has been the case in many parts of the developed world, and while mineral development is an important factor for economic growth it can also, if done responsibly, be a catalyst for social growth in developing countries.

The present economic impact of mining needs to be assessed within the perspective of the industry's present tendencies. For example, emerging economies are now major player in the production and availability of key commodities, such as copper (70%) and bauxite (40%) and with iron ore, precious metals, lead and others within this range. Also, the continuous declining trend of real metals price during the past 35 years represents a difficult challenge for mining companies to reduce production costs through technical and financial management.

Another key trend is globalization and the dominance of market economy, with three important elements: (i) the creation of global capital, goods and service markets; (ii) the creation of global communications and information space; and (iii), the emergence of global values. While the mining sector has operated at a global level for a long time, the establishment of global information and communication has had enormous consequences on the mining industry as it has meant that positive and negative impacts and experiences in the sector are quickly reported and transmitted throughout the globe. The emergence of global values is to a large extent the result of the changes in communications and information, but it is also due to the increasing realization that actions in one country can have profound effects on other countries at the economic, social and environmental levels. For the mining industry, the increase in shared environmental values throughout the world has been the most important change to date, although the recent emergence of shared socio-cultural values is likely to have an even more profound impact.

Other recent developments, such as the Asian financial crisis, and the down-turn in metal prices, in combination with the continued globalization, especially with respect to access to mineral deposits on a global scale, has resulted in an unprecedented competitive environment and the need for competitiveness at all levels. In the area of environment and social protection, the industry's exposure to an increased focus and awareness by the public at large, results in a need to address and integrate those factors in project design and operations at the earliest stage of development. In particular, the emphasis has moved away from the narrow environmental definition of sustainability to one of "sustainable communities"; that is, communities which are able to turn part of the wealth generated by mining into an asset base which not only results in wide-spread benefits from the operation of the mine but ensures that the community will have a continued economic future once the mine is closed. As a consequence, the discourse on politics and economics of mining are shifting from a primarily central government focus to include both regional governments and communities as well as the international community.

Most economic research on mining still deals mainly with the macro-economic impact of the industry, looking at the benefits – or lack of – to the national economy. And there is no doubt that mining can be an important source of foreign exchange and fiscal receipts for governments, providing an adequate legal and fiscal framework is in place. When well-managed, these resources can be used as an engine for overall economic growth and the outcome of mining operations can thus produce a significant impact on national economies, as in the cases, for example, of Chile, Peru, Botswana, Ghana, Mali, Papua New Guinea and others.

Another important economic impact of mining can be measured in terms of employment and income generation. Commercial-scale mining provides employment and skills transfer to more than 2 million workers with, in addition, an employment multiplier effect by a factor from 2 to 5. While mostly a poverty-driven activity, small-scale mining provides income to about 13 million workers and their families worldwide, in countries such as Bolivia, Brazil, Colombia, Venezuela, Burkina Faso, Ghana, Madagascar, Mozambique, Tanzania and Indonesia, among many others.

Taking into consideration the present trends affecting the mining industry, it is increasingly important to assess the economic and social impacts of mining at the community level. Recently, the World Bank Mining Department has been carrying out an in depth study in Chile, Peru and Bolivia, as well as other studies of mines in Papua New Guinea and Mali, West Africa, to assess such impacts. The studies demonstrate clearly that there are substantial social and economic benefits to local communities, but they do not come automatically and their sustainability is a key issue. The most positive cases are related to the growth of local small and micro-enterprise activity, providing supplies and related services to mining companies; and to local economic development and activity diversification. On the other hand, there is a clear need also to redistribute more tax revenues to local governments and to build capacity at the community level.

However, the position of mining remains controversial and true sustainable development is not just a matter of financial flows. While mining is a major contributor towards economic development, it has also been associated with causing a number of economic, environmental and social problems, which has led many to question the sustainability of the economic outcome of mining and propounded the resource curse theory. The industry is therefore challenged to (i) mitigate its negative impacts - in terms of environment, socio-cultural, health

and human development, governance, macro-economic management and corruption, as well as economic barriers to restructuring and real impacts on poverty reduction; and (ii) further improve and promote concepts and actions aiming at industry-community co-participation in the mine building process. The industry needs to ensure that its benefits are harnessed at both the local and national level in a sustainable fashion.

The contribution of mining to sustainable development needs to be considered in terms of economic and technical viability, ecological sustainability and social equity. In order to achieve this, governments, mining companies and local communities must work and cooperate on these issues through the different stages of a mining project and over a considerable time span, covering the period from exploration to mine operation, and to post-mine closure.

Cleaning up our mining act: A north-south dialogue

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Abstract. Historically, the availability of natural resources has been a pivotal element in the pursuit of political power and economic development. It contributed to improving people's standard of living, which translated into better health and increased life expectancy. Paradoxically, this road to riches and collective material prosperity was built at the expense of the long term well-being of the mining community by degrading its environment. Mining is first and foremost a risky business and a temporary activity. It is derided as a boom-bust industry. For both North and South, mining should be a boon and not a liability. This impact of mining is two-pronged. On the one hand, the impact is felt on the physical environment, mainly our support system, land, soil, water, ocean, and air, and on the other hand on our economic, social cultural and political milieu. The latter is far reaching and its implications are felt far beyond the performance of the sector. Mining can effectively foster sustainable development if the accrued rent from the depletion of mineral resources is continuously reinvested into other forms of economic and social development, inclusive of health and education, which in turn are more sustainable than mining. A healthy and continued multi-stakeholder consultation will go a long way towards "sustainability". Consensus should be built over the need to reconcile the collective interest with the local socio-economic expectations.

1. ALL MINING: HISTORIC DEVELOPMENT AND ECONOMIC REALITY

1.1. A snapshot of mining, past and present

Nowadays, mining is as much about economics as emotions! The activities of this industry fuel passionate debates that the industry, the governments and civil society are ill prepared to address in a constructive, proactive and candid manner. Since the end of the Cold War, the resource industry has increasingly been embroiled in the North-South value divide. The industry exposes conflicting views of development between the North and the South.

Historically, the availability of natural resources has been a pivotal element in the pursuit of political power and economic development. The industrial revolution was built upon the access, control and economic exploitation of minerals and coal, then oil and gas. It contributed to improving people's standard of living, which translated into better health and increased life expectancy. Paradoxically, this road to riches and material prosperity was built at the expense of the long term well being of the mining community by degrading its environment. In the past, there were only two ways of mining, the capitalist and the socialist models. Both were wasteful with dire impact on the ecosystem and the health of the workers and their community. Mining the socialist way was even more wasteful because profits and costs did not matter as long as raw material was available to supply-driven industrial plants. Nowadays, not only does industry have to correct the "sins of the past", but it has to integrate new, often open-ended expenses into its cost plans. To maintain profits, any cost-based industry is therefore compelled to continuously trim its labour force through *inter alia*, technological innovation. As a result, the industry is losing its historic political clout and multiplier effect. Nowadays, mining houses' shares have lost their original luster, they cannot compete with the new technology and communication companies.

Mining shares are not listed in the hot NASDAQ composite index. Mining is first and foremost a risky business and a bad investment is captive. It is also a very competitive business, with companies chasing the best and most economically viable mineral deposits. Since most project investments require large amount of equity and loan financing, decisions regarding their go-ahead or close down are taken outside the country where the project will take place. In the process, the national views and

development aspirations are usually ignored. This is not a value judgement, but the acknowledgement of a truism. The global dimension increasingly prevails over the national agenda.

Access and control over natural resources were the driving force behind the colonization drive. In some instances, mining became synonymous with predatory practices, and labour abuses. In many countries, particularly in developing ones, there is a lingering feeling that mining companies, mainly foreign-owned, are exploitative, manipulative and inattentive to local needs and sensitivities.

Mining has long been a globalized industry. It is more and more so, with headquarters in industrialized countries and operations/exploration/mining in developing countries. Mining employment in the former is becoming increasingly negligible. As a result, the industry is facing daunting cultural and social challenges. The ability to successfully and sustainable address these challenges will make the difference between winners and loosers. This challenge is even greater in countries, which are switching from a centralized economy to market economy and a democratic multiparty system.

1.2. Environment and social challenges

Mining comes big and small, and both forms are inherently disruptive to the environment and have always been associated with harsh working conditions. Mining everywhere, whether industrial or small scale, took place in horrendous conditions for the workers and the surrounding community. Fifty years ago, child labour was still a common feature of mining in some Western countries. Child labour still persists in the small scale operations of far too many developing countries.

Environmental and social concerns, conservation, protection, and rehabilitation beyond the mine itself are fairly new developments. Since the early1970s, the era of the first United Nations Conference of the Human Environment, the industry has evolved from an “end-of-pipe” mode to that of internalizing negative externalities, i.e., by integrating as production costs the protection and rehabilitation of the environment and related expenses linked to social and community programmes.

However, if large scale mining is more and more environmentally conscious, as long as it can pay for it, small scale mining, and more specifically its artisanal segment, is usually unable to meet environmental and social costs. This is particularly true in developing countries where environmentally adequate technology and access to loans are few and far between. Artisanal mining is mostly a hand-to-mouth activity practiced by poor rural people unable to make ends meet with the dwindling income of the land, and by a transient jobless population. During the last 20 years, the population pressure on ecologically vulnerable land in many developing countries and the economic deterioration, have caused an increase in artisanal mining activities, resulting in environmental and social degradation. To make matter worse, these activities are often clandestine and linked to other illicit pursuits like drug and small arms trafficking.

1.3. A gender insensitive industry

It is neither a sweeping statement, nor feminist rhetoric to say that the culture of mining is overly male-dominated and top-down. Industrial mining has been, and still is, a notable employer of male workers who are usually paid well above the national and regional average. Many mines employ contract workers housed in bachelor quarters. Other mines operate on a “fly in, fly out” mode to reduce non-productive costs and minimize the mine's footprint. The resulting disposable income often creates unexpected social problems like alcoholism and prostitution and their corollary, sexually transmitted diseases, and abuses against women. Women, either as miners’ wives or potential employees were not part of the mining environment. They were non-existent as far as the mine management was concerned. In some countries, women are even believed to be a bad omen for mining. Recent data indicate that in the US, mining, gas, oil industries, and waste management companies are the lowest employers of women. In all fairness, mining cannot be overly criticized for

ignoring women even if it brought dramatic and often negative changes to the family's income structure. By involuntarily eroding the central role of women in the family, the industry denied itself of the opportunity to improve the social environment of the mine. Evidence suggests that a harmonious family atmosphere contributes to a better workplace with fewer conflicts, accidents and injuries.

2. THE LIMIT OF THE BIOMEDICAL MODEL FOR HEALTH

Emerging social concerns call for a broader approach to health policy. The traditional biomedical concept of health implies that health is the absence of disease and injury, but it is a somewhat restrictive notion. Health cannot be construed as only the opposite of disease, for health incorporates a dimension of well being. Furthermore, one should try to improve health inclusive of detection and reduce treatment costs through enhanced prevention. A paradigm shift from treatment to prevention is thus called for. This also has an implication for the mining industry. The mining industry should move from its traditional “do no harm” stand to embrace health and in improvements of well being. By launching community health programmes, (World Alliance for Community health with WHO) as recent examples illustrate, the industry may be on the right path. Not only would the industry improve the health of its workforce, but also it would reduce its labour costs.

3. ECOSYSTEM AND SUSTAINABLE DEVELOPMENT

3.1. Ecosystem approach

Ecosystem means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Article 2 of Biodiversity Convention). An ecosystem approach should take into account all components, including humans and their complex interactions as well as the interconnectedness of the ecosystems.

The new approach to development enshrined in the Rio Declaration and Agenda 21 promotes sustainable development which in turn recognizes that the improvement of people’s health and their environment are prerequisites to achieving sustainable development. Seven years after Rio there is an increasing consensus on the inter-relation between economic growth, and environmental and health protection. There is more and more evidence that poor health and polluted environment are impediments to poverty alleviation and overall progress. WHO, the UN health organization, advocates that “*the health sector should show leadership by translating the preventive health message of Agenda 21 into practical action for its own institutions and professionals, as well as for those of other sectors*” (Health and Environment in Sustainable Development, 1997). The mining industry should take note of this, just as it is embracing sustainable development.

3.2. A two-pronged impact

In a life system perspective within a sustainable development context, the minerals/metals system has an impact on health and well being which is both positive and negative. This impact is two-pronged. On the one hand, the impact is felt on the physical environment, mainly our support system, land, soil, water, ocean, and air, and on the other hand on our economic, social cultural and political milieu. Generally speaking, positive impact is usually rapidly visible, sustainable or not, whereas negative impact, except for disasters, accidents and injury is more subtle and insidious.

The impact of mining development on the socio-economic and political milieu is far reaching, and the implications are felt far beyond the performance of the sector. Corrective policies are often politically thorny and their implementation deferred, because they commonly require that governments tackle controversial and deep-seated governance issues. Many governments will therefore resort to half measures such as subsidizing money loosing mines instead of devising innovative job opportunities for the miners.

4. MINING AND SUSTAINABLE DEVELOPMENT

4.1. Implications

Mining can address sustainable development concerns as long as mining is profitable. If required production costs are higher than income, a project is either mothballed or a mine is closed. Since the UN conference on Environment and Development in Rio de Janeiro in 1992, the term "*sustainable*" has been used and abused in almost every possible context. Simply speaking, sustainable development is development, which meets our present requirements but does not compromise the needs of our children and future generations. The concept therefore implies the precautionary principle.

The notion may be vague in the context of mineral resources development. The concept of sustainable mining supported by many companies is somewhat illegitimate. In a multi-generational time frame, mining per se is not sustainable, as minerals are finite and non-renewable resources. Although metals are partly amenable to recycling, the related processing commonly takes place in industrialized countries where the raw material is transformed and used. Mining development sensus stricto is hardy sustainable, unless it is integrated into a holistic development process, inclusive of the social, economic, and environmental dimensions. Mining can effectively foster sustainable development if the accrued rent from the depletion of mineral resources is continuously reinvested into other forms of economic and social development, inclusive of health and education, which in turn are more sustainable than mining.

The mining industry is taking sustainable development on stride. A group of leading mining companies, through the World Business Council for Sustainable Development, is launching a global independent analysis titled "The Global Mining Initiative" (GMI) to explore how the mining and minerals industry can best contribute to the transition to sustainable development. The GMI aims also at creating an industry infrastructure able to assist individual companies in this transition. The GMI also comprises a multi-stakeholders engagement process, the Mineral, Metals Sustainable Development (MMSD). Its task is to build a stakeholder dialogue at global and regional levels, and identify critical areas for the industry to act on. Most large mining, and energy companies are GMI sponsors, however some companies are more proactive than others. Some have adopted, and report on their sustainable development policy, and achievements. These companies endorse the views of Jim Cooney of Placer Dome in "*recognizing that it is responsible not just to shareholders but to a broad range of stakeholders".* It also called for "working partnerships with NGOs, and bilateral and multilateral aid agencies, in shared strategies with governments of developing countries to implement sustainable development".

It should be pointed out that sustainable development is a challenge for rich and poor countries alike. Although the industrial countries have the funds, technology, and institutional instruments to fix past damages and avoid making new ones, their governments sometimes make very unsustainable development choices to please certain segments of their constituency. These very same governments should therefore refrain from criticizing the sustainable development record of the poor countries.

One should also report the initiative that the Secretary General of the United Nations, Mr. Kofi Annan has recently launched with private companies, NGOs and labour organizations. The Global Compact challenges business leaders to promote and apply within their corporate domains nine principles in the field of human rights, labour standards and the environment.

4.2. Life cycle and minerals/metal cycle

Furthermore, mining is in itself one step in the minerals/metals life cycle, inclusive of recycling, mining site rehabilitation, and waste disposal. The minerals/metals' life cycle is bipolar with two principal spheres of activity which usually take place in different parts of the world. Both spheres involve activities which negatively impact on the ecosystem. The mining cycle starts with exploration and ends with closure and site rehabilitation. The minerals/metals cycle connects to the mining cycle through the ore-processing step and involves smelting, refining, use, transport, trade, consumption,

recycling, and disposal. Even for mining advocates like the International Council on Metals and the Environment (ICME) the "extent of the risk to human health and the environment posed by the production and use of metals is by no means clear"(1998).

Mining is about extracting metals and minerals from the ground for economic purposes. Metals and metallic elements exist within our ecosystem in stable or mobile forms. They are discretely distributed in minute quantities, usually in parts per million or billion. Metal species are naturally stable in any given environment. Mining, as any other human activity, is disturbing this equilibrium, i.e., the natural distribution of metals within the earth's ecosystems. Mines are found in areas where metallic elements are already in abnormal concentration (surface exposure or buried). Paradoxically, by extracting minerals, mining is adding metal species to the environment. These increases are referred to as anthropogenic sources.

In the past, industrial activity was limited to a few regions, atmospheric (emissions) and hydrospheric (effluents) pollution was more readily absorbed. Mining pollution is easily identifiable, and this "*point source*" pollution can be tackled. Smelter and refinery derived pollution may be more diffused because plants are often part of large industrial complexes and emissions can travel far away. This paper will primarily focus on the ecosystem impact of the mining cycle because it is of great significance to the development of developing countries and their relationship with the industrialized countries.

4.3. Internalizing negative externalities

It is argued that mining fits into the sustainability puzzle via its economic and social contribution to the host country's national economy. Sustainable development also implies the creation of an inter-generational transfer; mining can thus be considered a sustainable development activity provided it is integrated into the overall local and regional economy from the outset. An indicator of sustainable economic development in the mining sector would be the capacity of a mining venture to "*internalize*" its own social and environmental costs without direct or indirect subsidies. In the event that mining is the only economic development prospect for a particular region, as it is the case in many developing countries, particularly the less developed ones, it should be soundly planned to support both sustainable development for the community at large, and profitable operations for the corporation.

It is obvious that when social and environmental costs are not internalized, they are imposed on the local community. Mining should not be undertaken at the expense of the community's human life support system, that is by degrading renewable resources, such as soil, water, air, and forest; short term mining gains should not translate into long term human pain. It is becoming clear that States do better manage their non-renewable natural resources than their renewable ones, water is a case in point. Similarly, a tax holiday should be avoided since it is a form of government subsidy to the industry. As a result the government foregoes income which could have been directed to social services and infrastructure development for the use of the community. Tax holidays are crude instruments which aim at attracting investment. Governments should resort to smarter and more equitable ways to raise their FDI attractiveness. Recent examples have illustrated the dilemma for the governments of poor countries. Viable solutions are not easily found for the reconciliation of the countries' immediate requirement for income and foreign exchange with the longer term need of sustainable development. The mitigation of environmental degradation, and health hazard near the mine are the guarantee of the future well being of the local community.

4.4. The mining cycle and the ecosystem

Many mining companies claim that they borrow, use and return the land after mine closure. They should therefore ensure that the land is returned either in its initial state or in a state proper for other uses. The reality is too often different. One tends to forget that mining is a temporary activity, and

provisions for rainy days after mine closure, are usually over looked. As a result, the local community and governments are faced with extensive and costly cleanups.

Water contamination through seepage, spill or tailing dam failure is by far the most common, if not, the gravest accident. Tailing dam failure is usually highly visible because of the large volume of solid and sludge material discharged into valleys and rivers. Of major concern to the mining industry and the public is acid mine drainage and cyanide spill, which derived from the processing of sulphide and gold ores. Recent tailing accidents, which involved a large volume of acid sludge, have, and rightly so, given the industry a bad reputation. Such accidents have taken place in operating mines in both industrialized and developing countries, i.e., Guyana, Chile, USA, Philippine, Spain, etc… Although many of these collapses carried toxic material downstream, others can be compared to mud flows, which covered and damaged farming land and urban properties. Currently, "cyanide is the chemical of choice for gold recovery" (ICME, 1999), if handled and monitored by well-trained workers, the pollution risks are easily avoided. Although cyanide does not accumulate in the food chain, and decomposes rapidly, it can, even in small quantities, be deadly for water organisms, fish in particular. Experts in central Europe are claiming that the wildlife of the River Tisza in Hungry is dead and that a long time will be required for its resurrection. Various environmental agencies are looking into this matter.

No mining company is immune from an accident. However, the main shortcoming of cyanide gold extraction is the careless use of the process. By mining standards cyanide leaching is a relatively cheap form of extraction, which is often carried out by small, untested "junior" companies. These operations do not always abide by the same environmental ethics and standards as the blue chips companies. Lessons learned so far point to increased attention to risk assessment and reduction, emergency preparedness planning, co-ordination mechanisms and communication, and finally regulations.

The problem with tailing dams is that they become a mine legacy after the mine has closed its operation and have to be monitored through regular inspections. This, in turn, implies the establishment of specific mechanisms. To be trustworthy, these mechanisms require the participation of external actors like environment entities and community representatives. Lessons learned point to the need to keep into perspective and balance the short term scare with the long term damage. The later may involve costly and time-consuming environmental rehabilitation, the cost of which is often footed by the taxpayer. According to UNEP, there are some 5000 orphan or abandoned sites in the US alone. National Geographic (March 2000) estimates at some 16 000, the number of sites in need of some level of cleanup and rehabilitation. Twenty of them were major mines and are waiting for US$ million worth of cleanups. The task and expense will fall on governmental organizations and budget. In the uranium sector, orphan sits call for specific but urgent attention. Aquifer contamination is of great concern when land offers alternative economic potential.

Thanks to improved government regulations and stricter enforcement, fly-by-night companies are less and less common. The modern mines are increasingly meeting their environmental and social responsibilities. When national policies are either absent or inadequate by international standards, the industry implements its own voluntary initiatives. Cutthroat business competitors are increasingly acting collectively and co-operatively to improve their environmental management skills. Their motto is risk reduction because risk is bad business. However, much more has to be done on this front as recent spills have demonstrated.

An increasing number of companies understand that risk reduction starts at the exploration stage. Compared to mining *per se*, the environmental damage due to mineral exploration is far more benign. It can nonetheless be extensive on the social front. The arrival of exploration teams creates big expectations in the local population but these are rarely fulfilled since a very small number of exploration prospects become mines. Many people do not understand the implications, gains, trade-off, and risks associated to mineral development. The gap between people's expectations and mining

reality are often difficult to bridge. Here is where the involvement of NGOs may facilitate the dialogue between the affected community on the one hand, and the company and the government, inclusive of local government on the other hand. Exploration has therefore a negligible impact on health, although the presence of exploration crews may create some unforeseen problems in the form of transmissible diseases, as a result of this interaction.

4.5. The Honey pot effect in developing countries

Mining commonly takes place in remote areas away from population centres. In addition to the workforce brought in by the company, it commonly attracts scores of people looking for job opportunities. Harmful speculative migration refers to an uncontrolled population migration towards an economic project in any given region, but beyond the job offer possibility of both project and ancillary sectors. In many parts of the developing world, satellite shantytowns populated by migrants surround mines. These settlements sprawl out of control and usually stress the social and physical environment much more than the mining operations as such. The resulting negative impact is of concern both to mining companies and government. Because shantytowns thrive through the informal economy, their social needs are not commensurate to the tax levied. These needs are a great burden for the governments already stressed social budget. These ancillary but chaotic urbanizations have political stakes and often pit upcoming local leaders against the more established politicians.

Water supply and sanitation are also sectors, which are inadequate. Often established by the mining authorities to meet the needs of the mineworkers and their family these services cannot cope with the needs of the increased population. Deforestation is usually intense in the vicinity of these settlements. It exacerbates the noise, dust, and emission pollution from the mine. Deforestation translates into a loss of biodiversity and, consequently a change in the dietary habit of the local population. These changes, often coupled with poor sanitary conditions, lead to health deterioration. Evidence indicates that industrialization/urbanization (urban-rural migration) in general, and mining in particular, lead to dietary evolution. The latter may have negative short term implications on health if the appropriate authorities do not monitor it.

One very worrying aspect of the harmful speculative migration is the rise of new diseases, which were often unknown in the region. These diseases also affect the mineworkers and increase medical expenses of the mine. Moreover, this migrant population creates havoc within the local or indigenous population by trashing their environment and personal or ancestral property. The mines cannot absorb the influx of unskilled workers, most of them former subsistence farmers. They swell the informal sector, either providing services to the mine workers and their families or going to artisanal mining on their own.

In many developing countries, where precious metals and gems are mined, this transient population becomes itself involved with informal mining and competes with organized mining by trespassing mining property. They usually scratch and "high-grade" surface deposits, but they can also access the mineralization with excavations such as pits and galleries. Informal or artisanal mining is by far the most damaging form of mining in terms of ecosystem degradation.

4.6. The predicament of small scale and artisanal mining

Small scale mining (SSM) has neither the capacity nor the big pockets of the above mentioned companies to contribute to advancing the goals of sustainable development in the near future.

A radical rethinking of the sector should take place, for the sector to become a sustainable activity. In many instances, SSM and artisanal mining are caught in a policy limbo, cast off by national policy makers of developing countries in part because of the sheer complexity of the issues at stake.

According to ILO (1999), this segment of mining provides a subsistence income for some 100 million people mostly in Africa, Asia, and Latin America. Approximately 13 million people are currently carrying out this activity. Artisanal mining acts as a subsistence safety valve, as minerals become the natural resources of last resort. In many instances, it prevents the rural people from starving when crops fail as a result of drought. A variety of mineral substances are mined by the artisans, such as building and agricultural material, coal, and metallic ores. Gold and precious stones are the substances, which have contributed to make this sector so economically prominent and so environmentally controversial.

In many other regions, the miners earn three to four times more money than subsistence farmers do. However, with this short term economic gain comes severe social and environmental costs. Discouraging this activity is bound to fail as numerous examples have pointed out. Artisanal mining should become a formal activity for some, but alternative livelihoods should be stimulated for most people, otherwise social and environmental cost will to continue to escalate. Furthermore, social degradation is rarely contained as exemplified by the spread of diseases beyond the confines of the mining regions.

Artisanal mining is often a seasonal, and/or clandestine activity, particularly in the case of precious metals and gem mining. The sector is mostly unregulated and unsupported which results in severe environmental degradation, high crime rates, and atrocious social and health conditions. In Africa, gold and gem mining has attracted a large transient miner population. As a result, this activity may be a HIV/AIDS "vector". In 1999, the Ebola virus has also flared up in a gold mining camp of Central Africa.

Among the poor artisanal mining communities, women and children contribute significantly to household income. However, they are often the main victims of poverty and abuse, since their contribution is not acknowledged in economic terms.

4.7. A missed opportunity for women

In most parts of the developing world women in significant numbers have joined the artisanal mining population. ILO (1999) estimates that nearly half of the artisanal miners are women. Some 1.5 to 2 million are toiling in this area in one form or another. This activity, which is often non-ancestral, could have offered a level playing field for women, and a boon for their economic empowerment and enhancement of their social status. Unfortunately, it is rarely the case and this is the paradox of artisanal mining. Numbers alone do not change traditional attitudes. Artisanal mining continues to perpetuate the cultural bias against women.

Most women join the miners' ranks as low level labourers, not by choice but by need, to sustain their family, as they are often heads of households. Women are traditionally underpaid to do low tasks such as carriers, panners, sievers, sorters, crushers, washers, etc… With babies on their backs (Africa and Latin America) they are usually assisted by their grown up children. Women who go into mining as an economic alternative are better educated and therefore have more financial recourses. It is however ironic that the women who "make it", and achieve some level of economic independence, do it in the more traditional service sectors. These vary from trading, cooking, money lending, gold buying, and even prostitution. Because artisanal mining is so complex, it has not benefited from donor's support. To make matter worse, the majority of past assistance programmes have failed for a multitude of reasons. As a matter of priority one should develop assistance programmes able to offer status enhancement and income-generating alternative to women in the context of household and the community.

Women specific approaches should address the social and natural bias, which constrain their activities. Although the provision of social services to women and their dependants is a necessity, it remains a remote option since governments have rarely the available budgets. Moreover, the

migration and transient nature of the work does not encourage governments to make assistance available (assistance will rather go to established communities). Child labour is pervasive, and the 1999 ILO Convention on the worse forms of child labour clearly encompasses artisanal mining. Once again, the elimination of child labour is a daunting task beyond the budgets of many least developed countries (LDCs) governments. Schooling is no match for panning, which ensures that some income is generated to feed the child and his siblings. However, unorthodox approaches have been pioneered by hands-on NGOs like food-for-school programmes.

Strategies, which aim at creating income-generating alternatives for women, may be viable to reduce child labour. One should understand that too many vested economic interested have hampered the organization of this sector, and perpetuated the social misery of the involved population.

5. THE CULTURAL AND SOCIAL IMPACTS OF MINING

5.1. Mineral endowment curse

The challenge of mining is that it is a pioneer in term of investment and economic development. Its foray into new and remote territories find many governments and local communities ill prepared to interact with the industry. This pioneering role is not without risk, as the Economist of London eloquently pointed out in a recent article (29 January 2000) "*Multinationals face strong incentives to behave badly. Thus those in the natural-resources and mining business sector often cosy up to whichever regime is in power, however nasty, in order to protect their investment…*" and their competitive edge. First and foremost, a company must aggressively explore to discover mineral valuable reserves wherever they are! Share value is driven up by the company's ability to improve its profit margin, whether metal prices are up or depressed. It also depends on a healthy mineral reserve portfolio.

The activities of the extractive industry are now increasingly located in economies in transition and developing countries. The predicament of mining is that a large number of remaining world class metallic deposits if any, may be located in emerging but currently least developing countries with weak institutions, blatant social inequality, poor macro-economic policies, and little sensitivity to the rule of law. Mineral resources endowment, including oil, have had a corruptive effect on many governments paradoxically, causing both the impoverishment and restlessness of the population living in the mineral and oil producing regions.

These countries are particularly susceptible to the "*mineral endowment curse syndrome*". In other words, for some developing countries, oil, gas, and mineral is more a curse than a blessing. Relatively few countries have successfully used their mineral resources endowment to achieve diversified growth, poverty alleviation, and human security. Research indicates that contrary to common thinking, too many developing countries well endowed with mineral resources are under performing in terms of economic and social development in comparison with resource-poor countries.

The notable lack of political will to diversify and avoid dependence on finite, non-renewable, and depleting mineral resources is commonly compounded by the misallocation of the government investment budget. This situation leads to frustration and anger because of unmet socio-economic expectations in a context of increased social inequality and the perception of foreign exploitation. The proceeds of mineral exploitation, i.e., mineral rent, have often not been directed to development programmes and consequently have resulted in economic, social and political decline. Subsequently, reduced social expenditures have contributed to the worsening in the health sector. Broadly speaking, and notwithstanding the surrogate social role played by many mining companies in the vicinity of the mine, the overall social/health situation of many resource rich countries is often worse than that of resource poor countries.

This is an area, which warrants more research and better data. Available statistics are too incomplete or not comparable enough to realistically visualize the situation. In 1999, the Human Development Indices (HDI) of UNDP (based on three distinct indicators, longevity, education, and income per head) reveal that mineral producing countries like Niger and Sierra Leone are in the bottom five in term of HDI. Eleven oil and mineral producing countries are listed among the 34 countries with the lowest human development indices. The gender-related development index lists the same 11 minerals and oil producing countries among the 34 worse performers. The health profile reflects the same ranking.

5.2. Perception and values disconnect: Which value is it anyway?

This is still a controversial issue in many industrial circles. The standard principle behind foreign direct investment is that "*we bring our money, so accept our views and values*". This approach was also the norm in the 1990's in the more rarefied atmosphere of the aid organizations, whether multilateral or bilateral. Fortunately, an aid paradigm shift took place partly as a result of the poor sustainability of the past aid programmes. In the UN, development assistance now reflects a participatory consultation whereby the views, skills, and goals of the recipients are the driving forces of the co-operation. The new buzzword is "*bottom up*". When confronted with social and community issues business is also challenged to move from its trademark "*top down"* to a *"bottom up*" participatory approach. This all-inclusive multi-stakeholder dialogue is a process, which is still foreign to many mining company people. Community, governments, and NGOs are process oriented, as is the UN. As indicated earlier in this paper, the value disconnect is very obvious at the project development stage. Financing, and credit guaranty agencies as well as shareholders will "call the shots" in order to protect their investment. The mining company will abide by their decisions. The project will be designed according to "multinational criteria" which will prevail over the usually less stringent requirements of the national and local governments.

Because the multi-stakeholder dialogue aims at building consensus to move forward, the diverging cultures of community and business must coexist without clashing, and in fact become mutually supportive. An independent party can significantly facilitate this interaction by inter *alia* ensuring that the dialogue takes full advantage of each party's respective merit and strengths. The UN, NGOs, academia can all play this role in a meaningful way.

Consultation is very critical in mining (where to relocate a village, where to build a road to improve the livelihood of the local population, what kind of social services to provide, what to do when the mine closes, etc…). It is also important to respect the community's social values even if we in the North regarded them as backward. It is the first step to bridge the value gap, which is key to enlist the support and commitment of the population to the dialogue; and through dialogue, progress can be made. With regard to the health improvement campaign, it is important to first address the people's primary health concern. In doing so, we may subsequently obtain better results when pushing our own (supply-driven) promotion campaigns. A case in point may be the malaria Vs mercury campaign in the Amazon region of Brazil. The HIV/Aids sensitization campaign in Southern African mines also comes to mind. This topic warrants further discussions.

For the garimpeiros of Brazil, malaria is the main concern since it debilitates the miners. Mercury poisoning is a very remote and invisible risk for the garimpeiro. Furthermore, it affects workers responsible for auxiliary tasks. In Southern Africa, the HIV/AIDS campaign uses promotion strategies, which do not fully take into account the social/societal and cultural context of the target group. Campaigns should empower rather than allocate blame to the targeted individuals.

6. THE WAY FORWARD

6.1. From rhetoric to action: Raising awareness

Georges Clemenceau, the First War French statesman used to say that war was too important a matter to be left to the military. Likewise, one could apply the same logic to mining. Let's roll up our sleeves and help the miners to clean their act!

For both North and South, mining should be a boon and not a liability. In Canada and Australia, mining has plaid an important and positive role in the development of these countries. Many Canadian and Australian companies are currently active in many developing countries, people of which are also expecting to reap the profit of mineral development to improve their livelihood. Unfortunately, mining has occasionally misbehaved and has as result acquired a bad reputation. Now, it may be one of the most mistrusted and unloved industrial sectors!

This is a vexing paradox. Although the industry is increasingly becoming responsible towards its stakeholders and not only to its shareholders, it cannot dispel the dirty cloud over its name. Blue chips mining companies are now seeking partnership to work better, and civil society should be there to help, advise but also admonish if needed. The governments, North and South, should also be taken to task. They are responsible for the sound management of their natural resources on behalf and for the benefit of present and future generations.

After preaching for stakeholders' dialogue and partnerships, I cannot be too prescriptive in my recommendations, and I hope that our debate will contribute to show the way from rhetoric to concrete actions. I would like to make some suggestions for our debate. They may be provocative for some of you, and "*déjà vu*" for others. If it takes "*two to tango*", we need a *"ménage à trois*" to clean our mining act! Governments (central and local), corporations, and civil society.

6.2. Pragmatism for doing good

Far from making an apology for mining, I would like to encourage you to take a realistic and not an emotional look at mining. Its potential for the development of many communities, which may have nothing else to fall back on, should be acknowledged. Mining cannot be outright demonized, because mining is only one step in the mineral/metal life cycle. Mining may be the most obvious and visible culprit in terms of environmental and social stress. The other steps of the cycle also have negative effects. In many instances, they may even be more insidious and long term. In the era of technological revolution, some may argue that metals are becoming redundant, but we are still metal consumers and benefit from their use. Consequently, we tend to be more accommodating with metal pollution than mine pollution. It is the other side of the same coin.

Green and pro-poor NGOs have been instrumental in forcing blue chips companies to improve their social and environmental performance, and be more open about the process. NGOs should constructively engage with them. They can do so without compromising their independence, advocacy goals and financial autonomy. Moreover, they can hold the companies to their promise of transparent stakeholder dialogue. There is room for accommodation. NGOs come in various shapes and stripes. The more militant and "ideology-based" NGOs may continue their "no prisoner" policy with regards to corporations. Many others make their expertise and networks available to corporations in the context of selective partnership initiatives.

Like NGOs, not all mining companies are alike. One serious concern is the behaviour of the so-called "juniors" and medium-size national companies. The former concentrate their energy in fund raising and mineral exploration. While many are start up companies with genuine intentions, and small pockets, many others have a more speculative agenda. NGOs should discriminate between the two groups, and expose the bad performers to ensure that everyone complies with the highest standards of

environmental protection, and social responsibility. Rewards and sanctions could be foreseen on the basis of a mutually agreed system of certification.

NGOs in the North are increasingly understanding of the needs and realities of the South, and should not condemn its development efforts. They should help the South to develop without making the mistakes, we in the North made. The profligate consumption for natural resources cannot go on for too long. NGOs should be agent of change in the North, and continue to press for more development aid, particularly for countries, which use it wisely. There is a need for more dialogue at the local government level. Local authorities often do not have the necessary expertise and experience to properly engage with the private sector. The need to strengthen their capacities to do so should be matched with the empowerment of civil society.

Women groups and women research institutions have a major role to play and this role should be beyond the specific realm of gender issues. Women groups should be concerned with the impact of mining not only on women, but also on the community and its well being. Women groups should increase their networking with other groups, such as workers' unions, environment groups, church organizations, human right organizations, business associations, etc. This say is critical on issues such as post-mining regeneration, workers re-insertion. One important strategic issue for women group is trends in social and economic policy, inclusive of shift to market economy. It is clear those liberal economic policies and reduced social expenditures have a negative impact on women empowerment and welfare. This shift should not be carried out at the expense of women's socio-economic empowerment. The transition to market economy in CIS countries and Eastern Europe is a case in point. Otherwise, women are compelled to provide the social safety net to their family and community that should be the state's responsibility. They do so at the expenses of their own welfare.

Mining is a temporary activity, which is derided as a boom-bust activity. Therefore, the way forward for mining is to steadily improve what existed before the first hole was dug. A healthy and continued multi-stakeholder consultation will go a long way towards economic regional sustainability. Mining is an economic activity, dynamic of which is driven by profit making, competition over valuable mineral reserves, political posturing and advantage, and government self-interest. These realities have to be reckoned with for our discussions to be fruitful. A private mining company cannot afford to maintain a mine open if it is loosing money. However, it can work with the governments and the community in order to find socially acceptable stop gap solutions. These solutions are also trade-off. Short term job opportunities and the dependency on the mine are to be balanced with the long term objective of protecting the natural capital, sine qua none condition to ensuring post mining incomes. The economic benefits brought by the mine should pave the way to sustainable livelihood; otherwise one kills the golden goose.

A better management of the ecosystem to protect their integrity may contribute to lowering social and health costs. Cost reduction is an appealing notion for the private sector. Governments should work towards ensuring the sustainable livelihood of mining communities by balancing short term economic needs with the longer term objectives.

Finally, these realities do not preclude governments, North and South, to abide by the principles of good governance, such as inclusiveness, lawfulness, and accountability. By applying these principles to the management of their mining sector, mining will bring real and long term benefits to people. In many developing countries, the mining climate can be greatly improved by governments making policy changes, and abiding by these changes. Governments could initiate a national debate to build consensus over the need to reconcile the national collective interest with local socio-economic expectations. An equitable rent distribution system will go a long way to ensure that mining becomes a true agent for sustainable livelihood.

IMPACTS

Socio-Economic

(Session 2(a))

B. LABONNE

United Nations

Environmental and social impact of uranium mining in Australia

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Aastract. The mining of uranium at the Ranger and Jabiluka mines in Australia's Northern Territory has been assessed as a case study for the environmental and social impact of uranium mining in Australia. The level of environmental protection achieved has been very high. However, a number of social indicators reveal that the social impact of development in the region, including the mining of uranium, has been significant. A programme is now underway to redress these social issues. Links between social and environmental impact have been identified. In today's world, the standards and practices in environmental protection are as much determined by social attitudes as they are by scientific and technical assessment.

1. INTRODUCTION

The mining of uranium has been the subject of environmental and social concerns in the Australian community since the mid-1970s. Following the discovery of a number of major uranium deposits in what is known as the Alligator Rivers Region (Fig. 1) of the Northern Territory, a major public inquiry, the Ranger Uranium Environmental Inquiry (RUEI), was held. This inquiry not only addressed the potential environmental impact that could arise from the development of the uranium resources. It also assessed the likely social impact on the Aboriginal people of this remote region of Australia.

The RUEI concluded [1] that mining of the Ranger deposit could proceed without having significant impact on the environment provided that a comprehensive system of environmental protection was implemented. Importantly, it also concluded that the clearly expressed opposition to mining by the traditional Aboriginal land owners should not be allowed to prevent the development. The Australian Government accepted the recommendations of the RUEI and approval was given in 1977 for mining of uranium at Ranger to commence.

Following the government's decision on Ranger, approval was also subsequently given for mining of uranium at Nabarlek in the Alligator Rivers Region and at Roxby Downs in South Australia. However, when the Australian Labor Party came to power in 1983, the implementation of its "three mines policy" prevented the development of the Jabiluka and Koongarra uranium deposits in the Alligator Rivers Region as well as a number of other potential developments at other sites in Australia.

The Ranger and Roxby Downs mines are currently the only two fully operational uranium mines in Australia. However, following a further change in government in 1996, a number of other mines are being developed. These include Jabiluka near Ranger in the Northern Territory, and Beverley and Honeymoon in South Australia. In this paper, we explore the issues of environmental and social impact arising from uranium mining in Australia using the Ranger and Jabiluka mines as a case study. This choice has been made because two defining characteristics of the region highlight the significance of both environmental and social issues at Ranger and Jabiluka. First, the Ranger and Jabiluka leases are surrounded by Kakadu National Park which has been inscribed on the World Heritage List. Second, the land on which these deposits were found is Aboriginal land and the owners of the land have opposed the development of both mines.

2. THE ALLIGATOR RIVERS REGION

The Alligator Rivers Region, comprising an area of approximately 28 000 km^2, is broadly defined by the catchments of the East, South and West Alligator Rivers (Fig. 1). It is of outstanding heritage value for its unusual combination of largely uninhabited areas with attractive wild scenery, is highly biodiverse, and has a very large concentration of Aboriginal rock art of world significance.

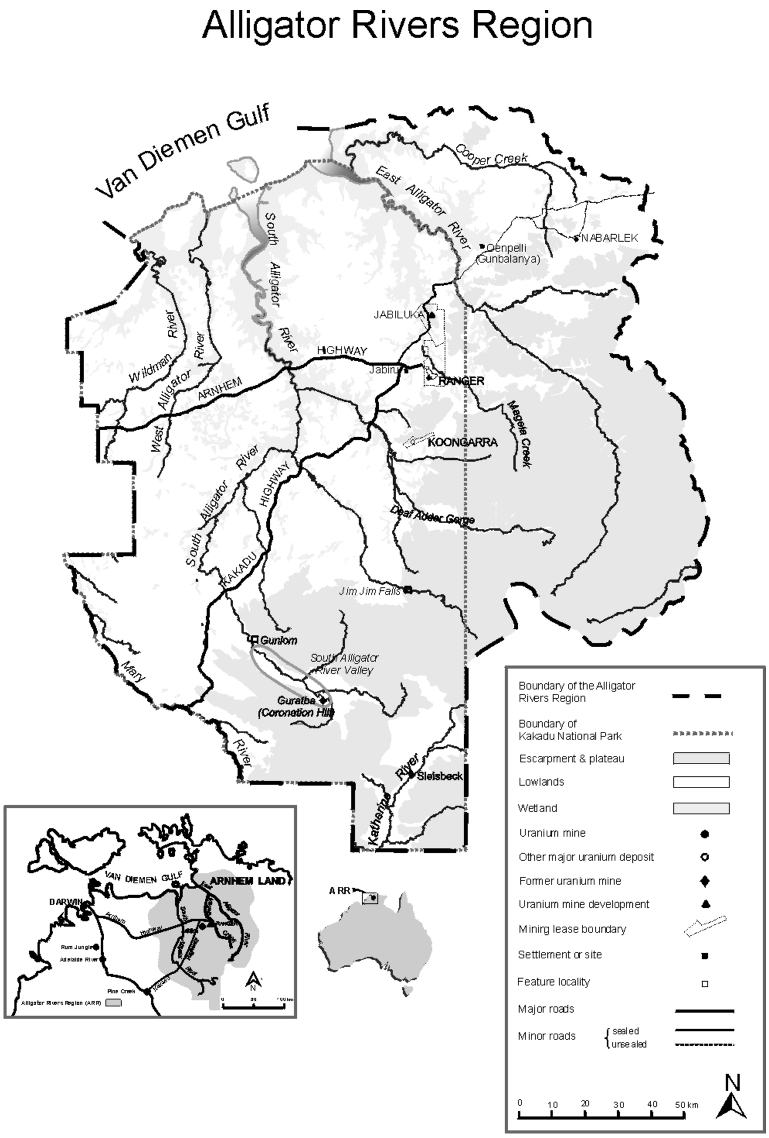

FIG. 1. Location map of the Alligator Rivers Region in the Northern Territory of Australia.

Its national and international importance is recognized by the inclusion of Kakadu National Park on the Register of the National Estate and its inscription on the World Heritage List. The flood plain areas within Kakadu are recognized as one of Australia's Wetlands of International Importance listed under the Convention on Wetlands of International Importance. The region is rich in natural resources, having a variety of terrestrial and aquatic ecosystems including sandstone heathlands, open woodland, monsoon rainforest, flood plains, large rivers, seasonal water courses and permanent billabongs, as well as large mineral reserves including uranium, gold and platinum group metals.

The region is within an ancient geological basin called the Pine Creek Geosyncline which has a long history of mineral production. Uranium exploration in the Geosyncline was stimulated by the discovery in 1949 of secondary uranium mineralization near Rum Jungle, south of Darwin. This was followed by a decade of intense exploration activity resulting in the discoveries of economic uranium orebodies at Rum Jungle and in the upper reaches of the South Alligator River valley.

All the known major uranium deposits of the East Alligator River uranium field have been discovered since 1969. Energy Resources of Australia Ltd (ERA) operates the Ranger Mine, eight kilometres east of the township of Jabiru. The mine lies within the 78 square kilometre Ranger Project Area (RPA) and is near the Magela Creek, a tributary of the East Alligator River. Following successive declaration in stages, the RPA is now surrounded by, but does not presently form part of, Kakadu National Park. Mining and commercial production of uranium concentrate have been underway since 1981. Mining of orebody No.1 was completed in 1994 while mining of orebody No.3 commenced in May 1997. (The smaller No.2 orebody is close to Mount Brockman, an Aboriginal sacred site, and will not be mined.)

Other orebodies discovered in the East Alligator uranium field were located at Nabarlek, about 30 kms east of Oenpelli in Arnhem Land, Jabiluka about 20 kms north of Ranger and Koongarra about 25 kms southwest of Ranger. The ore at Nabarlek was mined and stockpiled in 1979 and milling took place between 1980 and 1988. The site has been rehabilitated. The ERA proposal to mine Jabiluka has recently been the subject of environmental assessment and preliminary construction work has begun. There are no immediate plans for mining of the Koongarra orebody.

3. THE RECORD ON ENVIRONMENTAL PROTECTION

The extent to which the environment of the region has been protected from the effects of mining at Ranger has been summarized in Ref [2] and is the subject of a summary presentation at this Symposium [3]. Only the briefest of summaries is presented here.

An extensive programme of chemical monitoring has been in place throughout the period of mining. The chemical measurements made in the Magela Creek downstream from the mining operation but upstream from the point at which the creek enters Kakadu National Park have shown that, for all constituents, concentrations have been lower than the standards recommended by the Supervising Scientist by more than a factor of ten.

A programme of biological monitoring has been implemented since 1992 following an extensive research programme on the development of suitable site specific techniques. The programme incorporates creekside toxicological tests that have the potential to provide early warning of potential biological impact and measurements on the structure of communities of fish and macroinvertebrates.

An example of the results of biological monitoring is given in Fig. 2. The figure shows the egg production rate for freshwater snails exposed to waters both upstream and downstream of the mine over a number of years. While there is a significant natural variability in egg production rates, the variation at the downstream site is matched very well to that at the upstream site and the difference between the two sites is not statistically significant. The triangles on the graph indicate when water was being discharged from a pond that stores runoff from waste rock stockpiles at the mine site. The discharge of these waters clearly had no impact on the snail egg production rate.

An extensive radiological monitoring programme is also in place at the Ranger mine site to measure the radiation exposure of people living close to the mine. This programme measures radionuclides dispersed by the surface water, ground water and atmospheric pathways and converts these measurements into radiation exposure estimates. An example of the results obtained for the surface water pathway is shown in Fig. 3. In this case, annual radiation dose estimates have been lower than the public dose limit, 1 mSv per annum, by more than a factor of ten throughout the period of mine operation.

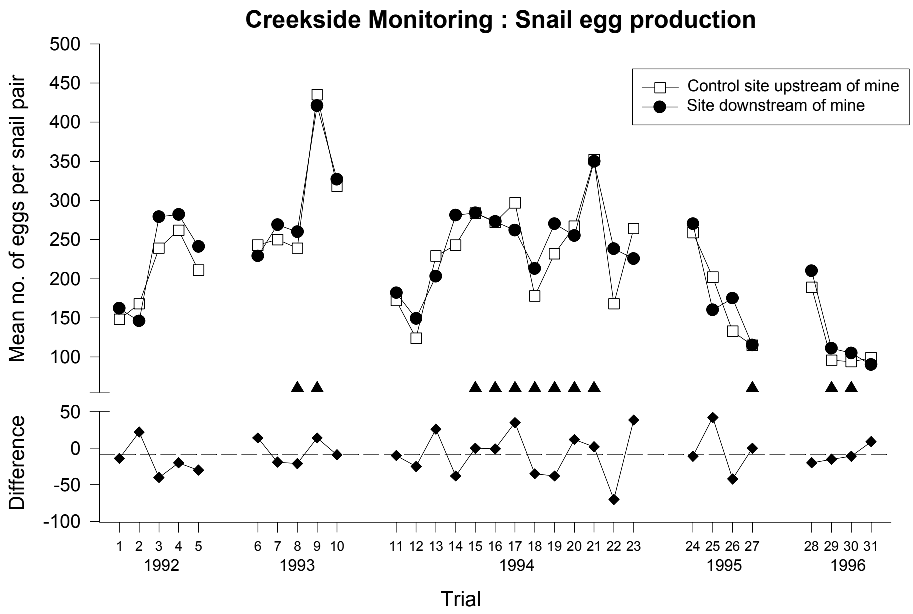

FIG. 2. Biological monitoring of the impact of mining at Ranger, freshwater snail reproduction. Data are shown for animals exposed to water from sites upstream and downstream of the Ranger Mine. Differences between upstream and downstream responses are also shown. Periods of water release are indicated by triangles.

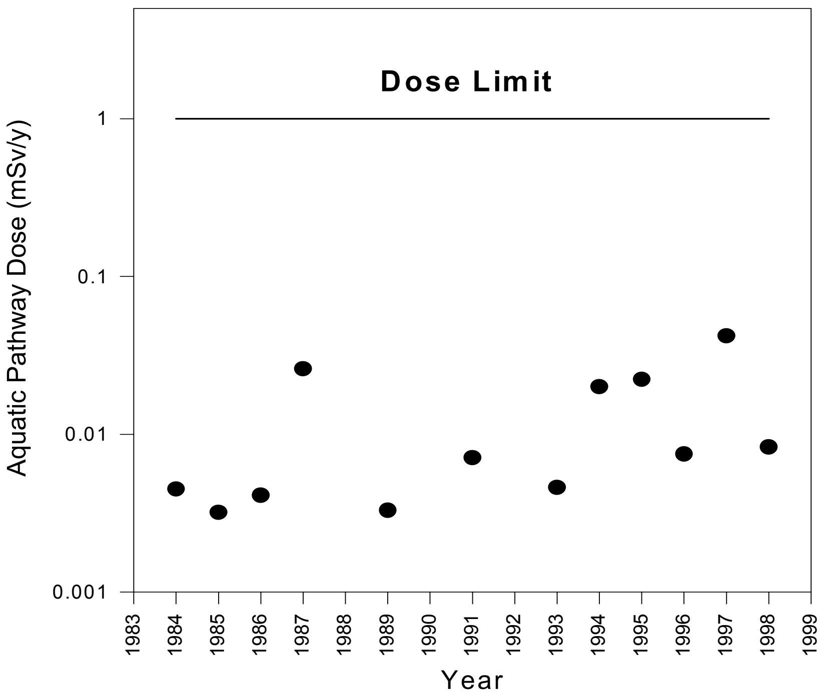

FIG. 3. Radiation exposure of members of the public resulting from operation of the Ranger Mine via the aquatic pathway.

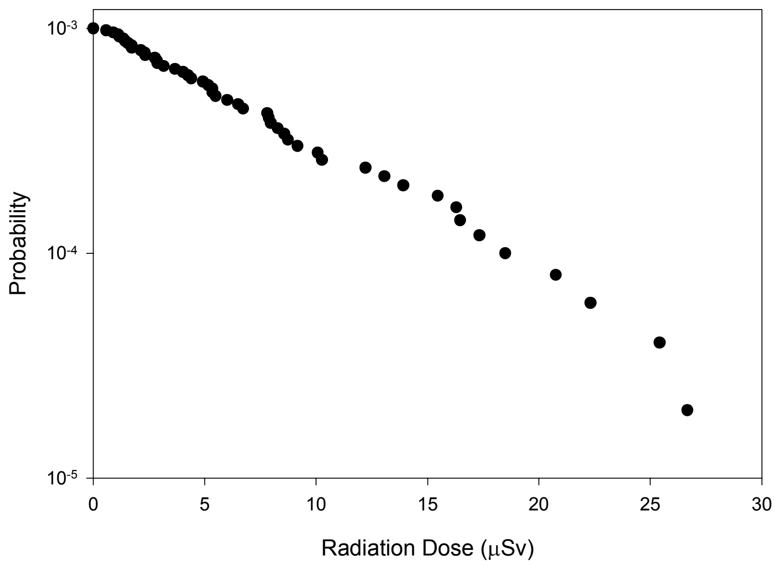

FIG. 4. Probability versus radiation exposure of members of the public resulting from the discharge of excess water from the Jabiluka mine site for the water management system proposed by ERA.

The conclusion that has been drawn by the Supervising Scientist from the results of the extensive chemical, biological and radiological monitoring programmes in place at Ranger is that mining and milling operations have been carried out in a manner that has enabled a very high level of environmental protection to be achieved for the people and the ecosystems of Kakadu National Park.

While the Jabiluka mine has not commenced operations, it has been the subject of an extensive environmental impact assessment process. Recently, the Supervising Scientist prepared a report [4] for the World Heritage Committee that addressed a number of environmental protection issues raised by the Committee. The report reviewed the hydrology of the area, assessed the potential significance of severe weather events and climate change, and presented quantitative assessments of the risks associated with the storage of uranium at the surface and of tailings underground.

For example, Fig. 4 shows the risk of radiation exposure to members of the public arising from the occurrence of a sequence of extreme wet seasons resulting in the capacity of the water storage dam at Jabiluka being exceeded with the resulting discharge of water to the surrounding environment. The results show that the probability that any member of the public would receive a radiation dose of 20 μSv, one fiftieth of the public dose limit, on one occasion during the 30 year mine life would be less than 1 in 10 000.

Similarly, Fig. 5 shows the probability with which an area of the Magela floodplain, downstream from the mine, would be subject to adverse ecological effects following the occurrence of a severe earthquake. At the 1 in 10 000 level of probability, the area that would be subject to definite adverse effects would be about 0.5 km^2, which is less than 0.3% of the total floodplain area. At the same level of probability, residual effects may occur for some species of invertebrates out to an area of about 5 km^2, but the system would recover following flushing by the natural waters of the Magela system.

The report to the World Heritage Committee concluded that the natural World Heritage values of Kakadu National Park are not threatened by the proposed development of the Jabiluka project.

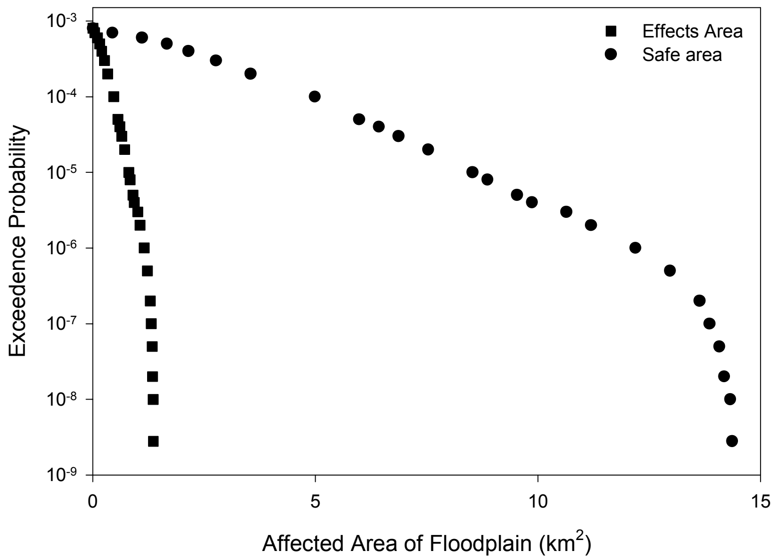

FIG. 5. Probability versus the affected area of the Magela floodplain for a severe earthquake. Beyond the safe area, no adverse effects are expected. Adverse effects on invertebrates are expected inside the effects area. Between the two areas, some residual effects may occur.

4. THE RECORD ON SOCIAL IMPACT

While the record on environmental protection at the Ranger mine has been excellent and the risk assessment for Jabiluka indicates that a similar high degree of environmental protection should be achieved if the Jabiluka mine is fully developed, the record on social impact is much less impressive. A more extensive description of the social impact issue will be presented [5] at this symposium. Only the key issues are summarized here.

As noted above, in the late 1970s the Australian Government approved uranium mining in the Kakadu region despite Aboriginal opposition. Recognising this, the government put in place a series of safeguards and offsets intended to minimize the risk to Aboriginal people as well as to protect the unique environment of the region. As the Ranger Uranium Environmental Inquiry intended, Aboriginal people in Kakadu would have employment opportunities and business development concessions that do not exist elsewhere. Educational opportunities would be provided and capital for development would be available (from mining royalties). It was anticipated that Kakadu National Park would act as a buffer zone, with traditional owners having the option of residing on their land away from the planned township of Jabiru and away from high visitation areas and utilising the rich environment for subsistence.

In addition, it was intended that the social impact of mining on the Aboriginal people of the region would be the subject of ongoing monitoring. Such a monitoring programme was carried out in the early years (1979–1984) by the Australian Institute of Aboriginal Studies (AIAS) under contract to the then Department of Aboriginal Affairs. The report submitted at the end of the AIAS study in 1984 [6] contained a number of recommendations to address issues that had been identified. From 1984 until 1996, however, no progress was made and the issue of the social impact of uranium mining was virtually ignored.

In mid-1996, in response to a request from traditional owners in the Kakadu Region, the Australian Commonwealth Government, the Northern Territory Government, the Northern Land Council (NLC) and Energy Resources of Australia Ltd (ERA), the operating company at the Ranger uranium mine, agreed to sponsor the Kakadu Region Social Impact Study (KRSIS). The request of the traditional owners arose following a change in the national government and the abandonment of the previous “three mines policy”, a decision that led to a proposal by ERA to develop a mine at Jabiluka. The KRSIS study ran in parallel with the Environmental Impact Assessment process for Jabiluka.

The organizational structure of the KRSIS study was, we believe, unique. It consisted of an Aboriginal Project Committee (APC) and a Study Advisory Group (SAG). The APC members, senior representatives of the various Aboriginal communities of Kakadu, were to determine the issues, the aspirations, the ideas and the expectations of Aboriginal people. The APC was provided with funds to enable the committee to engage consultants of their choice working under terms of reference determined only by the APC. The APC then provided its report [7] to the SAG. The SAG, consisting of senior representatives of the institutions and agencies influential in decision making for and about Kakadu, was to bring forward its collective knowledge and generate plans. It was to interact with the APC to transform the issues, aspirations, ideas and expectations of the Aboriginal people into actions that would make a difference; actions that would assist the move towards harmony for the parties. The SAG produced a Community Action Plan [8] that was considered by the Commonwealth and Northern Territory governments.

The KRSIS project found that there had been a number of positive social outcomes arising from development in the Kakadu region, most notably the highly successful management of Kakadu National Park under joint management arrangements between the traditional Aboriginal owners and the Commonwealth government. On the whole, however, the SAG concluded that the worst fears of the Aboriginal people of the 1970s had come to pass. Among the key findings were:

- While the conditions are neither demonstrably better nor worse than other Aboriginal communities in the rest of the Northern Territory, the living conditions of some of the Aboriginal communities in Kakadu are of a third world standard.
- Key social indicators for education, health and employment are as bad as any community in Australia.
- Alcohol misuse is chronically debilitating to individuals and social interaction.
- Competition among Aboriginal factions in the region over access to royalty money has been quite destructive.
- There is a lack of effective communication and understanding between the various co-habitants of Kakadu.
- Institutional arrangements, once intended to protect Aboriginal people from the pressures of negotiations, have unintentionally grown to become impediments to mutual interaction, appreciation and co-operative action.

The Kakadu Region Social Impact Study gave rise to an extensive range of recommendations to the Commonwealth and Northern Territory Governments. These recommendations fall into four broad categories:

(1) Improvements in social conditions

- The provision of improved housing, the provision of employment and training opportunities, the improvement of education and health services, measures to reduce the alcohol problem, and the improvement in sport and recreational facilities.

(2) Addressing cultural issues

- The provision of a Women's Resource Centre, measures to enhance the participation in cultural ceremonies, measures to improve communication between parties in the region.

(3) Promoting economic development

- The production of an economic development plan for the region, measures to assist Aboriginal people in the establishment of Aboriginal owned businesses, measures to remove the anomalies in the distribution of mining and tourism royalties, and measures to address the issue of funding substitution.

(4) Recognition of the rights of Aboriginal people as the land owners and empowerment

- Addressing the issue of Aboriginal ownership of the Jabiru township, measures to involve the Aboriginal community in the governance of Jabiru, measures to improve the provision of services to Aboriginal communities, action to resolve current disputes between various Aboriginal communities, the implementation of a comprehensive social impact monitoring programme.

The respective governments accepted most of the recommendations of the KRSIS reports and established a KRSIS Implementation Team in November 1998 to ensure that positive action was taken to address the issues raised in the reports. The Chair of the Implementation Team presented his first progress report to the Commonwealth Minister for the Environment in June 2000 [9].

In many areas progress of the Implementation Team has been outstanding in the short period since the establishment of the Team. Progress has been greatest in measures to improve social conditions, to address cultural issues and to promote economic development. Total funding secured in these areas is about $8 million and a further $2.7 million in funding is pending approval. It will, of course, be some years before the impact of these commitments is seen in the social indicators for education, health, employment etc.

The area where least progress has been achieved to date is in recognition and empowerment. It is in this area that the most intractable problems exist; for example, the issue of the ownership of the town of Jabiru. It is also in this area that current arrangements have been established under law or under binding legal agreements. Time will be needed to enable substantial progress to be made.

Overall, however, positive action in the field of social impact is now underway and this action has brought about a spirit of co-operation between many of the Aboriginal communities of the region and the agencies responsible for service provision and government. There is an optimism that the deficiencies of the past will be rectified.

5. LINKS BETWEEN SOCIAL IMPACT AND ENVIRONMENTAL PROTECTION

In the above discussion, the issues of environmental impact and social impact have been presented as if they are quite distinct issues. This has been the traditional approach adopted in most societies where environmental protection is seen as being governed by science and engineering and social impact is seen as a political issue.

The experience of uranium mining in the Alligator Rivers Region has, however, demonstrated that the two issues are inextricably linked and that the environmental protection standards and practices adopted today are as much determined by social attitudes as they are by the biological and physical sciences.

From the outset of mining at Ranger, it had always been anticipated that water contained within what was called the Restricted Release Zone (essentially water that had come in contact with ore, but not tailings water) would need to be released to the environment in unusually intense wet seasons. For this reason, the Supervising Scientist had conducted an extensive research programme on the dispersal of radionuclides in the surface water system, their uptake in local species of flora and fauna, the toxicological effects of the constituents of the water on local fauna, methods for biological monitoring etc. On the basis of this research, the Supervising Scientist had designed a control regime of standards and practices under which water could be discharged without causing harm to people of the region or aquatic ecosystems. He also had developed an extensive monitoring programme designed to demonstrate that people and ecosystems had been protected.

In 1995, a sequence of unusually intense wet seasons culminated in the need to discharge water from the Restricted Release Zone and the authorities gave approval for this to occur. However, the local

Aboriginal people strongly objected to the release of this water and the Northern Land Council, acting on their behalf, sought a court injunction to prevent the release. The legal application for the injunction failed but the operating company, in recognition of Aboriginal concerns, did not proceed with the release and gave an undertaking not to release such waters in future. As a result, the only method now regularly available to the company to solve water balance problems is to use land irrigation on the mine site. The latter method is considered scientifically inferior to direct discharge and it is a method that will increase rehabilitation costs to the operating company.

A minor incident at the Ranger mine during the 1999–2000 wet season resulted in the discharge of a small volume (estimated at 80 m^3) of tailings water from the physical containment structures and, after passing through constructed wetland filters, the water reached the main water-course near the mine. The public reaction to this incident was intense, particularly among local Aboriginal people. The Supervising Scientist was required to submit a detailed report [10] to Commonwealth Ministers on the incident and it was tabled in the Australian Parliament. The report demonstrated that there had been no harm to downstream ecosystems and that radiation exposure of people living in the region was totally insignificant. Indeed, it was estimated that the volume of water discharged would need to have been 200 times greater before it would have been detectable downstream from the mine. Nevertheless, an outcome of this incident has been that the operational procedures at the mine will, in future, need to be adjusted to ensure that not only are incidents that could cause harm be avoided, but incidents that could be *perceived* to cause harm are also avoided.

Currently, the Jabiluka mine is, following initial development of the portal and decline, being managed on an environmental care and maintenance basis pending negotiations between ERA and the Aboriginal traditional owners on ERA's preferred option for development of the mine. The background is too complicated to describe in detail here but the outcome is that the interim water management system, which was only designed for one year, is likely to be in place for a number of years. To adjust the interim water management system to meet long term environmental protection objectives, it will be necessary to discharge some water from the system in the coming year. A suitable solution from a purely technical perspective would be to use land irrigation on currently disturbed parts of the mine site. Because of objections from the local Aboriginal community, the company is being required to install a reverse osmosis plant to treat the water prior to irrigation.

These examples illustrate that, in today's world, the standards that apply to environmental protection, particularly in contentious areas such as uranium mining, are being determined, at least in Australia, as much by social concerns as by scientific and technical assessment. The reasons for this could be the subject of intense debate. However, in the case of uranium mining in the Alligator Rivers Region, several prime reasons are to be found in the above discussion on the social impact of mining.

First, it was noted that when approval was given for uranium mining to proceed in the region, the decision was made contrary to the clearly expressed wishes of the Aboriginal traditional owners. Second, apart from the successful inclusion of Aboriginal people in the management of the Park, the concerns and aspirations of Aboriginal people in the region were largely ignored for almost twenty years. Third, throughout that period, attempts to convey to Aboriginal people the nature of the scientific research that was being carried out and the meaning of the results of the research for the protection of the land and the people themselves were feeble and ineffective. The consequence has been that opposition to mining has become more entrenched (as the debate over the development of Jabiluka has demonstrated) and the assurances of scientists mean little or nothing to Aboriginal people. Thus, the social impact of development in the region has had a direct impact on the standards and practices adopted to protect the environment from the effects of mining.

6. CONCLUSIONS

The mining of uranium at the Ranger and Jabiluka mines in Australia's Northern Territory has been assessed as a case study for the environmental and social impact of uranium mining in Australia. It has been established that the mining and milling of uranium at Ranger have been conducted in a manner

that has led to a very high level of environmental protection and that a similar high level of protection is expected if the Jabiluka mine proceeds.

However, the record on social impact has not been impressive. Major deficiencies have been identified in living conditions of the Aboriginal people of the region, in their health and education and in employment opportunities. Alcohol misuse is a significant problem, communication between Aboriginal and non-Aboriginal communities is poor, and institutional arrangements have tended to disempower rather than empower Aboriginal people. A programme is now underway to redress these issues.

Links between social and environmental impact have been identified. In today's world, the standards and practices in environmental protection are as much determined by social attitudes as they are by scientific and technical assessment.

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Corporate social responsibility and aboriginal relations

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Abstract. All of Canada's uranium mining activity occurs in the northern half of the province of Saskatchewan in western Canada. This region has a total population of 38 000 people living in many small communities scattered over 250 000 square kilometres. Demographically, the north's population is 75% aboriginal representing the Woodland Cree, Dene, and Metis Nations. The majority of the aboriginal population of northern Saskatchewan are treaty Indians (First Nations). The dominant first nations group in the north is The Lac La Ronge Indian Band, also Saskatchewan's largest Woodland Cree First Nation. Despite the fact that the Lac La Ronge Band and other First Nations of the region do not have surface or mineral rights, other than those on their reserve lands, they have significant influence in the development process. The extraction of the mineral resources of Canada are now undertaken with very considerable input from first nations groups and with sensitivity to their treaty rights and aboriginal traditional rights. Treaty rights in Canada include, among other things, hunting and fishing, access to post secondary education and special taxation considerations. This presentation will introduce participants to a unique perspective on northern Saskatchewan's uranium mining industry. This perspective will be provided by Harry Cook, Chief of the Lac La Ronge Indian Band.In his presentation, Chief Cook will provide a first nation's perspective on industrial development generally and uranium development specifically. He will begin by outlining the challenges facing aboriginal people in Canada and will provide an insightful view of the historical conflict between industrial developers and first nations people. He will describe the aspirations of his people and the importance they place on preservation of the natural environment. He will also speak to the critical need now emerging for aboriginal people to seek a balance between retaining traditional culture and participating in the industrial economy. Chief Cook will describe the positive relationships that have formed in northern Saskatchewan between uranium mining companies and first nations people and the developments that have materialized as a result. He will present real and practical examples of sustainable development as manifested in social and economic activities that have come about because of these relationships, and how these examples can be transferred into similar environments around the world. Chief Harry Cook was raised on a trapline in northern Saskatchewan many miles from the nearest road, where he learned the history, tradition and culture of the Woodland Cree. As a young man he proved to be very adventurous for his generation, moving to a city many miles from the peace and isolation of his homeland. In the city he had a very successful career as a trades person, where he not only learned the ways of the non-Indian but also how to live comfortably in two distinctly different realities. He returned to the north after thirteen years in the city and served in several community leadership roles, before becoming Chief in 1987. He is now serving his sixth term. In addition to his duties as the senior authority for all Band activity, Chief Cook is the president of Kitsaki Development Corporation (KDC). KDC is one of Canada's most successful aboriginal development corporations, with 12 enterprises in its portfolio, gross annual revenues of $50 million CDN, and a workforce of 500. The two flagship companies in KDC, Northern Resource Trucking and Athabasca Catering, were born out of a relationship with Cameco, northern Saskatchewan's largest uranium mining company. Chief Cook also represents his people at the executive level in all matters related to provincial and national aboriginal governance. His skills as a leader and businessman have been recognized on several occasions with awards at the provincial and national level. They were also recognized at the corporate level with his appointment in 1992 to the Board of Directors of Cameco Corporation, where he continues to this day to bring the very important aboriginal perspective to Cameco's board deliberations.

1. INTRODUCTION

The La Ronge Indian Band is one of Canada's largest first nations groups. The Band has approximately 7000 members, living in six communities encompassing a total of 18 reserves, making it the largest in both population and land base in the Province of Saskatchewan. It is also among the most developed Indian Bands in Canada from a social and economic perspective with a sophisticated, band-operated social and economic governance structure.

Cameco is the largest uranium producer in the world. Uranium produced by the company is used exclusively for the production of electricity in nuclear energy plants around the world. Cameco is also acknowledged as one of Canada's leading proponents of corporate social responsibility in mining and a leader in the integration of aboriginal people in its mining operations. This success is largely due to the extensive consultations, over several decades, that Cameco and its predecessor companies have undertaken with aboriginal people. They have led to a better understanding of how resource development affects aboriginal people, how it can best serve their needs and how it can be undertaken in a more sustainable way.

2. NORTHERN SASKATCHEWAN

All of Cameco's Canadian uranium mining activity occurs in the remote region of northern Saskatchewan. The region has a total population of 38 000 people living in many small communities scattered over 250 000 square kilometres. Demographically, the north's population is approximately 80% aboriginal representing the Woodland Cree, Dene, and Metis Nations.

The majority of the aboriginal population of northern Saskatchewan are treaty Indians (First Nations). These people live primarily in communities on treaty reserve lands under government of Canada jurisdiction. The remaining aboriginal population (Metis Nations) and non-aboriginal population live in small settlements and villages under provincial jurisdiction.

The La Ronge Indian Band is a first nations tribe in the Woodland Cree Nation. Under the leadership of the Chief Cook and his council, band members continue to speak the Cree language and practise many of the traditions and customs of their ancestors. Although it is becoming increasingly more difficult to live off the land from an economic standpoint, many band members continue to trap, fish and hunt.

The population of the La Ronge Band is typical of the aboriginal population of Saskatchewan and northern Canada. It is younger, growing faster, less educated and less employed than the population as a whole. The rate of illiteracy among northern aboriginal people is at least double the rate in the general population. Even with improved access to quality primary and secondary education in the north today, as many as 75% of aboriginal children leave school before completing grade 12. Creating educational opportunities for its Band members represents a primary objective of the La Ronge Indian Band. Through leadership and persistence the Band council has dramatically improved high school completion rates by providing high quality access to primary and secondary education in all of its reserve communities. It also has one of the most active post-secondary education programs of any First Nation in Canada, with a current university program enrolment of more than 160 Band members.

Cameco's uranium mining operations are all on provincial crown land, and mining activities are governed under surface leases with the province of Saskatchewan. Despite the fact that treaty Indians of the region do not have surface or mineral rights, other than those on their reserve lands, the extraction of the mineral resource by Cameco is undertaken with considerable sensitivity to treaty rights and aboriginal traditional rights. Treaty rights in Canada include, among other things, hunting and fishing, access to post secondary education and special taxation considerations.

3. CAMECO'S DEVELOPMENT PHILOSOPHY

Cameco's development philosophy includes a complex array of economic, social and community relations programs that are designed to ensure that its activities are undertaken in a sensitive, inclusive and socially appropriate way. Employment and business development are the two primary components of this strategy.

In order to ensure the long term stability and acceptability of its resource development activities, Cameco seeks to maximize the social and economic benefits that flow from its operations to the people and communities most impacted. Cameco's mining operations have been successfully woven into the social, political and cultural fabric of northern Saskatchewan and particularly into the more than 20 northern aboriginal communities where many of Cameco's employees reside.

The social and economic development responsibilities that Cameco has accepted and agreed to in the surface leases are also reflected in the corporation's strategic objectives, corporate policies, vision and values statements, and the individual performance objectives of senior Cameco officials.

This development philosophy is now ingrained in the company's management approach in all of its domestic and international operations, and it is expected that Cameco's experience and commitment to this philosophy will continue to guide the company as it expands.

4. THE LA RONGE INDIAN BAND'S DEVELOPMENT PHILOSOPHY

The La Ronge Indian Band also has a clearly articulated development philosophy that was largely facilitated through their involvement in the uranium industry. In the early 1980's, despite the uncertainty and dramatic polarization of opinion on the issue of further expansion of northern Saskatchewan's uranium industry, the La Ronge Indian Band was the first aboriginal group to support the development. Through their active participation in three separate and extensive public reviews that were conducted on further uranium development, the Band leadership reached the comfort level required to make this important decision.

This decision did not diminish their legitimate concerns about protecting the environment or the potential loss of their culture, and these concerns still exist today. But with a rapidly expanding Band population in need of jobs, the significant opportunities that would come with uranium mining could not be ignored. Since then, hundreds of Band members have been employed in high paying jobs and Band-controlled enterprises have generated over $150 million in revenues through their direct involvement in the uranium mining industry.

5. THE EMPLOYMENT STRATEGY

According to northern and aboriginal people, employment is the most important social and economic opportunity flowing from mine developments in northern Saskatchewan. Cameco has facilitated the integration of aboriginal northerners by maintaining a seven-day in, seven-day out work schedule and a network of northern air traffic pick-up points for employees. This system makes it convenient for northern employees to work in the mines one week and remain in their home communities during the next.

Saskatchewan aboriginal people have become enthusiastic in pursuing job opportunities in the uranium industry, which provide significant employment incomes in a region of the province where little other permanent wage-based employment exists. For example, the average salary paid to Cameco employees at its Key Lake uranium mine is C $56 000 per year including benefits.

Cameco is committed to hiring from Saskatchewan whenever possible and provides priority recruitment for northern residents (as defined in surface leases), and in particular aboriginal northern residents, for its site operations. Cameco also attaches very significant northern employment requirements to all contractors doing business with Cameco. Today, all contractors are required, as a condition of their contract, to maximize the employment of northern and aboriginal people.

Cameco has approximately one thousand site operations employees: 600 in its workforce and 400 permanent contract employees. The company's aggressive northern employment strategy has resulted in a very substantial increase in the percentages of northern and aboriginal employment. Almost 50% of all new hires since 1992 have been people of aboriginal ancestry.

Today, 450 aboriginal employees, representing about 45% of its site operations workforce, make Cameco one of Canada's leading industrial employers of aboriginal people. Northern people employed in Cameco's mining operations collectively earn approximately C $20 million in direct salaries and wages every year, and the majority of this employment income remains in the north.

To increase the northern and aboriginal workforce and to meet its future needs in the north, Cameco is co-operating with various agencies representing federal and provincial governments, and First Nations and Metis organizations to develop a proactive, long term labour force development strategy.

As a component of this long term strategy, Cameco is making significant investments in support of northern Saskatchewan public and post-secondary education programs. In 1999, Cameco invested more than a million dollars in post-secondary education and training support, scholarships, education awards programs, summer student employment, science program sponsorships, school site tours, school-based athletic programs and career information initiatives. All were designed to encourage northern aboriginal children to stay in school, pursue post-secondary training and consider occupations in the mining industry.

As a result of these efforts, Cameco is beginning to experience substantial gains in the employment and advancement of aboriginal people in the management/supervisory, technical/professional and trades occupations. As of June 2000, Cameco directly employed 21 aboriginal managers/supervisors, 49 aboriginal employees in technical/professional occupations and 33 aboriginal tradespeople.

6. THE BUSINESS DEVELOPMENT STRATEGY

Aboriginal leaders in the north, as well as in the rest of the province, have long recognized the importance of business development and wealth generation as they pursue greater economic independence. Cameco's business development strategies support this by providing preferential consideration for business proposals containing northern Saskatchewan and aboriginal involvement.

Through this proactive business development strategy, Cameco has been able to accomplish significant and meaningful third party business development in the north. Volumes of northern purchases have increased from about C $10 million in 1991 to more than C $100 million in 1999, which now represents a very substantial part Cameco's total purchases in support of its northern mining operations.

Northern Resource Trucking (NRT) is one example of Cameco's northern business development strategy. It is also the flagship in the La Ronge Indian Band's stable of businesses and the dominant profit generator for Kitsaki Development Corporation, their economic development corporation. As such, it supports less profitable enterprises like their wild rice production company that remain important to the long term future of the Band.

In early 1994, Cameco negotiated a unique business arrangement with NRT. In return for an exclusive six-year contract for all Cameco hauling, NRT was asked to restructure its equity to provide ownership opportunities for other northern First Nations and Metis organizations. NRT's 71% aboriginal ownership consists of nine First Nations and three Metis communities representing the northern Dene, Woodland Cree and Metis people. Today NRT employs more than 120 people, has annual sales of C $18 million and has a permanent office and transit warehouse in the north.

Cameo has similar business arrangements with other northern First Nations Groups. The Mudjatik/Thyssen joint venture is owned by Thyssen Mining Construction Ltd. and the Mudjatik partnership, a consortium of northern aboriginal partners. Their Cameco contracts over the last year for underground mining and construction were worth more than C $39 million. Mudjatik/Thyssen employs more than 100 aboriginal people in some of the highest paid industrial jobs available. This watershed partnership represents the first time an aboriginal joint venture was awarded a contract for the sinking of a mineshaft in Canada.

Tron Power (and its sister company, English River Constructors), wholly-owned by the English River First Nation, had Cameco contracts last year worth more than C $9 million. Tron Power represents another milestone in Cameco's aboriginal business development strategy. They were the first wholly owned aboriginal company that successfully negotiated independent performance bonding for a C $5 million Cameco contract.

7. ABORIGINAL COMMUNITY CONSULTATION

Cameco has been consulting northerners with respect to its operations for many years. These consultations occur formally through Cameco and government-sponsored committees as well as informally through many site tours, community visits, and general public information sessions. Also, Cameco's shareholders have appointed Chief Harry Cook of the Lac La Ronge Indian Band to the Cameco Board of Directors to bring the First Nations perspective to Board deliberations.

As a result of these extensive consultations Cameco and the La Ronge Band have developed an intimate awareness of each other's concerns and aspirations. Aboriginal leaders are telling Cameco that they want economic opportunities for them and their children while mining activity is undertaken in the north and they want to ensure that they have the employment mobility to continue to participate in the Canadian economy after mining is gone. They also want to ensure that they can continue to live off the land during this activity and they want assurances that there will be no harm done to the natural environment so that they can rely on it after mining activity is concluded. Cameco's success in Canada with respect to sustainable development and aboriginal relations is a function of the company's willingness to operate within these considerations.

As a measure of the company's commitment, Cameco has spearheaded the negotiation of a comprehensive impact management agreement with a select group of aboriginal communities in close proximity to its Rabbit Lake operation. This agreement will become a model for similar agreements across the north. It includes an environmental protection agreement providing northern and aboriginal peoples with a guarantee that they will be compensated should they suffer any loss as a result of project emissions from a uranium mine. It also provides assurances that uranium mining will not limit in any way, the ability of aboriginal people to continue to live off the land and pursue their traditional lifestyle.

8. CONCLUSION

Cameco and the Lac La Ronge Indian Band are proud of their relationship. Cameco is particularly proud of its recognition as a leader in the employment of aboriginal people and in the development of

aboriginal business in northern Canada. The La Ronge Band is equally proud of its status as one Canada's most progressive First Nations. Together they are demonstrating that uranium mining can proceed to the mutual benefit of the aboriginal and corporate communities.

Cameco believes that the company's lengthy track record has contributed significantly to the current high levels of public support. In the most recent independently conducted opinion poll (November 1999), support for continuation of uranium mining in Saskatchewan was about 70%. Cameco will continue to work diligently to ensure that such confidence and trust in the company is well warranted in Canada and our intention would be to apply the same standards wherever we operate.

Uranium mining and indigenous social impact issues — Kakadu Region, Australia

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Abstract. This paper reports on indigenous social impact issues in the Kakadu/Alligators Rivers region of Australia. It briefly outlines the social history of the region, reflects on local, national and international attention being given to the impact of regional development on local indigenous (bininj) people, notes how social impact issues are being addressed and suggests some lessons learnt.

1. INTRODUCTION

The Kakadu/Alligator Rivers region is an area of approximately 28 000 km^2 located in the Top End of the Northern Territory of Australia. Most of the region (nearly 20 000 km^2) is incorporated within the World Heritage listed Kakadu National Park. Kakadu is one of Australia's premier national parks and one of only 22 sites listed (worldwide) as World Heritage for both its natural and cultural World Heritage values. The Australian government's nomination of Kakadu for World Heritage listing identified local indigenous peoples' spiritual attachment to the landscape, and the living cultural traditions that maintain linkages between people and country, as important elements of the World Heritage values of the park.

An important feature of the region is that it continues as the homeland for indigenous people — who refer to themselves (in their own language) as *bininj*. They are people who can claim to be part of the world's longest continuing culture, a tradition of 50 000 years of hunting, foraging and stewardship of the landscape. This long period of continuing occupation is recorded in important archaeological sites and an enormously rich (and internationally significant) heritage of rock art. Aboriginal people in the Kakadu region maintain strong cultural and religious beliefs that centre on an individuals personal attachment, and responsibility for, their traditional lands.

The region is also internationally known as Australia's uranium province — the location of significant, world class deposits of uranium ore.

In recent years there has been a major domestic and international debate about the impacts of regional development, including uranium mining, on the living cultural traditions of the local Aboriginal people. It has been vigorously argued by some key traditional land owners that uranium mining at the proposed Jabiluka mine will impact so much on their living cultural traditions that this will, in turn, impact on the World Heritage values of the park.

2. KAKADU AS A CULTURAL LANDSCAPE

Archaeological evidence suggests Aboriginal people have been living in the Kakadu region for at least 50 000 years [1]. These are some of the earliest dates for human occupation sites in Australia. One site where this has been demonstrated is located just inside the Jabiluka mineral lease.

Bininj people have a social organization system based on clans (small family groups of people) sharing management responsibility and stewardship of a clan estate. This relationship has been described as one of 'traditional ownership' and the legal concept of Aboriginal people as 'traditional owners' of land is now well entrenched in a number of contemporary legal arrangements across Australia.

Today around 1200 Aboriginal people live in the Kakadu region with about 450–500 living in Kakadu National Park. Local regional centres include the township/village of Oenpelli (operated for many years as a Christian mission to Aboriginal people — just outside the park) and Jabiru township — a new town established to house mine workers and support services.

About 300 bininj live in out-stations, or community living areas, in Kakadu National Park. Another 150–200 Aboriginal people live within the township of Jabiru (also in the park).

3. UNDERSTANDING THE PRESENT THROUGH THE PAST

3.1. The early years

The social history of indigenous people in the Kakadu region prior to World War II (WW II) was of limited contact with non-Aborigines and rapid de-population. It is estimated that at the time of the declaration of the park (1978) the Aboriginal population of the northern half of the park was perhaps just 4% of that prior to European settlement of the Top End of Australia. This depopulation is largely attributed to infertility (via introduced pathogens) and high mortality from diseases such as influenza [2].

Migration also played a part as some people moved away from their homelands, often for extended periods, to nearby townships like Pine Creek and Darwin. During the period 1910 — WW II European movement into the Kakadu region was restricted to that of Christian missionaries, buffalo hunters, struggling cattlemen and fossickers [3]. There was virtually no regional infrastructure and travel was largely dependent on walking, horses or coastal vessels.

WW II brought many military personnel to the Top End of Australia, the introduction of new technology and the development of regional infrastructure. It significantly broadened the contact that Aboriginal people in the Kakadu region had with the outside world and a small number of the military personnel who visited during the war returned to settle and explore small scale business opportunities in the region.

The wildlife and scenic beauty of Kakadu became more widely known. Fledgling tourism (safari) operations began, uranium ore was discovered and mined in the southern part of Kakadu and roads and airstrips were established.

3.2. The 60s – a decade of planning and change

At the beginning of the 1960's it began to be suggested that a large regional national park, representative of Top End ecosystems, should be established in the Kakadu region. In 1965 the first proposals for the establishment of Kakadu National Park were being officially considered [4]. A decade of planning followed as government officials aimed to reconcile park-planning proposals with other plans for regional development.

Park planning documents from that time made little reference to local bininj people. This was both a reflection of the times and the low numbers of traditional landowners resident in the area of the proposed park. Many of these bininj were living in places like the nearby township of Pine Creek, or working on buffalo camps and pastoral properties outside the country being considered for establishment as a park.

The discovery of world class uranium ore deposits within the area proposed as national park brought together a triumvirate of issues that created, and continues as, a contentious mix of conservation, uranium mining and indigenous social justice issues. At about the same time as the uranium deposits were being discovered important changes in community attitudes about indigenous people and their rights were taking place in Australia.

The Australian pubic expressed, through a national referendum, their view that the time had come to fully acknowledge indigenous Aboriginal people as full citizens of Australia, with full voting rights. Claims of indigenous land ownership and traditional title to land were taken into the non-Aboriginal legal system and Aboriginal Land Rights emerged as a political issue. A new Commonwealth (federal) government with a strong social justice and reform agenda came into power and commissioned a formal inquiry into Aboriginal land rights in the Northern Territory. Aboriginal land rights legislation — and proposals for joining Aboriginal land ownership with National Park management — were recommended to government [5].

3.3. The Ranger Uranium Environmental Inquiry (RUEI)

In 1975 the same government responded to community concerns about Australia's involvement in the growing uranium industry, and the prospect of large scale uranium mining in the Kakadu region, by establishing the Ranger Uranium Environmental Inquiry (RUEI). This was a major government initiative, considering evidence from hundreds of witnesses over a 24-month period.

The inquiry was broad ranging; considering economic and trade implications of not developing the Kakadu uranium resource, nuclear non-proliferation and nuclear safety issues. A large part of the inquiry was dedicated to consideration of regional environmental impacts should mining go ahead and a special focus was given to the potential impacts of regional development on the local indigenous people.

In addition the Inquiry was asked by the government to consider a claim by Aboriginal traditional owners for legal freehold title to their land under recently enacted land rights legislation — the Aboriginal Land Rights (Northern Territory) Act 1976.

In 1977 the RUEI announced its recommendations to government [6]. Key recommendations included:

- uranium mining should be allowed to proceed, in a staged fashion, despite the clear objections of traditional owners and other affected Aboriginal people.
- the Commonwealth government should retain title to land in the region and in turn make it available for inclusion in the park and claim by Aboriginal traditional owners.
- a land grant (under the terms of the new Land Rights Act) be made to traditional owners of the land sought for uranium mining and national park purposes.
- provision for the Aboriginal traditional owners of land where mining is taking place, and "affected aboriginals", to receive payment of mine royalty equivalents.
- that Aboriginal traditional owners of land in the region lease their land to the Commonwealth Director of National Parks for the purpose of a national park and that they enter into a joint management arrangement for the park.
- that the Commonwealth government ensure a very high level of environmental protection through the office of a Commonwealth Supervising Scientist.

4. THE SOCIAL IMPACT OF MINING AND DEVELOPMENT

4.1. Outcomes of the RUEI

The RUEI paid special attention to social impact issues and proposed a range of measures to address this, including the establishment of a joint managed National Park to act as a social impact 'buffer' — ensuring space between new residents, tourists and local indigenous people.

Special arrangements were made for the management of the township to be developed to accommodate mine workers and support services. The town would be declared as part of the national park, under the control of the Director of National Parks and Wildlife. Population limits for non-indigenous residents were recommended and restrictions placed on who could reside in the town.

A package of arrangements was negotiated and in October 1978 traditional owners signed agreement for both the Ranger uranium mine to proceed (including agreement on the payment of statutory mine royalty payments of 2.5% of the value of mine production) and the establishment of Kakadu National Park.

The stage seemed set for a prosperous future. A large metropolitan Australian newspaper ran a front page article on 'Stone Age millionaires' in the Kakadu region.

The early 1980s saw rapid development of the Ranger uranium mine, the Jabiru township and the park. It also saw the establishment of a local royalty receiving association, the Gagudju Association, to distribute the local share of mine royalty payments from the Ranger mine. Traditional landowners continued to be involved in a hectic schedule of further land claims and negotiations over the proposed Jabiluka uranium mine. In 1982 agreement for this mine was negotiated and approved on behalf of the traditional owners by the body responsible for the administration of the Land Rights Act — the Northern Land Council.

In 1983 government returned to the Australian Labor Party and for the next 13 years their policy of restricting the number of uranium mines operating at any one time in Australia prevented the Jabiluka mine proceeding.

For the major part of the 1980s the Gagudju Association was applauded as a model indigenous royalty-receiving organization — investing in business enterprises and tourism infrastructure and providing support services (housing, health services and education) to its members.

Membership of the Gagudju Association reflected an arguably generous definition of 'aboriginals affected' — the people said to be affected by mining operations at the Ranger uranium mine — and many beneficiaries did not actually reside in the region.

Bininj leadership of the Association revolved around a committee of peers who largely took a collectivist approach to decision making. Early committee members were people of the same generation who had shared close life experiences. Success was also strongly linked to a successful leadership alliance between two men — the senior traditional owner of the Mirrar estate (where the mining activity was taking place) and a younger man — comfortable in dealing with 'whitefellas' — from a neighbouring clan.

The apparent harmonies of the early 1980's began to fray by the end of the decade and into the early 1990's. The leadership alliance noted above ended on the death of the senior Mirrar traditional owner. Economic circumstances changed, the price of uranium fell and royalty payments decreased rapidly.

The Gagudju Association was forced to service bank loans taken out for investment purposes at the cost of services to its members. Key traditional owners became concerned about the long term future of the association and the quality of policy and management advice.

In this time of increasing tension the Australian government changed and with it a firm prospect that the Jabiluka mine would proceed. This was also a time when many traditional owners were increasingly distressed, and depressed, by the health of their community. A report on alcohol abuse [7] identified extremely high levels of alcohol consumption — and attendant social dysfunction — among Aboriginal drinkers and their families.

Poor health, poor housing, high mortality, high unemployment and low participation in the state school system were seen as both symptoms and cause of deep social malaise. In addition traditional owners had other challenges to accommodate — invasive weeds appearing on their country and increasing tourism use of the national park.

Many bininj families, especially those from the centre of the region, and those with their own indigenous language as their first language, increasingly felt a sense of marginalization; that their voice and interests were being lost in the hurly burly of day to day life. Other peoples' agendas seemed to dominate. Bininj began more openly questioning who was really benefiting from regional development.

4.2. The Kakadu Region Social Impact Study (KRSIS) and Jabiluka

This dissent, and the independent reporting of worrying social statistics, led the Northern Land Council to call for a social impact study before further consideration of the Jabiluka mine proceeding. In response to this request the Commonwealth government, Northern Territory government, the Northern Land Council and Energy Resources of Australia Ltd (ERA, the operating company at the Ranger uranium mine) agreed to sponsor the Kakadu Region Social Impact Study (KRSIS).

Dr. Arthur Johnston, a member of the KRSIS Study Advisory Group, has outlined the approach of the KRSIS in a paper presented earlier at this meeting [8]. To recap: the KRSIS found there had been a number of positive social outcomes as a consequence of development in the Kakadu region but that many bininj people's fears about strong negative social impacts arising from regional development had been realized.

The KRSIS Study Advisory Group found that:

- the living conditions of some of the Aboriginal communities in Kakadu were of a third world standard.
- key social indicators for education, health and employment were as bad as any community in Australia.
- alcohol misuse was heavily impacting on many families.
- local arrangements, including mine royalty distribution, intended to benefit Aboriginal people had become sources of negative social impacts.

The KRSIS Study Advisory Group made an extensive range of recommendations, embodied in a KRSIS Community Action Plan [9], to the Commonwealth and Northern Territory Governments. These included:

- Improvements in social conditions, including education, employment and training.
- Improved health care and access to education.
- improved infrastructure – especially housing and community services (power/water/sewage) for traditional owners and other bininj residents of the park.
- production of economic development plans for the region that focus on long term and sustainable economic opportunities for traditional owners.
- proposals to address the issue of Aboriginal ownership of the Jabiru township, enhanced traditional owner involvement in regional governance and the implementation of a comprehensive, locally managed social impact monitoring programme.

Coinciding with formal government responses to the KRSIS Community Action Plan the Bureau of the World Heritage Committee, lobbied by an alliance of Mirrar traditional owners and green groups, agreed to send a fact finding mission to Kakadu National Park. Its purpose was to make a recommendation to the World Heritage Committee on whether Kakadu should be listed as World Heritage in danger as a consequence of proposals for mining at Jabiluka.

A key issue for the fact-finding mission was a focus on threats to the living cultural traditions of traditional owners in the context of the findings of the KRSIS. The Australian government position has been that the park's World Heritage values are not in danger, that the KRSIS did report on unsatisfactory social circumstances of Aboriginal people in the Kakadu region but that these KRSIS-related issues can and are being addressed through the work of the KRSIS Implementation Team [10].

Most recently (June 2000) the Bureau of the World Heritage Committee, on considering Kakadu related issues recommended that:

> *"all affected parties and the Australian Government work to finalise a constructive solution to addressing the economic, social and cultural expectations of the people of Kakadu while protecting the full range of World Heritage values"*

4.3. Moving on from the KRSIS

Implementation of responses to the KRSIS study is being driven and overseen by a locally-based KRSIS Implementation Team and recently (June 2000) the Chair of the Implementation Team presented his first progress report (for the period November 1998–June 2000) to the Commonwealth Minister for the Environment [11].

Regrettably a key set of local traditional owners responsible for land where mining takes place or is planned, the Mirrar traditional owners, have (to date) rejected joining the KRSIS Implementation Team while mining industry representatives attend those meetings. Efforts to have them join the Implementation Team continue.

The KRSIS team, with broad representation from local Aboriginal representative bodies, the Northern Territory and Commonwealth governments, the Jabiru Town Council and ERA, has committed to pursuing implementation of KRSIS recommendations.

To date the focus has been on fundamentals – employment, training, community infrastructure, health and education. The development of regional bininj economic development plan is proposed and recently the Commonwealth government announced $600 000 AUD funding for an Aboriginal Education Unit, recommended by the KRSIS study, at the Jabiru Area School.

Significant policy issues raised in the KRSIS, such as governance, the future of Jabiru, and acknowledgment of traditional ownership of land in Jabiru, have yet to be addressed in full. These issues touch on complex legal issues and have significant implications for many people – and all levels of government. They have not been lost sight of and the options available for negotiation continue to be explored.

Local debates about how far and how fast regional development should proceed have also exposed differences between different bininj interest groups on what kind of future is best for all. There are those who reject current plans for regional development, including increased mining development, and others who want to engage with industry and exploit regional resources for what they see as the common good.

It is in this atmosphere that the traditional owners of the Jabiluka mine site area (the Mirrar) appear solidly committed to opposing the Jabiluka mine. It seems clear that much of this is based on their

resentment of their recent social history and of their negative experience of regional development over the past twenty years.

5. LESSONS LEARNED

Long term residents of the Kakadu region have been left to think about how things might have been different. There are endless answers to that question. Some thoughts on "*lessons learned*" include:

- The need to carefully manage the 'rush' of economic independence that can come with new and large cash flows in the early life of mining (or other large scale) regional development projects.

- The need to ensuring an agreed and appropriate mix of investment in both community development and business projects.

- Be wary of allowing representative bodies to be overly reliant on mine royalty incomes for community services – especially if these are linked to commodity prices and production levels.

- Work to ensure broad understanding within the local indigenous community of 'money lines' – where revenue comes from, how it is generated, appreciation of its value as a community resource.

- Ensure community decision making and reporting is managed in ways that stay in harmony with local cultural traditions and values.

- Recognize the danger and inherent instability in establishing artificial power structures that compromise traditional styles of decision making.

- Resource developers need to understand, and factor into their decision making, the cultural landscape (the business environment !) that they operate in.

- Responsibility for social impact issues needs to be determined early in the life of large scale development projects.

- Commitment needs to be made, and maintained, to on-going social impact monitoring, regular community reporting and adaptive decision making.

- Developers need to believe in, and engender, a work culture that accepts that local indigenous people need to be active players in the management of regional development – not just passive recipients of royalties.

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COGEMA's employment and training policy for its foreign subsidiaries

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Abstract. COGEMA has actively pursued a policy of employing country nationals for its foreign subsidiaries in Niger, Gabon, Canada and Kazakhstan. The process of replacing foreign staff by nationals in Niger is first described, detailing the personnel management objectives and procedures, the main difficulties encoutered, the current situation and the lessons to take from this experience. COGEMA's policies and ways applied in other countries to increase the proportions of nationals are then presented.

1. NIGER: REPLACEMENT OF FOREIGN STAFF BY NIGER NATIONALS IN SOMAIR AND COMINAK

The Niger uranium deposits are located in the centre of the African continent, on the southern fringes of the Sahara desert. The ore is extracted through open pit mining or underground mines and is processed on the spot. With an output of 3000 tonnes of uranium per year, Niger accounts for 10% of world production and is the third world producer, after Canada and Australia.

1.1. At the creation of SOMAIR in 1968 and COMINAK in 1978, the employment of Niger nationals was a challenge in a country where there was a critical lack of supervisory staff with training and experience in the mining industry.

1.2. This challenge was taken up by *both* companies: SOMAIR (Société des Mines de l'Aïr) and COMINAK (Compagnie Minière d'Akouta), and by the Government of Niger. The political support for the process of replacing foreign staff by Niger nationals was found to have a high priority and gave the process a strong impulse.

1.3. To make the process possible, it was necessary to set in place specially-adapted procedures for scheduling and managing the human resources within the two mining companies.

1.4. The human-resource management procedures were designed with a view to maintaining and improving the technical performance of SOMAIR and COMINAK. This necessitated extensive collaboration by the displaced staff.

1.5. The principle methods and proceures used were as follows:

- From the outset, creation of planning systems in the two companies for the staff directly responsible for drawing up plans for taking on more Niger nationals.
- Preparation of target organization charts varying with time by type of activity showing:
  - the positions necessary for operation and management of the companies,
  - the available human resources,
  - the necessary recruitement,
  - the required training.
- Detailed descriptions of positions to facilitate the replacement plans;
- Replacement plans implemented with suitable evaluation procedures;
- Careful selection and recruitment conducted without regard for outside influence on the company;
- Planning both basic and advanced training considering the perceived requirements and the perspectives for replacement;
- Intense general communication on progress with the process.

1.6. The process has not been uneventful; the main difficulties encountered are the following:

- The limited amount of specialized human resources then available in the country;
- The reduction in the number of supervisors leaving;
- The shortlisting of appropriate training centres both in Africa and in France;
- Attempts to apply outside influence in the management of human resources;
- The need to both increase the number of Niger nationals while applying a proactive policy of cost reduction.

1.7. What is the current situation?

The proportion of Niger nationals in the staff stood at 99% on 31 Dec. 1999 in both SOMAIR and COMINAK, which can be considered to represent an optimum value. COGEMA, the major stake holder and operator of the two mining companies, has thus met its commitments concerning the training and employment of Niger nationals, made at the time of creation of the companies.

The special nature of our profession, the operation of world scale open pits and underground mines, forces us to keep up with the best operated mines in the world.

The geographical and industrial isolation of the Niger supervisors employed in the uranium mines and the nature of the product, (i.e.uranium), means that efforts must be constantly made to adapt to new technology and market trends.

It is therefore necessary to constantly reinforce and improve the industrial management skills of the local supervisors. Their professional experience has to be diversified and enriched by special training and exchanges of experiences within the COGEMA group.

This process is possible due to the mobility between COGEMA's subsidiaries. This enables the employment in Niger for limited periods of experienced expatriate supervisors on secondment from COGEMA, and temporary assignment of Niger national supervisors to COGEMA's mining organizations abroad.

1.8. The main lessons are that:

- There needs to be a strong commitment by senior management;
- The human resources management must be appropriate and accepted, making continuous communication necessary;
- It is absolutely necessary to constantly assess progress and delays;
- The process of increasing the number of Niger nationals must be carried out with care;
- Success in this field depends on planning, implementing and checking; there is no scope for improvising.

1.9. The local impact of the process of taking on more Niger nationals in the area in which the two companies are located is important for the inhabitants of the towns that have developed hereby, Arlit and Akokan, as well as for those living in the surrounding area (some 75 000 people).

With 1782 staff at 31 Dec. 1999, receiving salaries substantially above the average in the country, and regularly paid, the workers of the mining companies have a purchasing power which has given rise to a substantial local economy.

2. GABON, CANADA AND KAZAKHSTAN

2.1. Gabon

In Central Africa, COMUF, a subsidiary of COGEMA, has been working uranium deposits in the Mounana region of Gabon for the last 40 years. With a total production of 26 612 tonnes of uranium, COMUF ceased production in July 1999 because the economically minable reserves are depleted.

In Gabon, like elsewhere, COGEMA has actively pursued a policy of increasing the proportion of Gabon nationals in COMUF, which reached 85 to 90% during the seventies and eighties. The figure culminated at 95.4% in 1996, three years before the works were abandoned. This figure is high for a sparsely populated country (approximately 1 million inhabitants). Uranium is not the major industrial activity in view of the other substantial resources that Gabon possesses (manganese, wood and oil).

2.2. Canada

COGEMA has substantial reserves of uranium in Canada. It is participating in a number of mining projects in the country through its 100% subsidiary, COGEMA Resources Inc (CRI). In the Northern Saskatchewan communities, many of which consist of native Americans, the residents are broadly and directly associated with the uranium mining projects in the form of advisory committees and working groups. Since the beginning of the Cluff Lake operations in 1980, the proportion of local inhabitants employed was 50.26%, and reached 56% at the end of 1999. At the Mc Clean Lake mining site, where work began in 1999, 50% of those working for COGEMA Resources are already northern Saskatchewan locals. Local workers perform a wide range of jobs in all aspects of the mining industry, both at supervisory and operating levels.

The exceptional richness of the Canadian uranium ore has made it necessary to set in place a policy of extremely strict surveillance of the environment and worker protection. Thorough training is provided for the operating staff, as well as for those in radiological protection and quality assurance.

2.3. Kazakhstan

COGEMA's subsidiary KATCO manages the company's uranium workings in Kazakhstan. The uranium deposits at Muyunkum are estimated to have reserves of 40 000 to 50 000 tonnes of uranium. They are to be mined by the in situ leach process, under a 25 year lease granted by the Kazakhstan Government. A pilot plant, construction of which began in April 2000, will be used to test the technical and financial feasibility of the operation. It has a planned rate of 100 tonnes of uranium per year. The facilities are projected to be expanded, should the feasibility of the operation be proved. Pilot plant production is scheduled to begin in July 2001. Currently, the project team consists of 31 persons, including 27 Kazakhstan nationals.

When its subsidiary KATCO was set up, COGEMA decided to include in the terms of the lease granted by the Kazakhstan authorities its policy of employing local staff. In the industrial phase, this should include up to 165 of the total workforce of 171. KATCO has also pledged to train local staff, allocating to it an annual budget amount to be agreed in conjunction with its partners. A special training effort is planned.

Perception versus reality: Bridging the gap between quantitative and qualitative information relating to the risks of uranium mining

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Abstract. Environmental impact of uranium mining in Australia is frequently raised as an issue of public concern. However, the level of concern both in terms of public agitation and political response has diminished over the last decade, largely as a consequence of many years of demonstrated high levels of environmental protection achieved at Australian uranium mines. Another reason is because of improved information now accessible to the public on mine environmental management systems, monitoring results, and audit outcomes. This paper describes some communication methods developed for the uranium mines of the Alligator Rivers Region of the Northern Territory. These methods have improved the effectiveness of dialogue between stakeholders, and better inform the public about the levels of environmental protection achieved and the level of risk to the environment and the community. A simple approach is described which has been developed to help build a mutual understanding between technocrats and the layperson on perceptions of risk and actual environmental impact.

1. INTRODUCTION

Uranium mining in Australia is an issue which commonly attracts much public interest, not least because several of our mines are located in an area of outstanding landscape, cultural and biological values near the Kakadu National Park world heritage area. In terms of perceived hazards uranium mining is generally not discriminated, in the mind of the Australian public, from the rest of the nuclear fuel cycle. Uranium mining, transport of radioactive materials, nuclear reactors and disposal of radioactive waste are commonly raised as different parts of a single issue in national and state level elections.

The Australian government’s policy is to allow uranium mining under strict environmental controls. The Office of the Supervising Scientist, established specifically to develop techniques for and to oversee the highest levels of environmental protection practicable for the uranium mines of the Alligator Rivers Region in the Northern Territory, plays a major role in communicating the level of environmental protection being afforded, and the levels of risk to humans and the environment. Whilst many years of demonstrably very high levels of protection and low risk have reduced the levels of concern in many parts of Australian society [1], most environmental groups and affiliated political parties still raise concerns as to the perceived levels of risk. Clearly this impacts upon the sustainability of the uranium industry in Australia, and has done much to contain the level of development of the uranium mining sector over the last three decades. In this respect, the future success of the industry in this country depends to a significant degree on how well the industry performs in reducing risk and protecting the environment; and how well this performance is communicated to the general public and flows through to influencing public opinion.

2. PERCEPTIONS OF RISK

Communication of scientifically valid estimates of risk to the general public is a notoriously difficult task. The public’s perceptions of risk in relation to a technology are strongly influenced by collective experiences in the use, benefits, and level of understanding of, that technology; and also the level of control the public, individually or collectively, has over the technology. Therefore, whilst the risk of death or injury from car travel is high relative to say air travel, the greater level of familiarity,

immediate benefit, general understanding of the technology, and ability to exert control of car use leads to the perception that the level of risk from this form of transport as acceptable. In contrast, the greater statistical safety of air travel does not lead to a perception of lesser risk because aeroplane passengers are disempowered through a lack of technical knowledge and control.

Similarly, the general public feels disempowered and over-awed by the technical complexities of the nuclear industry. Furthermore, perceptions are coloured by three very significant attributes peculiar to the nuclear industry: the invisibility of radiation, which magnifies fear because of the inability to smell, see or feel a potentially lethal health risk; the very long time scales of potential health and environmental impacts and the feeling of powerlessness over a potential hazard that will impact upon our children or grandchildren; and the association between the nuclear industry and nuclear weapons.

It is not realistic for us as technical experts to expect to persuade the public of the low risks associated with uranium mining without being sympathetic to the concerns of the public. It is important to establish and maintain dialogue in words and ways that establish understanding. Whilst it may be more precise in a scientific sense to communicate in technical terms, we fail if we cannot convey our message in a manner understandable to the listener — poor communication skills by scientists is a major reason for public mistrust of many technological advances, such as food irradiation, genetic engineering, and cloning. Indeed, in any discussion we have with the public, as much weight needs to be given to public perceptions as technological fact, as they can often be at least as influential in decision making by government as the information provided by technocrats and bureaucrats

3. APPROACHES TO IMPROVED COMMUNICATION OF IMPACT AND RISK

The Australian government considers that it is not sufficient to communicate the environmental performance of uranium mines through the normal channels of reporting used by in the mining sector – that is, reporting by the industry to the regulatory authority, and reporting by that authority to parliament (note there is an increasing trend for companies to voluntarily prepare annual reports of their environmental performance for general public distribution, in addition to their commonly brief reports to shareholders). In the case of uranium mining, the government expects that environmental issues are open to public scrutiny, and has established special forums at which results of environmental management and monitoring by the mining company, and supervisory monitoring or auditing undertaken by government, are reported to interested stakeholders.

3.1. Stakeholder consultation forums

The forum established for the mines of the Alligator Rivers Region in the Northern Territory is known as the “Alligator Rivers Region Advisory Committee”. It meets twice a year, usually within a week of environmental audits undertaken jointly by the federal and state government authorities (the Office of the Supervising Scientist and the Northern Territory Department of Mines and Energy). This forum is made up of representatives from the uranium mining and exploration companies; the Federal and State departments of mines, resources, environment and health/radiation safety; mine workers union, community environment groups, local town council, and Aboriginal associations.

The business of the meetings of this forum is to receive and discuss reports on recent developments from the companies (e.g. mining activities, plant expansion, exploration etc); the environmental audits undertaken by the government; any regulatory matters including reports of any infringements; and developments in government policy or standards as a consequence of research, international developments, or past events at the mines in the region. The committee is independently chaired, with the intention of de-politicising the process. The emphasis is to analyse the information presented, and to discuss how any substantive issues of concern to some of the stakeholders can be remedied.

These forums form a key part of a cycle of continuous improvement applied to environmental management and reporting at the uranium mines of the Northern Territory (Fig. 1).

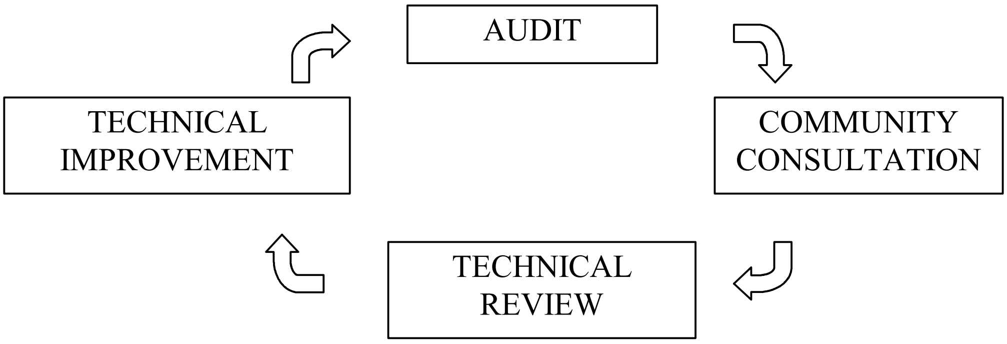

FIG. 1. Community consultation forms a key component in the government's approach to continual improvement in environmental protection at uranium mines.

It is quite clear that the differing views expressed by different stakeholders commonly reflect different levels of technical understanding, fundamentally different philosophical positions regarding mining generally and the mining and use of uranium specifically, and different levels of response to risk.

The catch-phrase *perception is reality* has been coined to emphasize the need to deal seriously with the (commonly not well technically founded) concerns of the public. To trivialize their concerns is to demean them and their representatives, and so deepen levels of mistrust which commonly typify the relationships between those in or close to the industry, and the broader community. In other words, for these forums to achieve the objective of trustful and informative dialogue on environmental protection in uranium mining, the concerns of the public must be considered no less seriously as other matters, even though those concerns may in many instances be poorly founded in a technical sense. Key components of building a base for effective communication include openness and transparency of process, complete information sets, regular communication at appropriate times, and mutual respect. Information must be prepared in a way which can be understood and jargon must be minimized.

3.2. Impact matrix

In order to assist in achieving effective communication between technical specialists and the general public in relation to the environmental impacts of the Ranger uranium mine, a simple matrix method was developed [2] to convey information objectively on the environmental impacts of non-compliance events at the mine (Fig. 2). This matrix allows the nature of events to be plotted objectively in terms of the measured severity and duration of an impact.

The categories along each axis are selected to be meaningful both to the scientist and the layperson. Severity of impact reflects the major impacts that might occur on the biota of the region around the mine, as it is the most vulnerable element of the environment surrounding the mine (most of the data which are collected in the monitoring program focus is on the aquatic biota in the creek system which flows within one km of the mine).

Severity is graded from **no change detectable** (i.e. by any chemical, physical or biological measure); to **physical or chemical changes only** (i.e. physical or chemical evidence of change but no measurable biological effect); to **stress or behavioural change to individual organisms** (e.g. changes in movement, feeding habit, egg production numbers); to **mortality within some species** (e.g. observed deaths, reduced hatching or germination); to **change at the ecosystem level** (i.e. numerous deaths such as a widespread fish kill).

Duration is graded from **less than one month** (i.e. recovery within a season/life cycle stage for most animals); to **up to a year** (i.e. recovery after the complete annual seasonal cycle of wet and dry seasons, during which the ecosystems of the region are "flushed" by floods, drought or fire, reproduction of most life forms has occurred, and significant migrations have taken place): to **up to**

the life of the mine (e.g. a chronic pollution problem may cause environmental damage for as long as the mine operates, but may cease when the mine closes, allowing environmental recovery); to **indefinite** (i.e. persisting beyond mine closure).

3.3. Grading the significance of impact

The parameters along the two axes of the matrix represent measurable and therefore objective gradings of time and bio/physio/chemical characteristics of the impact caused by an incident. An attempt can be made to describe with some objectivity the relative levels of impact encountered within each cell of the matrix (e.g. “short term mild impact”, Fig. 2). However, the *significance* of the impact will inevitably be interpreted differently by different interested parties, reflecting their philosophical position towards uranium mining, and their place on the risk averse — risk sensitive continuum.

This interpretation of significance is shown by the classifying the cells of the matrix into broad categories. Here, the broad categories of environmentally significant; moderate environmental impact, and no significance are used here. The Supervising Scientist’s view of the relative levels of significance are shown by the shading in Fig. 2 [2]. Clearly, the interpretation of significance by different stakeholders will differ; in the extreme case, for example anti-nuclear group, it is probable that all cells above “no change detectable” would be classified as of significant environmental impact (calling up bioaccumulation of toxicants, no safe radiological dose arguments etc to support that approach).

	DURATION OF IMPACT			
SEVERITY OF IMPACT	**Less than 1 month**	**Less than 1 year (less than a complete seasonal cycle)**	**Within project life (estimate No. of years to recovery)**	**Indefinite**
Change at the ecosystem level	**Brief serious impact**	**Short term serious impact**	**Extended serious impact**	**Long term serious impact**
Mortality within some species	**Brief moderate impact**	**Short term moderate impact**	**Extended moderate impact**	**Long term moderate impact**
Stress or behavioural change to individuals	**Brief mild impact**	**Short term mild impact**	**Extended mild impact**	**Long term mild impact**
Physical or chemical changes only	**Brief non-biological impact**	**Short term non-biological impact**	**Extended non-biological impact**	**Long term non-biological impact**
No change detectable	**No impact**	**No impact**	**No impact**	**No impact**

FIG. 2. A matrix of ecological impact integrating severity with duration, overlaid with a “significance” rating - heavy shade = significant impact; medium shade = moderate impact; light shading = insignificant impact [2].

The importance of the matrix is that the objective character of the impact can be differentiated from the subjective assessment of the significance of the impact. This allows stakeholders with different philosophical positions in the stakeholder forum to agree on the character of the impact, but disagree on interpreting its relevance. Thus a common understanding is established upon which the (technical/scientific) reality can be distinguished from the (political/ethical) perception. As the basis of the exchange possible within the stakeholder forum is non-political, the focus of discussion becomes more directed at the technical realities and ways of reducing the risk of recurrence of incidents. The issue of significance of impact is then seen as an ethical issue pursued in a political context outside the technically focussed stakeholder forum described above. However, it is clear that the stakeholder group has been effective in reducing the level and style of political rhetoric from anti-nuclear groups as the low levels of environmental impact achieved by the uranium mining operations in the Northern Territory have been effectively communicated.

The matrix may also be used in a pro-active sense, by determining appropriate regulatory responses to incidents of different types. For example, it may be decided that upon any incident occurring which plots in the "significant impact" zone, the mine must stop operating until an appropriate investigation is undertaken, remedial action agreed with regulators, and permission granted at a suitably high level within government. Such an approach elevates the status of the matrix to a higher level of significance, provides a pre-determined benchmark for industry, and security to concerned stakeholders that appropriate action will be undertaken when needed.

4. APPLICATION OF THE MATRIX TO RANGER MINE

The operator of the Ranger mine are required to report any operational infringement or any other event which has the potential to impact on the environment surrounding the mine, cause harm to people living or working in the area, or cause concern to traditional owners or the broader public.

Since 1979, 120 incidents have occurred. Notwithstanding that the government requires every incident to be reported, regardless of the actuality of environmental impact, the number of incidents is commonly quoted by anti-nuclear groups as evidence that the mine is unsafe and should be closed down. It is useful therefore to plot these incidents on to the matrix to clearly display the distribution of these incidents in terms of the severity and duration of impact, as judged by the Office of the Supervising scientist (which is required to make an assessment of each incident independent of the company's assessment). The matrix is reproduced in Fig. 3 with the 120 incidents at Ranger plotted.

The Office of the Supervising Scientist has determined that all but two of the 120 incidents caused no significant environmental impact, either of an immediate or longer term nature. The 118 events were generally undetectable by chemical, biological or radiological means after cleanup operations which were always undertaken as soon as possible after detection of the incident. They related mostly to small volumes of contaminated water escaping outside control areas (mainly from pipe or bund failures, water used to quell bushfires around the mine site); minor mill incidents (e.g. stack scrubber failure, clogged filters, process liquor spills); minor spills of tailings slurry mainly from pipe joint failures (spills generally contained within bunds along the pipeline); and spills of diesel fuel.

A small number of incidents related to spillage or mishandling of uranium concentrate. The most serious of these was in July 1982 when concentrate spilled onto two workers in the packing facility. However, rapid action ensured that the health of the workers was not compromised. This incident is plotted as "stress or behavioural change to individuals … of less than 1 month duration".

The incident which is plotted as "mortality within some species … duration less than one month" resulted from a spill of diesel from tanks at the power station which drained into a retention pond of contaminated water in December 1995, killing 40 water birds. The Supervising Scientist concluded that this was the first unacceptable environmental impact that had arisen as a consequence of operations at Ranger.

SEVERITY OF IMPACT	DURATION OF IMPACT			
	Less than 1 month	**Less than 1 year (less than a complete seasonal cycle)**	**Within project life (estimate No. of years to recovery)**	**Indefinite**
Change at the ecosystem level		*significant*	*impact*	
Mortality within some species	1			
Stress or behavioural change to individuals	1	*moderate*	*impact*	
Physical or chemical changes only	14			
No change detectable	104	*insignificant*	*impact*	

FIG. 3. Assessment of ecological impacts arising from incidents at the Ranger mine from 1979 to September 2000.

As a consequence of the reporting of these incidents, the company has either voluntarily or upon the advice of the regulating authorities, undertaken reviews or audits and improved operational procedures or staff training programs. For example, staff training and awareness was revised after the 1982 uranium concentrate spill, and bund management and operational procedures were revised after the 1995 fuel spill. Generally, the number of incidents reported has fallen as remedial responses have reduced the probability of recurrence.

It should be noted that, in November 1996, a contract worker was killed whilst using an excavator to dig foundations for the mill expansion. While this incident is obviously of great concern, it falls in the category of non-radiological workplace safety. It is therefore not listed as an environmental incident.

While the list of incidents reported appears large, this is a reflection on the rigour of the reporting framework. The assessment of environmental impact for each incident demonstrates a high level of environmental protection is being achieved at the Ranger mine.

5. CONCLUSION

For almost 20 years, uranium has been mined and milled at the Ranger in an area surrounded by national park which is on the World Heritage List because of its biological diversity, landscape and Aboriginal culture. For these reasons the mine has been subject to a rigorous system of regulation and supervision unequalled anywhere in Australia and probably anywhere else in the world.

In spite of this rigorous level of supervision, and a track record of sound environmental management, the mine is still frequently a target for criticism by the community. Whilst much of this criticism stems from anti-nuclear groups who oppose the mine on philosophical grounds, other parts of the

community also express concerns from time to time, including local Aboriginal groups. It is important to communicate the actual levels of risk to the health of the environment and the local people. An effective way of doing this is to engage representatives of the interest groups and share with them the unadulterated results of environmental monitoring and environmental auditing on a regular basis, within a system that is able and willing to consider the concerns of those stakeholders and respond in a meaningful way to them – for example, by undertaking research directly into areas that concern them.

There is much literature on risk and how to identify and manage it. However, it is advisable when dealing with issues of concern to the public, like uranium mining, not to apply these approaches purely on a technical basis. Public concern about the nuclear industry means that political risk will continue over the future of the industry. We therefore need to consider the perceptions of risk held by the layperson just as seriously as those risks we know and understand from our technical analyses.

The social dimension is often overlooked in the assessment of mine environmental performance. One could argue that a mine is performing poorly for as long as the public perception of the mine is negative, regardless of the quality of performance assessed on technical grounds. The approach outlined in this paper describes one attempt to close the gap between technical evaluation of mine performance and society's assessment. The objective is to reduce the gap between perception of performance in the public mind, and actual performance as demonstrated by people like us. In this way, public pressure can be used positively to improve environmental performance in our industry where needed, and public acceptance of good performance will inevitably lead to less resistance to the development of the uranium mining industry.

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IMPACTS

Environment and Safety

(Session 2 (b))

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Environmental issues in the 21st century

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Abstract. This paper provides an overview of some of the environmental challenges facing the uranium production industry in the 21st century. For many years, the linear, non-threshold (LNT) model has been regarded as a prudent hypothesis for radiation protection purposes. This paradigm has been challenged at the same time for both underestimating and overestimating the risks from ionizing radiation. The reality is that the ability of conventional epidemiology to distinguish small risks will always be limited by statistical power at low doses. In the future, there will be increased emphasis on better understanding the effects of ionizing radiation at the cellular (and sub cellular) level. The concept of "controllable dose" has been proposed as an alternative to the International Commission on Radiological Protection's (ICRP) current approach to dose limitation. The concept is that if the most exposed individual is protected, then society as a whole is protected. A hazard ranking scale based on comparisons to natural background levels of radiation has been proposed. Adoption of a concept such as "controllable dose" would require a parallel re-evaluation of the concepts and application of collective dose and ALARA optimization. The protection of non-human biota is an issue of considerable interest in many countries. The science in this area is rapidly evolving, as are discussions of a more philosophical nature. For example, should the focus of environmental risk assessment be the sustainability of the population or should the focus be to limit effects on a single member of the population? The future of environmental risk assessment should be of great interest to the uranium production industry. A systematic approach to risk assessment addressing the full scope of potential hazards — environmental, human health, engineering, financial and others — will be increasingly important in the future. What level of risk is it reasonable to accept? What is meant by "reasonable"? How much risk can be engineered away, for how long, and at what cost? This paper explores these issues both from a scientific perspective and from the perspective of what is "reasonably practicable". From the author's perspective, such issues, conceptually at least, can be addressed within a risk-based framework for managing hazards.

1. INTRODUCTION

The uranium production industry includes the mining and milling of uranium ores, the conversion to nuclear fuel materials and the production of fuel elements. The focus of this paper is on the front end of the fuel cycle, which handles natural rather than enriched uranium. This paper looks at the mining and milling of uranium ores, the refining and conversion of natural uranium to uranium hexafluoride and the production of natural uranium fuel. The issues described in this paper are important for planning new facilities, licensing and operating existing facilities, and decommissioning.

This paper discusses selected environmental issues which affect the uranium production industry including:

- the use of the linear non-threshold model for radiation protection;
- the concept of "controllable dose" as an alternative to the current ICRP system of dose limitation;
- the future of collective dose and ALARA; and
- the application of a risk-based framework for managing hazards.

The role of multi-stakeholder interactions in the development, planning, operation and decommissioning of uranium production facilities is, and will continue to be, an important consideration. The role of multi-stakeholder participation in environmental assessments is discussed in an accompanying session and will not be discussed in this paper.

2. LOW-DOSE AND LOW-DOSE RATE RADIATION EXPOSURE

2.1. Linear non-threshold

Human populations have always been exposed to ionizing radiation: from cosmic rays; from naturally occurring radionuclides in the air, water, and food; and from gamma radiation from the radionuclides in rocks and soils. The level of exposure to natural radioactivity varies by a factor of 10 (or more) depending mostly on where people live and partly, on what they eat or drink.

Since the beginning of the last century, with the discovery of radioactivity, people have also been exposed to additional increments of radiation resulting from human activities of various kinds. Except for that from medical diagnoses and radiotherapies, these are typically much smaller than the exposures from natural sources.

At low doses (and dose rates) of ionizing radiation, the risk arises principally from damage to the nuclear material (DNA) in the cell, resulting in the development of radiation-induced cancer in those exposed or hereditary disease in their descendants. Although the probability of both cancer and hereditary disease increases with radiation dose, it is generally considered that their severity (if the effects do arise) does not. These are termed "stochastic" effects, and have been the subject of reviews by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (e.g. [1], [2]) and other scientific bodies including committees of the U.S. National Academy of Sciences (e.g. [3], [4], [5] [6]) and the Atomic Energy Control Board's (AECB) Advisory Committee on Radiological Protection (ACRP) [7].

A recent report by the ACRP defines low dose in terms of unavoidable radiation exposure from natural sources [7]. The ACRP note:

> "The average annual exposures to the whole body are roughly 1 mSv (1000 μSv) per year in areas of normal background but this is increased to over 4 mSv per year in areas of high exposures due to high concentrations of primordial radionuclides in the soil. Similarly, the average annual effective dose to the lung due to inhalation of radon and its short lived progeny from natural sources might be taken to be about 1 mSv per year, but this can be increased to 10 mSv per year or even more. On this basis, one might define low dose rates as anything up to say 10 mSv per year or 0.03 mSv per day."

2.2. Risk estimates

For the purposes of radiation protection, it is widely assumed that the probability of inducing excess cancers or excess hereditary risk in people exposed to ionizing radiation is directly proportional to the total radiation dose received, even at low doses and low dose rates, and that there is no "safe" or threshold dose of radiation below which these biological effects will not be produced. This is commonly referred to as the linear, non-threshold (LNT) model.

For radiation-induced hereditary (genetic) disease, no statistically significant increase has been detected in any human population, and risk estimates have to be based on the results of animal studies. No evidence of any significant increase in genetic or partially genetic defects has ever been observed in any group of irradiated humans that has been studied, including the children of the atomic bomb survivors [6].

The ICRP [8], in its most recent recommendations for radiation protection purposes, adopted the LNT model for projecting risks at low doses. In developing its risk coefficients, the ICRP considered the available epidemiology data, as summarized for example in the UNSCEAR and BEIR V reports, and applied a dose rate reduction effectiveness factor (DRREF) of two by which risk estimates derived for

acutely-delivered low-LET radiation (such as to the survivors of the atomic bombings at Hiroshima and Nagasaki) were divided. On this basis, the ICRP adopted the risk (probability) coefficients for stochastic radiation effects, for workers and for the whole population including children, shown in Table I.

TABLE I. NOMINAL RISK (PROBABILITY) COEFFICIENTS FOR STOCHASTIC EFFECTS

Exposed Population	Adult workers	Whole population
Risk (% per Sv)		
fatal cancer	4.0	5.0
non-fatal cancer	0.8	1.0
severe hereditary effects	0.8	1.3
Total	5.6	7.3

To provide a context for the applicability of the ICRP risk coefficients, consider that in Canada about 28% of all deaths are due to cancer. Radiation exposures from natural sources are about 2 mSv per year in Canada. Assuming an average life expectancy of about 70 years and a theoretical probability of 5×10^{-5} fatal cancers per mSv (i.e. 5% per Sv) for the public, then the theoretical probability that radiation from all natural sources would induce a fatal cancer at some point during an average lifetime would be about 1.0%. Applied to the natural mortality rate from cancer, this theoretically suggests that about 4% (i.e. $\frac{1}{28} \times 100$) of the normal probability of death from cancer in Canada may be due to natural background radiation. This comparison is of course dependent on the assumption of linearity. Thus, we should perhaps say that natural background radioactivity (at the "typical" level) in Canada might contribute at most about 4% of the background cancer risk.

Although both the linear non-threshold model or the linear-quadratic (without threshold) models have been widely used for assessing biological effects at low doses of low-LET radiation, there has been extensive debate as to what the shape of the dose-response relationship is at doses below those at which radiation-related effects can be directly determined. Some evidence from both human and animal studies suggests that in certain cases, notably for the induction of bone cancer by ^{226}Ra, a practical threshold dose exists below which the chance of producing a bone cancer within the normal lifespan is virtually zero. Below this dose level, the chance of developing a radiation-induced cancer would be very small, or zero as the word threshold implies. The BEIR IV report [3] preferred to include the possibility that there could by chance be a small probability of a radiation-induced cancer even below this practical threshold, so that one should speak more properly of this as a quasi-threshold (see also [9], [10]). The data on ^{226}Ra and bone cancer in humans were interpreted by the BEIR IV committee to indicate that:

> "The time to tumor appearance apparently increases with decreasing dose and dose rate. Below an average skeletal dose of about 0.8 Gy [16 Sv], the chance of developing bone cancer from ^{226}Ra and ^{228}Ra during a normal lifetime is extremely small-possibly zero." [3]

There is also some evidence of a reduction of cancer rates on exposure to very low doses of radiation, resulting from the stimulation of repair mechanisms overall; however, UNSCEAR 1994 [2] concluded

> "Extensive data from animal experiments and limited human data provide no evidence to support the view that the adaptive response in cells decreases the incidence of late effects such as cancer induction in humans at low doses" [2].

Cancer occurs naturally (in the absence of enhanced radiation exposure) at an appreciable rate. Thus, at low doses it is difficult to determine with reasonable certainty what the level of effect may be, and indeed whether any effect attributable to radiation has occurred. The mortality of the atomic bomb survivors shows statistically significant dose response down to approximately 50 mSv [9].

Overall, it should be acknowledged that below doses of about 100 mSv, the dose response relation is uncertain. **In the near-term, it should not be anticipated that either UNSCEAR or the ICRP will move away from the linear non-threshold model for radiation protection.** In the future, however, it is expected that further development of molecular biology will improve our understanding of the mechanisms of cancer and lead to an improved basis for estimating the risks from exposure to ionizing radiation. Thus, it is important to consider how this would affect dose limitation and other aspects of radiation protection in the future. Finally, it should be noted that a new issue, namely the potential for radiation to induce non-cancer disease mortality such as heart, digestive and respiratory disease seems to be an emerging issue which will require careful monitoring by the industry [11], [12], [13].

3. APPROACH TO RADIATION PROTECTION

The current system of radiation protection, described in the 1990 recommendations of the ICRP [8], is based on the **policy decision** to use the linear non-threshold (LNT) model for stochastic risks. The LNT model has, for many years, been regarded as a prudent and reasonable hypothesis for radiation protection [7]. The use of the LNT model implies that there is some risk for any dose, no matter how small. Even if it were possible to totally eliminate dose from human activities, dose is unavoidable and any practical system of limitation must address this. The current [i.e.1990] system of dose limitation includes three main elements:

(1) **justification**: that is, the activity must result in more good than harm;
(2) **optimization**: there should be an attempt to maximize the net benefits;
(3) **limitation**: risks to individuals must be kept below acceptable levels.

Clarke [14] has discussed some of the challenges to the use of the LNT model for radiation protection and suggests it is time to consider a change to the current approach [of the ICRP] to radiation protection. He has proposed an alternative to the current approach of the ICRP based on protecting the individual from the risks of ionizing radiation from sources which can **reasonably** be controlled. (It should be noted that Clarke's proposal is simply a proposal for consideration by the radiation protection community and has no special status at the present time.) The critical element here is to develop an operational definition of "reasonably". Clarke proposes that

> "If the health of the most exposed individual is trivial, then the total risk is trivial- irrespective of how many people are exposed."

As currently envisaged by Clarke [15], the new protection scheme for doses from [reasonably] controllable sources would be based on a set of action levels which in turn are based on multiples of natural background radiation as shown in Table II.

TABLE II. LEVELS OF CONCERN AND INDIVIDUAL EFFECTIVE DOSE

Category	Annual Dose
Serious	>100 mSv
High	10–100 mSv
Normal	natural background
Low	0.1–1.0 mSv
Trivial	0.01–0.1 mSv
Negligible	<0.01 mSv

One of the issues with the calculation of collective dose to the public and hence with ALARA calculations which involved dose to the public, is that, at present, the calculations are most often unbounded in space and time. For example, in estimating doses, UNSCEAR currently calculates global doses from an activity for 10 000 years into the future. Such practice results in the summation of doses to individual, which could reasonably be considered as trivial and which are very uncertain. A recent study of population dose due to ^{222}Rn from uranium mill tailings [16] illustrates the problem of unbounded integration of collective dose. SENES [16] estimates that a large fraction (>80%) of the collective population dose is incurred by people living beyond 100 km of the mill tailings sites. The area-weighted average radon concentrations in the 100–2000 km region around the mine sites are estimated to range from (essentially) zero to about 0.2 mBq m^{-3}. These concentrations are more than 50 000 times lower than typical outdoor background concentrations. Incidentally, even the (area-weighted) concentrations in the <100 km region are factors of 200 or more lower than background concentrations. Beyond 2000 km, the incremental concentrations are lower still, with individual doses in this region estimated to be more than a factor of 3000 below the 10 μSv y^{-1} dose rate suggested by Clarke [14] as being negligible. In many respects, it is the use of unbounded collective dose, combined with LNT which has resulted in large expenditures for remediation of contaminated sites. **It seems likely, as we move into the 21st Century, that international and national bodies will be reviewing the system of dose limitation and the role of collective dose.**

4. RISK

From a general perspective, risk is a factor in every action being taken and every decision being made. Even in the case of the "do nothing decision", an element of risk may be present. Thus, to discuss risk in a meaningful manner for a particular audience requires some agreement on the scope and nature of decisions required, along with a uniform basis for the discussion of the risk assessment and a process that allows appropriate interaction with and feedback from potentially affected stakeholders.

There are many different forms of risk, depending on the scope of the question under consideration and the perspectives of the various stakeholders. Moreover, the various stakeholders may also, or perhaps are likely to, have widely varying opinions as to the "value" of a potential hazard. For example, acid drainage[1] may have the potential to affect a local fishery. The value assigned to the potential (temporary) loss of the local fishery by local fishing enthusiasts, regulators, NGOs and the company might be quite different.

Life is full of uncertainties. Is it going to rain tomorrow? Will the probable maximum precipitation (PMP) event occur next Tuesday or the Tuesday after or indeed at all? The fact that risk inherently involves chance or probability leads directly to a need to describe and deal with uncertainty. Dealing with uncertainty of course involves not only assessing uncertainty but the need to communicate uncertainty and the implications of the uncertainty to others. This is not always an easy task. Not all hazards are valued as equivalent. For example, most people would consider that a 1% chance of getting a speeding ticket was remote are unlikely to consider a 1% chance of an airplane crash to be remote. In essence, risk management is a means of facilitating making decisions affecting risks to human life, environmental damage, corporate liability, etc. versus available funds.

Risk Management is a decision making process involving consideration of political, social, economic, and engineering factors which are combined with risk assessment to develop, analyze, and compare options and to select between them. In general, the objective is to achieve the optimal (i.e. managing the assets to achieve the “most acceptable” solution) trade-off between maximizing the benefits and minimizing the risks and costs.

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[1] Acid drainage, either from sulphur-containing mill tailings or from sulphur-containing waste rock, represents a large environmental hazard to the mining industry including uranium mining [17]. It can be anticipated that concerns over acid drainage and consequent management costs, especially those for decommissioning, will increase as society’s interest in environmental risks increases.

Intrinsic to risk management is an identification of potential risks along with their characterization and the quantification of the consequences or costs of managing the risks. Risk management is concerned with weighing or comparing the various risks. It is generally agreed that Quality of Life issues are important both to individuals and to society as a whole. Quality of Life is a phrase that is widely used in discussion of local, community and national objectives for social well being. However, it is not always clear how to measure Quality of Life issues or perhaps even what the phrase "quality of Life" actually means. Moreover, there is not uniform agreement about how such valuations should be done, or even what Quality of Life issues should in fact be considered in such an analysis. Many of these issues are well discussed in [18] and [19].

The establishment of formal integrated risk management principles for decision making involves major technical challenges including socio-economic valuation of risks (e.g. with respect to human life, for example, morbidity, mortality, years of life added or lost and increasingly various of the less tangible issues related to Quality of Life [19]). Some issues are not as readily quantifiable in a common metric (typically monetary) and the risk management, cost benefit framework must be able to address these issues in the future.

From an environmental and human health perspective, technical risk assessment practitioners often define "risk" in some manner that essentially states it as being the product of the frequency or probability of a potential hazard combined with the potential consequences associated with the specified potential hazardous event if it occurs. Thus:

$$Risk = \sum_{\substack{overall\\relevant\\hazards}} (probability\ of\ \ hazard\ i) \times (consequences\ if\ \ hazard\ i\ occurs)$$

The literature describing hazard identification and how to assess consequences, if the hazard occurs, is large and these subjects are not discussed further in this paper. The issue of when a hazard is "reasonably probable" is briefly discussed below.

5. WHAT IS "REASONABLY" PROBABLE?

It is now a common requirement for trusts to be established for the decommissioning of mines and other fuel cycle activities. The idea is that the operator provides guaranteed funds to undertake preventive or remedial measures to avoid environmental risks associated with possible hazards that may arise at some future time. One example might be the periodic replacement of the cover or some other engineered structure associated with mill tailings. Another example might be the chance of an accidental release of uranium (or hazardous chemical) from a uranium processing facility. Another purpose of the fund would be to provide monies which could be used to remediate any loss of containment and environmental damage that might result from say, the failure of a section of a tailings dam with consequent spread of tailings to the environment.

In determining the necessary level of funding, the stakeholders, typically the company, various regulators, and increasingly various NGO's and members of the affected public must negotiate the amount of money that to be set aside and the details of the financing. If the long term environmental integrity of a site is dependent on man-made structures then these features will need to be maintained and possibly replaced on a periodic basis. The funding for the trust fund would then consider such future costs, perhaps on a discounted basis.

An important aspect for the viability of the trust concept is its schedule of funding. An unnecessarily large up-front expenditure might unnecessarily restrict development of an otherwise economically and environmentally sound project. The schedule and amounts of payment needs to reflect the anticipated risks and when these risks might be expected to occur. For long term considerations, the NRC distinguishes between timeframe for design objectives and actual

performance (e.g. reclamation to provide reasonable assurance of control of radiological hazards for 1000 years to the extent practical, but in any case, for at least 200 years). Risks that are expected to occur only after the engineering life of a structure, say for example 100 to 200 y, would require a relatively modest present value capitalization as opposed to some event which might reasonably be expected to occur within say a 20 y or 30 y window. Thus, what is reasonably possible and when such events might occur is an important consideration.

Industry surveys of chief financial officers and legal counsels at Fortune 500 companies found broad differences in the interpretation between what value separates "reasonably possible" the gray area between "probable" and "remote" events [20]. The paper concluded that not all "like" contingent liabilities are treated similarly, and went on to recommend that the Financial Accounting Standards Board Statement (FASB) [21] should attach probability definitions to the terms as follows:

- probable – greater than 70% likely to occur,
- reasonably possible – (likely) between 20% and 70% chance of occurrence, and
- remote – less than a 20% chance of occurrence.

From a statistical perspective, one might consider that remote events correspond to unlikely events (e.g. events to occur by chance alone). A common selection of this probability are 95% confidence intervals or p-values of 0.05 and these both imply that something more extreme (perhaps remote) would happen by chance only 5% of the time. This would suggest an upper bound for remote events could be 5%. This value is also near the lower values of probabilities given by the survey respondents [20].

6. ECOLOGICAL RISK ASSESSMENT

Potential risks of radiation to the environment have been the subject of much discussion over the past few years and have been the focus of various recent symposia (e.g. [22], [23], [24]). UNSCEAR 1996 [22] has provided a recent overview of the scientific literature on effects of radiation on the environment. The ICRP has established a Task Group to define terms of reference for a working group on environmental risks [15].

In Canada, recent initiatives of the federal department of the environment have assessed all aspects of the uranium fuel chain, from mining and milling through to power generation and waste management. The tiered Priority Substance List (PSL-2) assessment considered both the chemical toxicity and the radiological toxicity of the radionuclides released ([24], [25]). The study found that only uranium has the potential to result in chemical toxicity for uranium mines, mills and waste management areas. The draft PSL-2 has been issued for public comments following which, it is likely that the evaluation will move to the risk management stage. This is especially important for facilities such as those in the Elliot Lake area which have already been subjected to intense public and regulatory scrutiny through comprehensive environmental assessments which include an evaluation of risks to the environment and which are already decommissioned.

It is beyond the scope of the present paper to review the draft PSL-2 document. However, it should be noted that some aspects of the draft PSL-2 document are controversial and subject to ongoing debate. One example, is the determination that 21 ppm U in lake sediment is toxic when sediments in many lakes in Canada exceed this level naturally.

A few of the issues arising from the PSL-2 evaluation include the determination of relative biological effectiveness (RBE) for various receptors and endpoints, the development of expected no effect values (ENEVs), and the selection of appropriate ecological receptors and endpoints for evaluation. To illustrate, assessment endpoints are usually formal expressions of the actual environmental values to be protected (e.g. fishable and swimmable waters). Measurement endpoints are specific, measurable environmental features that can be related to particular assessment endpoints. For

example, fish production and survival could be determined for a lake or stream and used as a measurement endpoint that relates to the assessment endpoint of maintaining fishable waters. A further question is how big an effect on the population, 1%, 5% or 50%, is required to affect the viability of the population.

In view of the current international interest in environmental risk, it seems clear that this subject will be of cautionary interest to the uranium industry in the future.

7. CONCLUSIONS

Abundant and reliable electrical energy is crucial to support economic, health and social needs. Nuclear energy should be a major energy provider, especially with the ongoing concerns with greenhouse gas emissions and global warming. However, many of the public are suspicious of nuclear energy and have concerns with environmental, safety and decommissioning issues associated with the uranium fuel cycle. These concerns must be addressed thoroughly and openly for the nuclear option to remain viable. From the author's perspective, the risk assessment/risk management framework is well suited for this purpose. The industry will have to accept that the LNT model is likely to be used for many years and provide strong argument that even with LNT, that at low doses and low dose rates, the risks are small. Alternatives to the current system of dose limitation are required. In particular, it is important to revisit the concept and application of collective dose when there is no limit either spatially or over time to the integration. The industry must also develop methods to take account of the full range of risks, whether they be health, environment, corporate or social within the risk management framework. The current "hot button" is environmental risk (i.e. risk to non-human biota). Above all, the industry must be thorough, open and willing to work with multiple stakeholders to develop a defensible and coherent approach to risk management.

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Environmental considerations for the expansion of Olympic Dam, South Australia

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Abstract. A recent $2 billion[1] expansion at Olympic Dam saw production capacity increased to 200 000 tonnes of copper cathode, 4500 tonnes of UOC, 80 000 ozs of gold and 850 000 ozs of silver from the mining and milling of about 9 million tonnes of ore. The Expansion required the prior preparation and approval of an Environmental Impact Statement (EIS). Design Criteria and Codes of Practice applied during design and construction of the Expansion ensured that no environmental incidents occurred during construction, and implementation of an Environmental Management System has ensured that operation of the expanded facilities continues to have low impacts.

1. INTRODUCTION

The Olympic Dam orebody, discovered by WMC Resources Ltd in 1975 is located 560 km North of Adelaide in South Australia. It is located in a sparsely populated arid area with annual average rainfall less than 150 mm in a region that is used predominantly for pastoral activities. Air temperatures range from 0 degree minimums in winter to 48 degree maximums in summer. The nearest towns are that of Roxby Downs (pop 3000), 13 km S which was established to house the operation workforce, and Andamooka (pop 700) an opal mining town 35 km NE. The mineral resource contains 2320 million tonnes of material at a grade of 1.3% copper and 0.4 kg/tonne uranium together with gold and silver. Included in this resource is a proven and probable reserve of 605 million tonnes of ore at a grade of 1.8% copper, 0.5 kg/t uranium, 0.5 g/tonne gold and 2.5 g/tonne silver. The orebody is amongst the largest copper and uranium resources in the world and is able to support production for many years to come.

The Project was initially developed in the period 1986 to 1988 with subsequent minor expansions in ensuing years to a capacity of 85 000 tonnes/year copper and 1700 tonnes/year uranium in 1994.

A recent $A2 billion (US $1.2 billion) expansion saw annual production capacity increased to 200 000 tonnes of copper cathode, 4500 tonnes UOC, 80 000 ozs gold and 850 000 ozs of silver from the mining and treatment of about 9 million tonnes of ore. Revenues from this production are approximately split 70% copper, 25% uranium and 5% gold and silver.

The spread of products has some obvious advantages but also provides challenges in achieving best practices in health, safety, environmental and technical issues. The expanded operation uses the most advanced technologies to provide a low cost, safe and clean workplace with minimal environmental impact. Careful consideration was given to the management processes necessary to achieve this goal during the planning and execution of the expansion.

This paper outlines some of those management processes that were adopted during the Expansion Project.

[1] 1 billion = 10

2. ENVIRONMENTAL IMPACT STATEMENT

2.1. Environmental impact assessments

The Olympic Dam Project has been subjected to a comprehensive environmental assessment process from its inception. This included an environmental impact assessment of the initial operations, licence approval processes, the preparation of a waste management plan and the preparation every three years of environmental management programmes.

The original project was covered by State and Commonwealth approvals of an Environmental Impact Statement (EIS) prepared by Kinhill Stearns in 1983 and permitted the mining and processing of up to 6.5 million tonnes of ore for the recovery of 150 000 tonnes of copper plus associated products.

In the original project and subsequent expansions mining and metallurgical processes followed the principles outlined in the 1983 EIS. The major expansion planned in 1997 was to continue to use these processes essentially unchanged other than to incorporate improvements in technology and measures for enhanced environmental performance, waste minimization, energy and water conservation and occupational health and safety.

The Commonwealth and State Governments determined that any expansion beyond the production levels approved in the 1983 EIS would require the preparation of a new EIS.

The environmental impact assessment process adopted in Australia comprises the release of EIS terms of reference by Government, the publication of the EIS, a public display period during which the public and Government agencies may comment on the EIS, the preparation of a response document (referred to as a Supplement to the EIS), and the release of a Government Assessment Report. The Assessment Report considers both the EIS and the responses by the company in the Supplement.

2.2. Process

The environmental impact assessment procedure for the expansion project required that draft guidelines prepared by Commonwealth and State governments would be released for public comment for a period of four weeks. Finalized guidelines for the preparation of the EIS were then issued by the Governments that incorporated changes resulting from the assessment of public comments.

The EIS was then prepared by WMC and then following approval for its release by the government was open for comment from the public and by government departments and agencies for an eight week period. WMC then prepared a response to these comments in a Supplement to the EIS.

In total, the EIS attracted 39 public submissions, 13 submissions from State Agencies, and 3 submissions from Federal agencies. The comments covered the full range of matters covered in the EIS, including questions on the project description, water management, land use, Aboriginal culture, the biological environment, tailings management, air quality and noise, radiation, project infrastructure, social environment, economic impacts, rehabilitation and decommissioning, and management and monitoring.

The most comment was made on water management, tailings management and radiation. The water impacts included possible impact of water supply on the Great Artesian Basin, the possible effects on mound springs and the accuracy of borefield drawdown modelling. The EIS described two options for tailings disposal and management – the conventional paddock method which had been used previously, and the possibility of a central thickened discharge method. As a result of comments received, it was decided to continue with the conventional disposal method. The major radiation issues related to the long term containment of tailings material, and the assessment of radiation doses, and their associated risk.

The Supplement and EIS was then given further consideration by respective State and Commonwealth government ministers before a final approval was given for the project to proceed.

2.3. Approvals

The EIS was released in May 1997, and the supplement was released in October 1997. A Joint Assessment Report was prepared by the State and Commonwealth Governments in late 1997, and included recommendations for approval of the proposed Expansion. The State approval was given in December 1997, however the Commonwealth approval was subject to internal delays and was not formally given until June 1998.

The Assessment Report was a combined State and Federal Government report. Australia is a federation of states, thus there are separate State and Federal EIS processes, however by agreement with the two Governments these processes were coordinated for the project. No major issues were raised, however a number of recommendations were made. Most of these recommendations related to commitment to ongoing monitoring. Recommendations of a one-off nature have been undertaken.

The approval provides for expansion of Olympic Dam in two stages, initially to 200 000 t/a copper, and ultimately to 350 000 t/a copper. The approvals confirmed the two stage Expansion subject to three principal conditions – the mining and minerals processing methodology is not significantly varied, the sub aerial tailings disposal method continues to be used, and the water use and management practices continue to remain in compliance with existing approvals.

2.4. Awards for excellence

The completed EIS was awarded a 1998 Engineering Excellence Award from the Institution of Engineers, South Australia, and the 1998 ACTEW National Engineering Award for Excellence in Environmental Management.

3. ENVIRONMENTAL CODES OF PRACTICE

3.1. Purpose

Three Environmental Codes of Practice (ECP's) were prepared to meet EIS commitments for ecologically sustainable development through the minimization, and avoidance where possible, of significant environmental impacts during the construction of the planned facilities. The three separate ECP's covered the construction of a new 275 kV transmission line some 230 km long, upgrade of the 210 km water pipeline to the borefields, and construction works at the mine and minerals processing plant. A summary of the main points of the ECP's is given below.

The ECP's were intended to provide project management and engineering design staff and constructors with a concise understanding of the:

(a) physical, biological and heritage features of the project area;
(b) procedures to be followed to minimize environmental impacts associated with design, documentation, construction and commissioning of the expanded facilities and associated works;
(c) monitoring and audit reviews to be undertaken during the course of the work to verify compliance.

3.2. Responsibilities

The Olympic Dam Expansion Project (OEP) was under the control of a Project Director who was responsible for ensuring that the ECP's were distributed to the engineering designers for each work

package, to the OEP Construction Manager and to other personnel responsible for verifying implementation of the code.

3.3. Legislation

The various sections of Government legislation relating to the protection of the environment having particular application during construction were referred to in the ECP's.

3.4. Site environmental procedures

In addition to complying with the requirements of the ECP's, Constructors were required to comply with the following specific environmental management procedures which were prepared for the expansion project:

(a) Environment and Heritage Management
(b) Site Excavation Permits
(c) Waste Management.

3.5. Environmental clearances

The facilities for the expansion were planned, where possible, so as to avoid areas of particular environmental sensitivity. Engineering design managers consulted with the OEP Environmental Adviser in order to identify specific environmental and heritage considerations to be taken into account during the design process. Construction activities were planned and executed so as to minimize, and avoid where possible, the potential for environmental and heritage damage.

Constructors had to submit a request for an Environmental Clearance to the Environmental Adviser before any construction work could commence in any area. Depending on the nature of the work to be undertaken, a separate excavation permit may also have been required. The request for Environmental Clearance was accompanied by a work method statement prepared by the Constructor detailing:

(a) the scope of work
(b) machinery to be used
(c) how the work was to be undertaken
(d) the extent of ground disturbance necessary to undertake the work
(e) specific rehabilitation measures to be undertaken.

Rehabilitation measures were, in particular, to address the prevention of erosion and to promote the re-establishment of native vegetation.

Approval of the work method statement required the sign off of the Constructor, the Construction Manager and the Environmental Adviser prior to the issue of an Environmental Clearance.

3.6. Consultation

Local residents, pastoralists and Aboriginal groups were widely consulted about the expansion. WMC has made considerable effort to develop and maintain good relations with the regional community. The actions of construction personnel were therefore to be such as to continue to foster these relations, both within and external to the project area.

3.7. Land management, access and Flora and Fauna conservation

Care was taken to ensure that construction activities were not to alter or impede natural drainage patterns or increase sediment run-off, and that removal of vegetation was minimized. Topsoil was

stripped and stockpiled separately from other excavated material for use in subsequent surface restoration as directed by the Environmental Officer.

All vehicle access to construction sites within the project area was via existing sealed roads. Where temporary roads were required within construction sites they were to follow the planned alignments of the final road network, or were to be over surfaces to be disturbed during construction.

Vegetation, particularly on sand dunes in the area, provides important habitats for native animals. It was therefore, important to retain as much of the native vegetation cover as possible. Because of their importance as nesting and breeding sites for a variety of birds and other animal species, mature trees and tall shrubs were not permitted to be cleared without written authorization from the OEP Environmental Adviser.

3.8. Aboriginal sites

WMC continued to provide opportunities for Aboriginal people to inspect sites both during and following construction. Aboriginal sites were not to be disturbed with a site avoidance strategy implemented during planning for the expansion. Prior to commencement of construction all known Aboriginal sites were identified and clearly marked.

All construction activities were confined to the designated work areas, with access to adjacent areas prohibited. It is particularly important to avoid potential offence to Aboriginal people through inadvertent access to sites of cultural significance.

3.9. Water conservation

Water supplies at Olympic Dam are limited and expensive, and WMC has in place a water conservation strategy to improve the water use efficiency in its operations and for domestic purposes.

Constructors were to ensure that water use in their respective work areas was efficient, and that a culture of waste minimization was developed and maintained by the workforce.

Wherever possible, stormwater and mine water was used for construction purposes and dust suppression.

3.10. Pollution and waste management

All construction areas were kept free of litter, and solid wastes were regularly removed for recycling or disposal at the Olympic Dam Waste Transfer Control facility.

All fuels, oils and lubricants were stored in accordance with Australian Standards and clearly signposted, designated and segregated according to the nature and quantity of material stored. All storage areas were properly bunded to fully contain accidental spills.

Dangerous goods and hazardous substances were required to be used, transported and stored in accordance with the requirements of the South Australian Dangerous Substances Act covering toxic, corrosive and flammable substances.

3.11. Occupational health and safety

A site occupational health and safety plan was prepared by OEP management.

Within the framework of the overall plan, individual Constructors were to undertake an assessment of risks to their respective workers and prepare specific plans and procedures for their particular operations to include but not be limited to:

(a) safe work practices
(b) vehicle operations and safety
(c) fire precautions
(d) storage and handling of dangerous goods
(e) health and first aid
(f) heat stress
(g) precautions against venomous snakes
(h) communications including emergency services
(i) contingency plans.

Constructors were to ensure that all workers were familiar with the plan, verify compliance, and conduct such inductions and remedial training as necessary to meet duty of care obligations to the workforce.

3.12. Radiation safety

Radiation Safety at Olympic Dam is subject to regulation by South Australian government authorities, and is implemented on site by specialist WMC radiation safety staff. The National Health & Medical Research Council, Worksafe Australia and the International Commission on Radiological Protection (ICRP) recommend an effective dose limit of 100 mSv over a period of five consecutive calendar years, with a maximum of 50 mSv in a single year. This equates to an average limit of 20 mSv/yr for designated workers. WMC has adopted an internal individual target limit of 10 mSv/yr.

Radiation safety staff conducted an ongoing radiation monitoring programme for the construction workforce, the details of which were the subject of a separate information handout for each worker. Radiation safety was also addressed during the induction of the workforce prior to their commencement on site. No person is permitted to commence work on site at Olympic Dam without having been inducted.

3.13. Monitoring and audit

Monitoring and inspection of construction activities and Constructor's environmental management practices were undertaken throughout the construction period.

The monitoring was to ensure compliance with the ECP and requirements of environmental clearances and of site rehabilitation and restoration progress.

4. DESIGN CRITERIA

4.1. Aim and philosophy

The aim of the Design Criteria document was to provide direction on the operational occupational health, safety and environment standards for the expanded facilities at the design stage. It takes into account many years of operational experience at Olympic Dam and is designed to be a practical guideline for ensuring compliance with all relevant legislation, commitments of the EIS and to specify the standards to be met for WMC facilities.

The philosophy used in the document is to involve formal hazard management consisting of three integrated components. Hazards must be identified, their magnitude must be quantified and then they must be controlled as appropriate. Quantification is essential as it provides the justification in the control stage. Control can take three forms:

(1) designing the facilities to design out, as far as practicable, occupational or environment risks.
(2) using safe working systems and procedures that minimize risks.
(3) using personal protective equipment that controls impacts if risk situations occur.

The document provides a formal framework for considering workplace and environmental hazards.

Matters for specific consideration for the Mine and the Process Plant design are covered in the document and summarized below.

4.2. Legal requirements

The Design Criteria document outlines the legislation requirements to be met for Occupational Health and Safety and General Environmental Duty.

4.3. General safety and hazards

4.3.1. Design criteria document approach

In relation to General Safety the Design Criteria considers:

(a) plant layout design
(b) working procedures
(c) safety equipment
(d) manual handling and heat stress
(e) lighting and vibration equipment
(f) equipment guarding and machine guards.

Types of Hazards that can be present at Olympic Dam are listed and categorized as acute exposure hazards and chronic exposure hazards. Chronic hazards are those that are liable to be detrimental to health following long term exposure, and acute hazards are those that may produce immediate traumatic injury.

4.3.2. HAZOPS

The Design Criteria document detailed the philosophy of the approach to plant design to minimize chronic and acute hazards, and was complemented by a two stage Hazard and Operability study (HAZOP) process.

The first stage (preliminary) HAZOP was undertaken during the preliminary design, and identified the key chronic and acute hazards in all sections of the mine and plant, and potential control methods. The identified potential hazards from the preliminary HAZOP were reported on in the EIS.

During the detailed design stage remedial measures were adopted into the design to ensure that the exposure to workplace hazards was minimized. As part of the detailed design, detailed HAZOPS were conducted for each section of the plant, and also for tie-in of the various plant sections.

These HAZOPS adopted the practice of an external facilitator with extensive experience in the conduct of HAZOPS, together with a team comprising design engineers, operational engineers and others. The HAZOPS were open meetings and any personnel with an interest or something to contribute could attend. Some of the HAZOPS were conducted by videoconferences to ensure that all personnel with potential input to the HAZOP were accommodated.

Regulatory authorities were kept fully informed of the HAZOP schedule and in fact were invited to attend and participate in any HAZOP sessions they wished.

4.4. Mine

4.4.1. Fire suppression

This section of the document covers where fixed fire detection and fire fighting equipment should be located and the requirements for fuel storages and conveyor fire suppression systems.

4.4.2. Dust control

The general approach to dust control in the Mine is, in order of precedence, to:

(a) suppress formation of contaminant
(b) confine or isolate contaminant
(c) ventilate to remove that which escapes.

In special circumstances, personal respiratory protection is specified.

4.4.3. Radiation control

The As Low as Reasonably Achievable (ALARA) philosophy is adopted.

The principal means of providing radon daughter control is to be by:

(a) providing a sufficient flow of air to control levels
(b) keeping the transit time of air through the mine to workplaces as low as possible to reduce formation
(c) designing permanent working locations on the intake side of sources
(d) bulkheading or backfilling worked out areas.

The design limit for radon daughter concentration in occupied workplaces is to be less than 1.0 $\mu J/m^3$.

Gamma dose is to be reduced by considering:

(a) minimization of exposure time
(b) maximising distance of operator from ore
(c) interposition of shielding between source and personnel
(d) keeping personnel away from high grade ore intersections except for specific production tasks
(e) locating permanent access drives and ramps in waste or low grade material where reasonable.

The Design Criteria proposes 10μGy/h as the level at which use of protective measures is to be reviewed, should personnel be required to spend their working time in the location for extended periods. Control measures would include use of remote controlled mining equipment.

4.4.4. Noise control

Occupational exposures to noise should be as low as reasonably achievable and below any regulatory requirements. The site operates on a 12 hour shift basis, which reduces the applicable limit for noise exposure to operators from 85 dB(A) to 83 dB(A).

The goal for noise to operators is 80 dB(A) or less. Where this is not achievable, as a last resort, hearing protection may be used for noise control with areas requiring it to be clearly signposted. Operator cabins and control rooms are to be sound proofed so as to ensure noise levels are less than 80 dB(A).

4.4.5. Ventilation and mine planning

The general approach specified is that ALARA principles be adopted and that the mine ventilation system is to be designed within these principles and to more than meet standards set by all the relevant statutory authorities in relation to concentrations of radon daughter products, diesel fumes, blasting fumes, dust and the maintenance of satisfactory working conditions underground.

4.5. Process plant

4.5.1. Spillage control and cleanliness

Cleanliness of the facilities is of vital importance for maintaining occupational hygiene, radiation protection, safety standards and environmental standards. The ability to clean and to keep clean all plant is an explicit aim of all engineering design.

The general principles of spillage control are:

(a) design to reduce the probability of spillage
(b) containment of the potential contamination
(c) collection of any spilt contaminants.

4.5.2. Dust control

Similar to requirements for the Mine, with design criteria for respirable dust in the workplace set at 0.5 mg/m^3 thus ensuring compliance with the Worksafe Australia exposure standard for silica.

4.5.3. Fire suppression

Similar to Mine for fire detection and fire fighting and with the requirement that the plant layout should allow clear access and escape routes that are high and wide enough for fire, rescue and ambulance vehicles.

4.5.4. Noise control

Similar to Mine requirements.

4.5.5. Radiation control

Past experience and monitoring has demonstrated that exposure to radon daughters is insignificant in the Process Plant. Gamma radiation has been found to be only significant in areas of bulk storage of radioactive material. These areas are the yellowcake storage shed, and the slag handling areas. The storage of these materials is to be in areas away from permanently occupied areas or areas frequented by personnel.

Airborne radiation contamination should be controlled by the measures outlined for dust control.

4.5.6. Workplace contaminants

The Design Criteria required that facilities be designed and engineered to prevent the release of contamination into the work environment but recognized that this may not be achievable in all cases. As a design rule, all workplace contaminant concentrations should be as low as reasonably achievable and certainly within any recognized limits.

The exposure standards defined under the Worksafe Australian Standard for Exposure Standards for Atmospheric contaminates in the Occupational Environment are used as maximum concentrations with design goal to be for no more than 25% of these levels.

For all processes a formal risk assessment procedure must be followed to:

(a) identify all potential emission source locations

(b) identify all potential contaminants from the sources
(c) make an assessment of workplace concentrations
(d) select appropriate control mechanisms, if required, to ensure that workplace concentration levels meet the design goals.

4.5.7. Stack emissions

The EIS and the State's Environmental Protection Act required that "…all reasonable and practicable measures to prevent or minimize any environmental harm…" must occur. To formalize this process a risk assessment procedure must be followed for all sources of airborne pollution. The process is to:

(a) identify all potential emission source locations
(b) identify all potential contaminants and characteristics
(c) make an assessment of emission quantities and ground level concentrations of all potential contaminants and the frequency of such occurrences
(d) select appropriate control measures to ensure that emissions comply with levels set below regulatory limits.

4.5.8. Tailings disposal

After consideration of alternatives the design of the tailings disposal facility continued the previous practice of conventional paddock systems with a lined centre decant draining excess liquor to separate evaporation ponds. As previously it was intended that a portion of the tailings be deslimed and used in the mine backfill facility, the target for this amount was set at 20% of the total. The design criteria included the need to:

(a) limit radon flux while the disposal systems are being used
(b) limit the lift-off of dust from the tailings surface during the operation of the TSF
(c) ensure that the rehabilitated structures remain intact under climatic and seismological influences in the very long term
(d) limit the quantity of radon released from the surface of the rehabilitated structures in the very long term
(e) limit the contamination of underlying aquifers in the very long term
(f) ensure that accidental intrusion into the tailings repository is avoided in the very long term.

5. RESULTS

The effectiveness of the processes used in design and construction of the expanded facilities is indicated from the results of radiation monitoring and accident frequency rate measurements.

For the period 1/7/98 to 30/6/99 assessment of employee radiation doses has shown that no designated employee received more than 50% of the annual dose limit of 20 millisieverts. The annual average dose to all designated employees was 1.9 millisieverts with a maximum of 9.2 millisieverts.

The site wide Lost Time Injury Frequency Rate (LTIFR) is approximately one third of the National Industry average.

It should be noted that the operation of the mine and plant is covered by a comprehensive Environmental Management System, which includes quarterly review with the authorities and submission of an annual report. The Design Criteria document and ECP's used in the design and construction of the Expansion complemented this EMS.

Environmental impact of the Ranger uranium mine, Alligator Rivers Region, Northern Territory, Australia

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Abstract. Stringent environmental controls have been applied to the Ranger mine, in the Northern Territory of Australia, because of its location in an area of outstanding natural and cultural values. The adjacent Kakadu National Park contains a wild and extensive biodiversity, striking landscapes, ancient Aboriginal rock art and a living Aboriginal culture. A special regime of biological, radiological and chemical monitoring has been applied to protect the environment and detect even very low intensity impacts. The results from this regime demonstrate to the government and general public that the high conservation values of the national park around the mine are being properly protected. This paper describes the techniques used to measure environmental impact at Ranger, and summarizes the results of over 20 years of monitoring. The overwhelming conclusion is that a very high standard of environmental protection has been achieved.

1. INTRODUCTION

For twenty years, uranium has been mined and milled at the Ranger mine within an area that is surrounded by Kakadu National Park (Fig. 1), around 12^{o}S in the wet/dry tropics. The region includes deeply dissected sandstone plateau and escarpments, falling to gently undulating sandy lowlands, drained by rivers which are tidal for over 60 km inland and which have extensive floodplains inundated by several metres of brackish water during the wet season. Ranger mine, about 70 km from the coast, is about 20–25 m above sea level.

The national and international importance of Kakadu has been recognized by its inclusion on the Register of the National Estate and its inscription on the World Heritage List [1]. The flood plain areas within Kakadu are recognized as one of Australia's Wetlands of International Importance listed under the Convention on Wetlands of International Importance. Much of the land in the region, including the land on which the Ranger deposits were found, has been recognized as part of the traditional estate of the Aboriginal people of the region. For these reasons, operation of the mine has been subject to a rigorous system of regulation and supervision [2].

Both state and federal governments (i.e. Northern Territory and Commonwealth) have roles in environmental management. The mine is regulated by the Northern Territory Government's Department of Mines and Energy, whilst the Commonwealth stipulates the overall environmental standards, oversees environmental practice by the company and application of regulation by the NT government, and develops monitoring techniques

The environmental impact study for Ranger [2] identified that the significant risks from the mine would be from chemical contamination of surface and groundwater, and airborne and waterborne radionuclides. A special concern arises from Aborigines who maintain a traditional lifestyle near and downstream of the mine, potentially exposing them to direct emissions from the mine, higher chemical or radionuclide exposures through bioaccumulation in foodstuffs and ingestion of soil and dust.

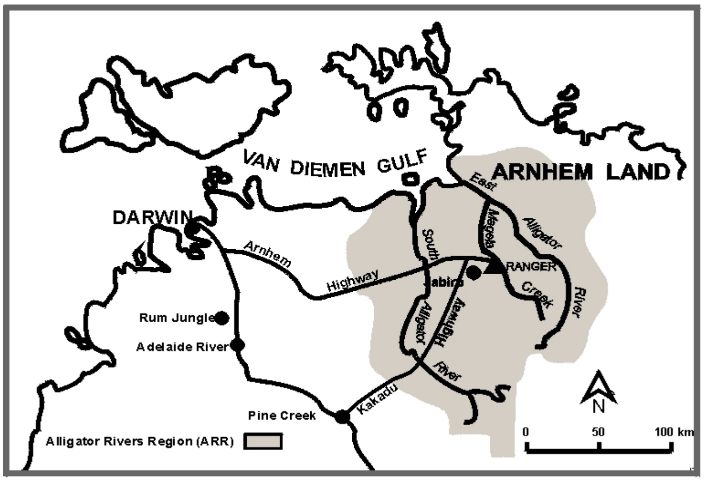


FIG. 1. The Alligator Rivers Region, and location of the Ranger mine.

2. WATER MANAGEMENT SYSTEM AND CONTROL MEASURES

Water at Ranger is managed to reflect the potential for it to become contaminated (Fig. 2). The 'Restricted Release Zone' is the area where water may come in contact with rock containing more than 0.02% U (i.e. water from the mine pit, runoff from the ore stockpiles and mill site, process water, and tailings water). The 'Non-Restricted Release Zone' comprises undisturbed areas and waste rock dumps with less than 0.02% U.

Water from the non-RRZ is allowed to overflow into tributaries of Magela Creek, north of the mine site, subject to checks on water quality prior to overflow and the local community being informed. Excess water from the RRZ is disposed of by irrigation onto remnant native bushland within the mine project area, by treatment in constructed wetland filters, and by enhanced evaporation techniques.

Water in the process circuit (i.e. mill water and tailings water) must be totally contained. It is recycled through the mill and is lost by evaporation in the tailings repositories (i.e. tailings dam and pit No.1) and in the milling process.

3. WATER QUALITY STANDARDS IN THE RECEIVING WATERS

The control regime at Ranger comprises measures to protect aquatic ecosystems and people; and a monitoring program to assess the adequacy of the control measures. The monitoring program uses a mix of chemical, biological and radiological techniques.

The chemical controls consist of a set of standards, which set the maximum allowable increase in the concentration of contaminants in the waters of the adjacent Magela Creek. There are also limits on the total loads of chemicals. These chemicals were chosen after careful assessment of the chemistry of ore and waste rock and substances used in the milling process and consideration of the US EPA recommendations for the development of water quality standards [3].

Preliminary standards were derived considering the natural fluctuations of water quality in the creek. A detailed toxicological assessment was made for those substances that could give rise to concentrations outside the bounds of natural variation. A × 10 factor of safety was then added to provide a very high level of assurance against biological impacts.

In addition to these chemical standards, the rate of water release is controlled so that the dilution by creek water is greater than a minimum value determined by toxicological tests. These tests determine the lowest concentration of the effluent in creek water at which a change is detected for some sensitive

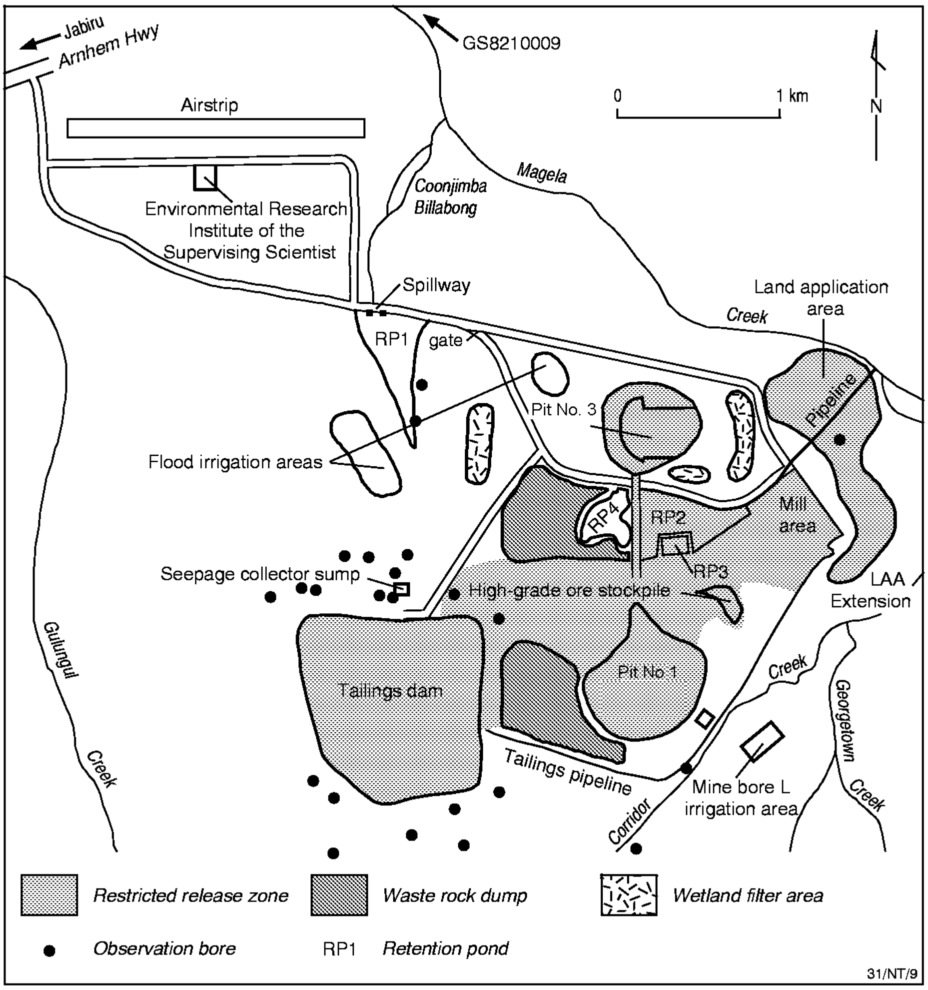


FIG. 2. The principal features of the Ranger water management system.

measure of the animal's health (the [1]LOEC) and the highest concentration at which no effect is observed (the [2]NOEC). The geometric mean of the lowest NOEC and LOEC values for the three species tested is then divided by a safety factor of 10 to obtain the minimum dilution rate for the effluent. Nineteen species of local aquatic animals and some plants were tested to determine those most sensitive to change yet amenable to laboratory breeding and maintenance [4]. The actual minimum dilution factor required for effluent released to Magela Creek would be the larger of the factors determined by these chemical and biological procedures.

4. MONITORING SYSTEMS

The mining company carries out a comprehensive monitoring regime, and check monitoring is done by the government authorities. The company must collect data for key points on and around the mine site for both surface and ground waters, analyse these data, and investigate any divergences or trends. If there is any risk of contamination passing outside the mine project area, intensive monitoring requirements come into force; for example, if a release of RRZ water were to be allowed into Magela Creek in the future, a full chemical analysis of the effluent water prior to release would be required, plus daily measurements in the first week of release and once weekly thereafter, and daily measurements of upstream and downstream water quality in Magela Creek and one week after release ceases.

[1] LOEC - Lowest Observed Effect Concentration
[2] NOEC - No Observed Effect Concentration

A number of biological monitoring methods have been developed to demonstrate whether the aquatic ecosystem is being fully protected [4]. These techniques are: (a) creekside tests that enable a short term assessment of the impact of release, and (b) population and community structure tests that assess the long term impact of the mining operation on aquatic ecosystems.

In the **creekside** tests, species of fish (*Melanotaenia nigrans*) and freshwater snails (*Amerianna cumingii*) are exposed to water collected from upstream and downstream of the mine site. The tests look for any differences in larval survival for the fish species and egg production and juvenile survival for the freshwater snails.

The **community structure** of macroinvertebrates is studied and differences compared with observations from control streams (i.e. away from mining areas). In addition, macroinvertebrate communities are monitored in water bodies on the Ranger site, in unaffected billabongs near the mine in Magela Creek and other catchments. Fish community structure observations are also made at sites on and off the Ranger lease and compared with similar observations from creeks unaffected by mining. Finally, counts of migrating fish in Magela Creek are made each Wet season.

5. ASSESSMENT OF IMPACTS

5.1. Chemical impacts

The concentrations of the principal contaminants in Magela Creek downstream from the mine are compared with the recommended standards in Figs. 3 and 4. The recommended standard is shown as a solid line.

Sulphate concentrations increased steadily over the first ten years of mining because of runoff from the waste rock piles into Magela Creek via the seasonal settling pond overflows. Improved on-site catchment management led to a reversal of this trend. The observed concentrations have always been at least a factor of ten lower than the recommended standard. A similar pattern is observed for magnesium, where the maximum observed concentrations are lower by a factor of five than the recommended standard for protection of aquatic ecosystems.

The maximum concentrations of uranium increased slowly until 1991. The origin of the higher values in 1991 was an accidental overflow of a bund around the high-grade ore stockpile. The bund was subsequently re-engineered to divert any future overflow to the mine pit. The maximum value recorded in 1996 was from sample contamination. In all years, the maximum concentrations of uranium have been lower than the recommended standard by at least a factor of five.

5.2. Biological impacts

In the creekside tests, species of fish (*Melanotaenia nigrans*) and freshwater snails (*Amerianna cumingii*) are exposed to water collected from upstream and downstream from the mine. The tests look for any differences in larval survival for the fish species and egg production and juvenile survival for the freshwater snails [5].

Fish larval survival at both sites was between 80% and 95% with a relatively low variability (Fig. 5). The difference index between the upstream and downstream responses is also plotted; the mean value of the difference is approximately zero and the spread of differences from this mean are not statistically significant. Periods of mine effluent discharge (indicated on the graph as 'RP4 release') had no effect on the survival of larval fish. The data for snails show that there is quite a significant natural variation in their egg production rate; patterns of variability at the two sites are similar and not statistically significant, indicating the effluent release had no detectable effect on the reproductive rate of freshwater snails.

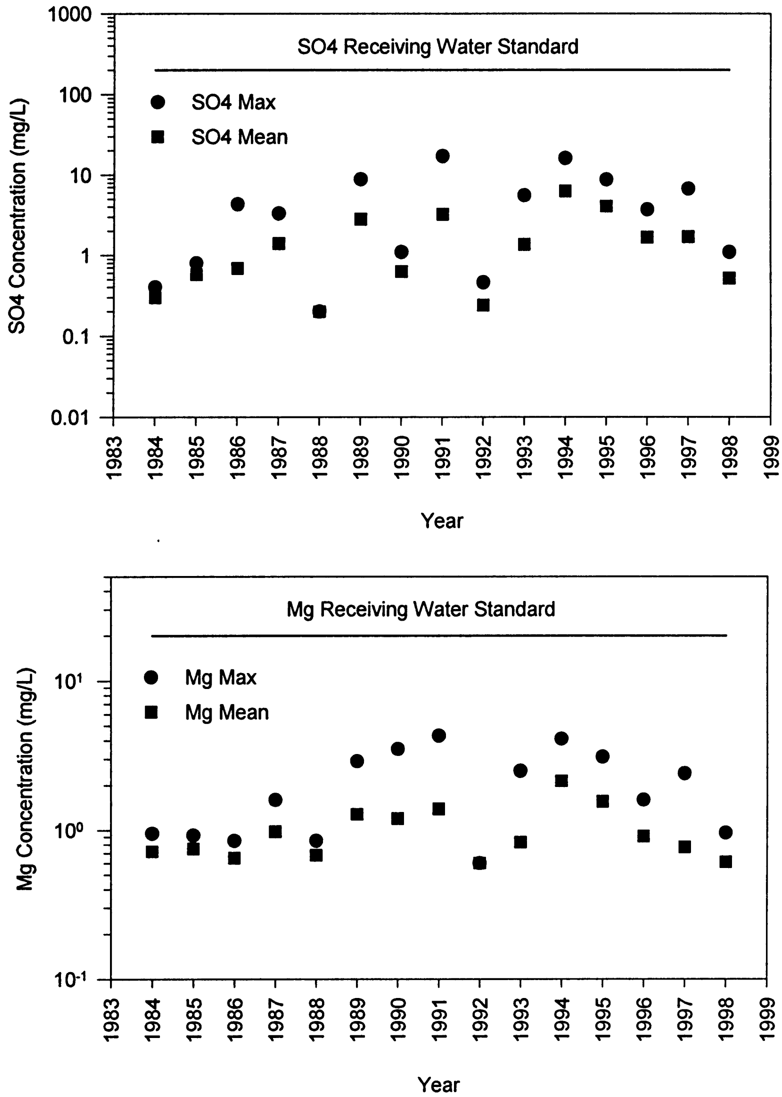


FIG. 3. Comparison of sulphate (upper graph) and magnesium (lower graph) concentrations at gauging station GS8210009 downstream from the Ranger Mine with the receiving water standard recommended by the Commonwealth. Note the logarithmic scale.

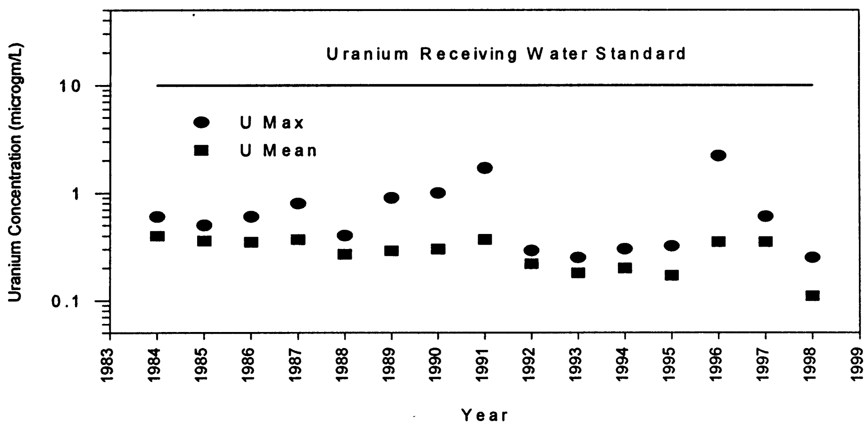
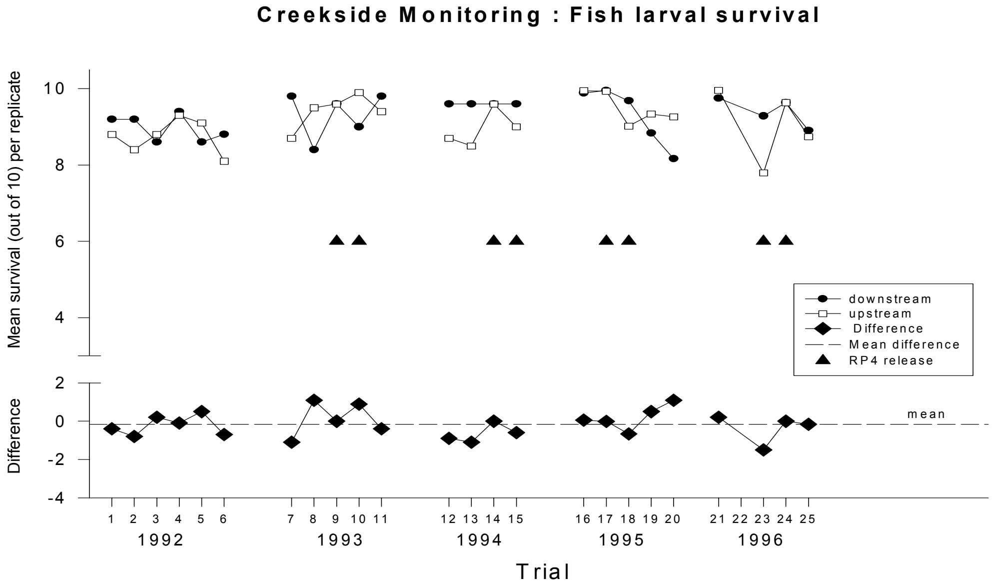


FIG. 4. Comparison of uranium concentrations downstream from Ranger and the receiving water standard required by the Commonwealth. Note the logarithmic scale.



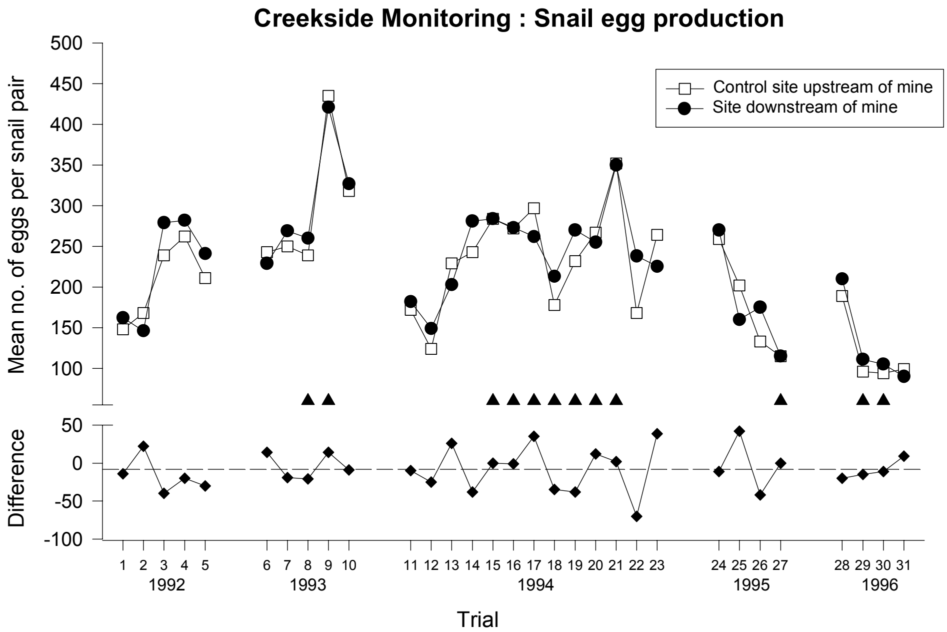


FIG. 5. Biological monitoring using fish larval survival (upper graph) and freshwater snail reproduction (lower graph) from sites upstream and downstream of the mine. Difference indices also shown. Periods of effluent release indicated by triangles.

Macroinvertebrate communities have been sampled at the end of significant Wet season flows. Data for the 10-year period 1988–1997 are shown in Fig. 6 and expressed as dissimilarity measures, which range from 0 (the taxa and relative abundances of two samples are identical) to 1 (nothing in common)[6]. Dissimilarity results are shown between the upstream and downstream sites over time (lower graph), and between consecutive years at the upstream site (upper graph). The dissimilarity index between the upstream and downstream sites is smaller than the natural variation at the upstream site. Hence, any change in community structure that has occurred downstream from the mine is not ecologically significant and may have been due to natural variability.

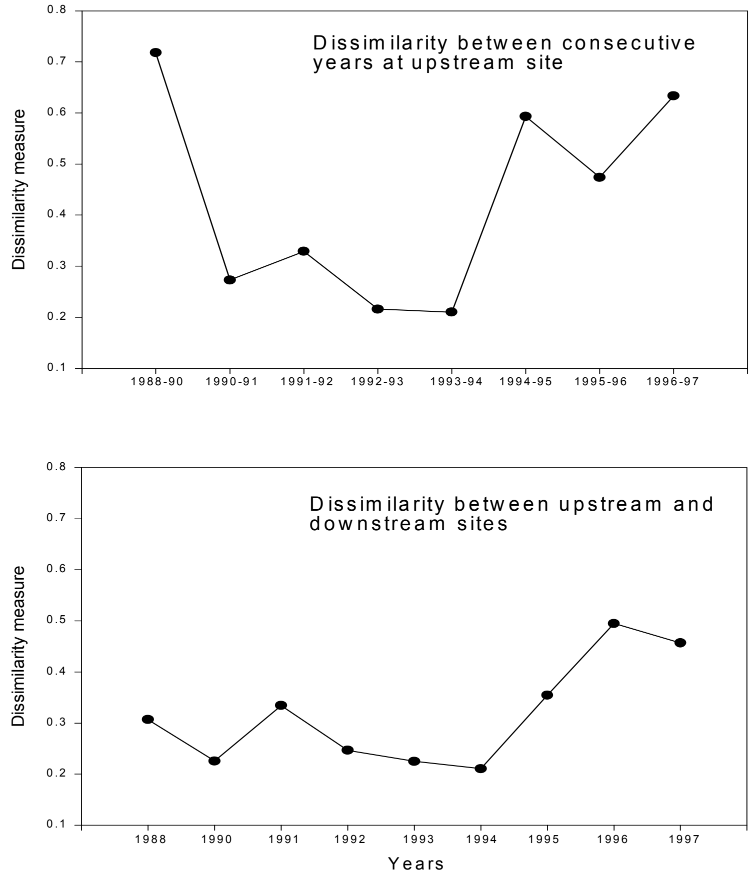


FIG. 6. Dissimilarity (using the Bray-Curtis measure) in macroinvertebrate community structure in Magela Creek over time at an upstream site (upper figure), and between upstream and downstream sites (lower figure). Family-level data analysed.

In addition to these studies, work has also been conducted on fish migration patterns and fish community structures which indicate that no effects are detectable on the dominant fish species of the region [7].

5.3. Radiological impacts

5.3.1. Impacts on humans from aquatic pathway

Radiation exposure of people can only be measured directly by the use of intrusive techniques such as the analysis of urine and faeces samples and whole body monitoring. The estimated doses received by people are so low that they could not be detected by these methods and their use is therefore not justified. For this reason, radiation exposure of members of the public is calculated, not measured.

Release of radionuclides into the surface waters downstream from the mine does not give rise to enhanced concentrations in drinking water for the non-Aboriginal population of the region since the local potable supply is derived from groundwater bores that are unaffected by mining. The major effect of such releases is increased concentrations of radionuclides in aquatic flora and fauna through bioaccumulation. As Aboriginal people consume traditional foods from the creek system downstream of the mine, they constitute the 'critical group'. In the case of the aquatic pathway, doses are calculated by modelling the physical transport of radionuclides in the surface water system, estimating the uptake of these radionuclides in aquatic flora and fauna, using the diet of the critical group to estimate the total intake of each radionuclide and converting this ingested intake into radiation exposure. Wherever

uncertainties exist, conservative assumptions have been made; e.g. it is assumed that 70% of all food consumed by the people concerned is derived from traditional hunting and fishing. This is certainly an overestimate.

Radiation doses have been calculated by:

- modelling the physical transport of radionuclides in the surface water system;
- estimating the uptake of these radionuclides in aquatic flora and fauna; and
- using the diet of the critical group to estimate the total intake of each radionuclide and converting this ingested intake into radiation exposure.

The annual intake, I_i, of the i^{th} radionuclide of the uranium series by a member of the critical group resulting from the discharge of a total quantity, Q_i, of that radionuclide during the wet season has been calculated [4] using the expression $I_i = U_i Q_i$

where the intake per unit release, U_i, is given by $U_i = k_w \sum_j m_j T_{ji} + k_s \sum_r m_r T_{ri}$.

The sum over j includes all aquatic foods of mass m_j consumed per annum by members of the critical group and the sum over r includes terrestrial foods of mass m_r. The coefficients T_{ji} and T_{ri} are the corresponding concentration factors; k_w and k_s are coefficients derived from the physical transport model. The maximum quantity of each radionuclide that may be released each year, L_i, is given by $L_i = A_i / U_i$

where A_i is the ingested intake of the radionuclide that would give rise to an exposure of 1 mSv obtained using ICRP recommendations [8]. Since releases of a number of radionuclides would occur at the same time any release of water is subject to the restriction $\sum_i (Q_i / L_i) \leq 1$.

The relative significance of the various food items with respect to radiation exposure is indicated in FIG. 7. The main potential dose is contributed by freshwater mussels, followed by fish and water lily roots. The exposure via freshwater mussels relates to the bioaccumulation of radium [9].

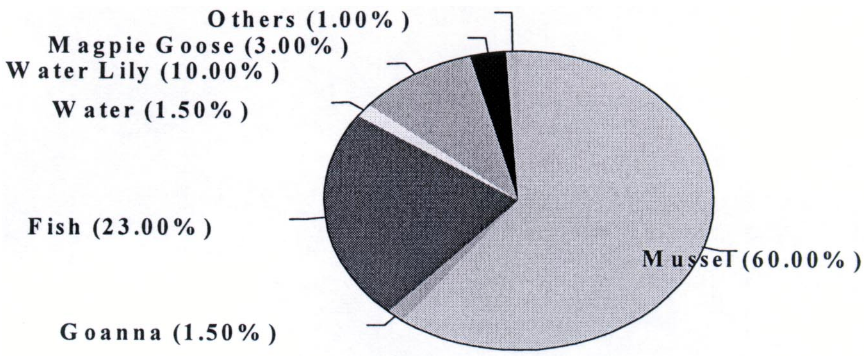


FIG. 7. Contributions to radiation dose from the traditional diet of Kakadu region Aborigines [10].

5.3.2. Impact on humans from atmospheric pathway

As radon can disperse over large distances from the point of emanation, its atmospheric concentration at a location several kilometres from a mine could be due both to radon sources associated with the mining project and to natural background sources. Therefore, the contribution from these two sources needs to be distinguished because the regulatory dose limits apply only to the contribution from the mine-related source. The need to make this distinction becomes important when the combined radiation dose due to both mine-related and natural sources exceeds the prescribed limit, as is the case at Ranger.

Mine-related and background radon levels can be discriminated by comparing radon and radon progeny concentrations from wind sectors containing only the natural background sources, against those from wind sectors containing both background sources and mine-related sources [10]. A

simplified version of the method is used to estimate public doses from Ranger (Fig.8, lower graph) [7]. The radiation exposure of members of the public living in the vicinity of Ranger due to the dispersion of radon and its progeny from the mine has always been less than 10% of the recommended dose limit. Similar methods have been used to determine the dose due to dispersion of radionuclides in dust from the mine, which is about 5% of the recommended dose limit.

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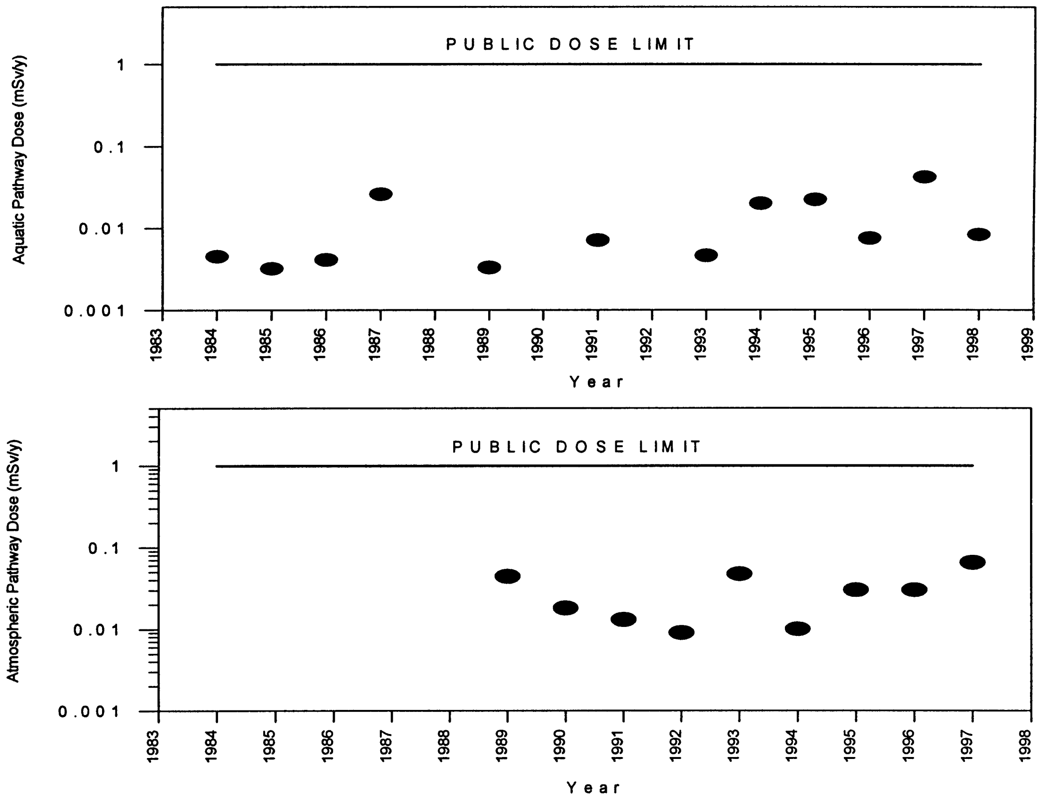

FIG. 8. Radiation exposure of members of the public resulting from the Ranger mine via the aquatic pathway (upper graph,) and the atmospheric pathway (lower graph). Note logarithmic scale.

5.4. Specific incidents at Ranger and their impacts upon the environment

The operator of the mine is required to report to the supervising authorities any significant environmental events or incidents that have the potential to cause adverse impact on the environment surrounding the mine; cause harm to people living or working in the area; or cause concern to traditional owners or the broader public. All such incidents are assessed by the Supervising Scientist and are reported in his annual report to the Australian Parliament.

Over one hundred incidents have been reported and investigated since 1979. None has been judged to have any lasting environmental impact; two resulted in short term impact [4]. One involved spillage of yellowcake onto a worker in the packing facility (1982), and the other was a spill of diesel into a pond of RRZ water (i.e. water contaminated with U) in 1995 which killed 40 water birds. The Supervising Scientist concluded that this was the first unacceptable environmental impact that had arisen as a consequence of operations at Ranger.

5.5. Long term environmental protection issues

Concerns are sometimes publicly expressed about the likelihood of future environmental impact particularly with respect to seepage of contaminants from tailings repositories and the long term dispersal of the radioactive tailings themselves.

Following rehabilitation, all tailings will be below the surface of the natural landscape with the highest point of the tailings mass many metres below the surface and no higher than mean sea level. The erosional stability of landforms at Ranger have been assessed as in the order of millions of years. As the effective radiological half-life of the radionuclides in the tailings is about 77 000 years, the radioactivity of the tailings will have decayed away before any risk of the tailings mass being exposed and dispersed by erosion. Hence, from the perspective of tailings dispersal, the rehabilitated Ranger site does not represent a long term environmental risk.

The long term dispersal of contaminants via seepage into groundwater is not expected to be a significant hazard. The tailings will be placed in the mined-out pits which will be treated (by grouting, the use of filter beds etc) to minimize interaction between the tailings pore water and the fractured rock groundwater aquifer of the Ranger region. The waste rock used in the construction of the rehabilitated landform at Ranger is, unlike that at many other mines, very low in sulphur. No significant impact from sulphate or acidity is expected to occur in the long term.

A thorough assessment of the probable long term impact arising from the dispersal of radionuclides in seepage from the mine pits requires detailed hydrogeochemical measurements and modelling. However, a relatively straightforward but conservative estimate can be made by calculating the rate at which any substance leaves the tailings repository (using typical ground water velocities and tailings pore water concentrations) and determining the increase in the concentration in the waters of Magela Creek using typical volumes of water flowing in the creek. This calculation yields a dilution of about 1000:1.

The concentration of radium in tailings waters is higher than the natural concentrations in Magela Creek by a factor of about 1000. On this basis, any seepage to Magela Creek will have a radium concentration similar to naturally occurring concentrations once it is diluted in the creek. However, this estimate is highly conservative since it takes no account of the very significant levels of adsorption of radium on the rocks of the aquifer, and the fact that the permeability of the tailings is much lower than that of the aquifer. It also assumes that all solutes in groundwater from the tailings repository reach the creek near Ranger rather than much further downstream or even in the sea.

6. CONCLUSION

The adequacy of the environmental protection regime at Ranger been assessed by extensive chemical, biological and radiological monitoring programs which have been continually upgraded to take into account the results of new scientific research. The chemical monitoring program has shown that contaminant levels in the receiving waters have remained below stringent regulatory standards throughout the entire period of mining, and have been significantly below the concentrations predicted by the Ranger environmental impact study [2]. Biological monitoring has shown that the mine has had no detectable impact on a range of sensitive indicators of ecological health including the survival of larval fish, the reproduction of freshwater snails, the migration patterns of fish, and the community structure of fish and macroinvertebrates. The radiological monitoring program has shown that the radiation exposure of people living in the vicinity of the mine, either through consumption of foods collected from downstream waters or through radon dispersed from the mine site, has always been significantly lower than the internationally recommended limit on radiation exposure of members of the public.

The operation of a mine cannot be conducted without there being limited spatial and temporal impact on the environment. The environment on the mine lease itself is certainly disturbed but the objective

of any environmental protection regime is that there be minimal impact off-site and that this impact is within standards that are set to ensure a high level of environmental protection. A number of incidents have occurred at the mine, but none has had any lasting impact on the people, biodiversity or landscapes of Kakadu National Park.

The overwhelming conclusion is that mining and milling operations have been conducted in a manner that has enabled a very high standard of environmental protection to be achieved for the environment, landscape and people of Kakadu National Park. World's best practice rehabilitation planning is expected to preclude any significant radiological and ecological long term impact from the site and the post-mine buried tailings mass.

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Role of continual environmental performance improvement in achieving sustainability in uranium production

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Abstract. Although the term sustainable development is commonly used today, there is not yet a commonly accepted definition. Various ways of measuring sustainability have been proposed. To show how these issues are being effectively addressed in modern uranium developments, we will review some methods of defining the environmental component of sustainable development in the mining and mineral-processing sector. Environmental impacts associated with uranium extraction and processing in modern facilities are modest. Air and water emissions are well controlled. Waste materials are subject to comprehensive management programmes. The size of the impacted area is smaller than in other energy sectors, providing good opportunity to minimize land impact. Experience over the past three decades facilitated gradual, persistent, but cumulatively significant environmental improvements in the uranium production sector. Cameco's uranium mining and processing facilities exemplify these improvements. These improvements can be expected to continue, supporting our argument of Cameco's environmental sustainability.

1. SUSTAINABILITY IN A URANIUM PRODUCTION CONTEXT

The term "sustainable development" is simply a modern name for a long-standing practice. At Cameco, we call it responsible management. Sustainable development refers to meeting the needs of the present without compromising the ability of future generations to do the same.

In reviewing the sustainability debate as it is currently being played out, we are struck by two observations:

(1) The issues related to uranium production have changed little over the past three decades. There seems to be little acknowledgement (or interest) from over-detractors about how these issues have evolved since the 1970s.
(2) Nuclear advocates are generally supportive of the view that material human progress is both a desirable and a sustainable goal.

At Cameco, we both mine and process uranium, so we can examine sustainability in one of two ways: either as part of the nuclear power sector or as part of the mining and mineral processing sector. Because they involve non-renewable resource extraction, mining and milling practices have often been challenged for their sustainability. This posture assumes that we want to preserve the resource itself for future generations, and that the need for that preservation is known.

Most definitions of sustainable development, however, encompass what has become known as the triple bottom line: economic growth, environmental balance and social progress. In other words, to be classified as sustainable, we must integrate economic development, environmental, and social growth needs to produce viable business opportunities.

We will show that today's uranium mining and processing follow the principles espoused in sustainable development. In particular, we will focus on the environmental aspect of the triple bottom line.

Uranium production is environmentally sustainable, largely because it generates a clean energy fuel with very little environmental impact. The high energy content of this fuel, combined with relatively low volume of materials used during its mining and processing, and the fact that this natural resource has no significant commercial application other than energy production, gives it inherent advantages in a sustainability context. As well, the size of the impacted land area, or footprint, associated with a modern, high-grade uranium mine facility is relatively small. For comparison, contrast the energy content of uranium either already mined or in projected reserves and resources with the energy content of the coal from a modern, higher-grade, surface coal-mining facility. Since it is home to the largest US coal operations, we will look at the Powder River basin of Wyoming, USA.

Source	Site	Energy Density (J/ha)
Nuclear	McArthur River	8×10^{17}
	Key Lake	5×10^{16}
	Rabbit Lake	3×10^{16}
Coal	Powder River basin	3×10^{12}

These numbers are only order-of-magnitude estimates. They do not include thermal losses in conversion from heat to electricity, nor transportation and material-processing energy consumption. The estimates are based on disturbed surface lease size and total proven and indicated material reserves and resources. The extent of land disturbance for coal has not been factored in, but it is likely higher than the 8, 22, and 34% of leased land disturbance associated with McArthur River, Key Lake, and Rabbit Lake respectively. Nevertheless, the estimates demonstrate nuclear's much higher energy density, which in itself can be environmentally advantageous when coupled with good environmental controls.

Table I summarizes some generic issues surrounding the nuclear sustainability debate.

If we look at uranium production as an entity within the mining and mineral-processing sector rather than in the nuclear sector, we can effectively compare its environmental sustainability efforts with other organizations in the mining sector. Placer Dome Inc, a major Canadian mining company which focuses on gold and operates 15 mines in six countries on four continents, offers a good comparison. Table II summarizes Placer Dome's six sustainability commitments. Table III summarizes Placer Dome's key environmental sustainability issues and reporting indicators.

As the following details demonstrate, if we compare our efforts in environmentally sustainable mining development to that of Placer Dome, we find that:

(a) General mining-sector sustainability commitments are not outside the range of commitments of modern uranium developments.
(b) Priority sustainability issues associated with gold mining are very similar to those associated with uranium production. In effect we, too, are focusing on what others would call general sustainable mining issues.

Why is this sustainability issue of interest to the uranium production sector?

(a) Sustainable development is a significant current trend. Various governments are attempting to structure their economic and social policies on development within this framework.

TABLE I. EXAMPLES OF ECOLOGICAL SUSTAINABILITY ISSUES IN NUCLEAR FUEL PRODUCTION

Issue	Response
Uranium production breeches the principle of intergenerational equity, largely because of the toxicity of its wastes.	Modern tailings and waste rock management plans coupled with decommissioning financial assurances address future liability.
Uranium production breeches the precautionary principle. Uncertainty about long term impact should prevent current activity.	While more research into long term impact is always a good idea, there is sufficient information to make reasonable predictions.
Uranium production has an unacceptable level of ecological risk.	Modern uranium production is a well-controlled enterprise.
Nuclear fuel chain is a significant source of CO_2 emissions.	Nuclear emission inventories show very modest CO_2 contributions whereas worldwide fossil fuel emissions contribute 20 000 million tonnes of CO_2 annually
Money invested in nuclear power development diverts limited funds from more effective means of combating global warming – such as energy efficiency measures.	Conservation is important, but growth in high-reliability energy demand is inevitable.

TABLE II. SUMMARY OF PLACER DOME SUSTAINABILITY COMMITMENTS

- Regularly assess environmental conditions (address priority issues).
- Provide for effective involvement of communities (develop public participation).
- Establish credible monitoring and verification programmes (analyze, verify and report data).
- Provide training and resources to develop employees (continuous learning).
- Conduct or support research programmes (research alternatives for sustainability priorities).

Work actively with government, industry and stakeholders to improve public policy, laws, and regulations in support of sustainability (global leadership).

(b) Positioning ourselves within this framework will impact our growth potential, could make regulatory assessment and approval processes faster, and will make us more desirable development partners in the eyes of local communities, bankers, and other business partners. Arguably, this position could also broaden public acceptance and support.

(c) Over the next few years, a programme that certifies mining operations with global sustainability standards may develop. If this occurs, uranium production activities may be judged against these standards. However, it is possible that some will want to exclude uranium from the sustainability in mining debate because of philosophical differences

regarding the role of nuclear power. Similar attempts at exclusion occurred in the global warming debate. We should resist such attempts because uranium mining is a sustainable undertaking.

(d) Discussions about environmental sustainability are in part discussions about improving environmental performance. These discussions stimulate positive change within an organization, encourage a culture of improvement, and provide concrete examples of managing complex issues.

(e) We should consider structuring our public reporting requirements to follow sustainability reporting guidelines. Table IV sets out some likely requirements.

TABLE III. KEY ENVIRONMENTAL ISSUES IDENTIFIED IN PLACER DOME'S SUSTAINABLE MINING PROGRAMME, AND KEY REPORTING INDICATORS

Environmental Issues

— Surface water use [a]	— Waste dumps
— Surface water quality [a]	— Open pits
— Groundwater seepage [a]	— Leach pads
— Acid rock drainage – operational and post-closure [a]	— Air quality
	— Natural off-site water system management
— Chemical (cyanide) management [a]	— Enhanced environmental monitoring
— Tailings management [a]	— Sensitive biological issues (at specific sites)
— Closure [a]	

[a] Judged sustainable priorities.

Key Report Indicators

- Safety (lost-time injuries, fatalities)
- List of regulatory compliance exceptions
- List of environmental incidents
- Fresh-water consumption levels
- Chemical use and discharge rates (cyanide)
- Land reclamation progress

TABLE IV. TYPICAL ENVIRONMENTAL SUSTAINABILITY PERFORMANCE REPORTING GUIDELINES

- Energy consumption, source, and reduction initiatives, particularly greenhouse gas emission reduction
- Material consumption, and reduce, reuse, recycle and recover (4R) initiatives
- Water use, source, reduction initiatives
- Emission, effluent and waste inventories, waste destination, 4R initiatives, progress in achieving reduction targets
- Transport requirements
- Documentation of environmental assessment efforts
- Documentation of industry association activities
- Documentation of environmental research and environmentally-based charitable donation activity
- Supplier performance assessments
- Life cycle analysis/product stewardship assessment
- Land use/bio-diversity assessment
- Regulatory compliance assessment
- Documentation of public consultation effects
- Emergency response preparedness assessment

2. ROLE OF CONTINUAL IMPROVEMENT

At the end of the day, the degree to which we get involved in the sustainable development debate and how we are compared to developments elsewhere in sustainable mining and mineral processing seems less important than simply delivering good, responsible, environmental management.

Regardless of the context in which it is presented, be it sustainable development or just good management practice, it is clear that much has changed over the past three decades in the uranium production sector. At Cameco, we have improved in each area proscribed by sustainability: economic growth, environmental balance and social progress.

We will continue to pursue improvements, if for no other reason than to improve public confidence, which in turn, should translate into more timely and efficient regulatory permitting processes and provide improved control of our future liability costs.

Broadly speaking, continual improvement is practised through environmental assessment prior to operation, use of various risk assessment methodologies throughout the lifecycle of a facility, ongoing efforts to reduce environmental risk, enhanced environmental monitoring to study ecosystem interactions, and research into the long term behaviours of waste facilities. These are fine sounding words, but we need specific examples of concrete improvements in the uranium production sector. Summarized below are some such examples, based on Cameco's experience and organized to correspond to the sustainability-based concept groupings described earlier.

2.1. Closure

The closure phase of mine and mineral-processing facilities, known as decommissioning, is a dominant sustainability issue, both from human and ecological perspectives. Today, good conceptual plans for decommissioning are an integral requirement of the environmental assessment process, whether the facility is new or undergoing significant changes. Plans include built-in designs for closure, progressive decommissioning during operation, achieving decommissioning goals while providing operational phase environmental controls, long term modelling of future environmental behaviour, and financial assurances for future decommissioning requirements. These plans must be adaptable, and are in place at all Cameco sites.

At all Cameco uranium mines, areas no longer in use are landscaped and revegetated to return them as much as possible to their predevelopment state. Our Key Lake revegetation plans had to be reformulated because the harsh regional environment and lack of organic material in the sandy topsoil retarded plant growth. So we took a lesson from the local natural environment, gathering seeds to successfully re-establish the area.

Decommissioning plans reduce future liability and ensure that sites are left in a safe state. Reducing future liability is a goal all stakeholders can agree on. Interestingly, long term modelling of environmental behaviour at northern Saskatchewan mines demonstrated that control of non-radionuclide contaminants such as arsenic and nickel are as much the dominant environmental drivers as radionuclides. We obviously share these non-nuclear issues with many other industrial sectors. Our modelling work also demonstrated that non-mineralized waste rock piles could present more significant planning challenges in decommissioning than uranium mill tailings. Nevertheless, it is fair to say that without well-defined, comprehensive decommissioning plans, we could not get approval for new developments. Furthermore, these plans are independently reviewed before licenses are issued.

2.2. Tailings management

Over the past three decades, we have seen the advent of purpose-built, lined tailings impoundments as well as in-pit tailings disposal facilities with hydraulic barriers and hydraulic by-pass mechanisms.

These facilities minimize groundwater contamination by minimizing the interaction between tailings and the surrounding hydraulic environment. At Cameco's Key Lake site, a mined-out open pit is now used as a tailings facility. Ultimately these tailings will become a low-permeability mass contained in a permeable envelope.

Long term modelling must demonstrate sustainable safeguards. For example, residual levels of discharge from tailings facilities must be compatible with the carrying capacity of the local environment and they must rely solely on passive environmental controls. Failure to demonstrate this level of protection requires either design modification or modification to the characteristics of the tailings themselves. For example, a current focus is in exploring ways to lower tailings porewater arsenic concentrations.

Is the level of protection offered in the current generation of tailings management facilities sufficient? Our regulatory authorities and we think so. Acceptance of these facilities is based on conservative assumptions, and involves a much higher level of analysis than previous analyses or than analyses in other mining sectors. It is interesting to note that the concepts developed for management of tailings at the Rabbit Lake facility (pervious surround and bottom drain) are used as the reference model for a proposed solid waste disposal facility for Canada's largest city. Both uranium production as secondary by-product recovery from other mine and mineral processing activities and the use of *in situ* leach techniques have obvious additional benefits from a tailings management perspective. Higher ore grade is another obvious advantage. Modern tailings management has improved much from the past.

2.3. Waste rock management

There has also been much progress in waste rock management over the past three decades. Before mining proceeds today, long term, well-articulated management plans based on pre-mining leachate-characteristic testing must be in place. Today's high-grade deposits, with much reduced waste rock volumes, permit increasingly extensive management plans to be put in place.

We have seen a transformation from surface stockpiling of unsegregated, uncharacterized waste to comprehensive handling based on the rock's acid-generation potential and secondary metal leachate characteristics. We now segregate problematic material on lined pads pending secondary handling. It is stored for re-use as backfill or for use as an ore diluent during processing. This reduces radiation exposure while solving a waste management problem at the same time. We bury problematic waste rock in excavations prior to decommissioning, and we practice sub-aqueous disposal to prevent oxidation. In Cameco's in situ leach projects, waste material remains underground or is returned underground.

Integration of waste rock management and tailings facility closure requirements has also been proposed, despite the economic disadvantage of double-handling waste rock. Long term, integrated plans for mine closure, tailings management, and waste rock management are prerequisites today. Although some may argue that more should be done, few could disagree that substantial change has already taken place, nor that current plans have not been well studied. We can safely say that the long term impacts will be very modest.

2.4. Surface and groundwater quality management

Two of the main groundwater-quality management techniques currently in use are:

(1) Lined pads for ore stockpiles and problematic waste rock storage; and
(2) Secondary containment facilities such as concrete tunnels to carry tailings and waste water lines, containment trenches, dikes, and paved terraces around processing areas.

At the Key Lake facility, mined-out excavations hold tailings and waste rock. During operation, these repositories require ongoing dewatering for the purpose of hydraulic containment, providing environmental control until such time as we can demonstrate that the residual impacts are minimal. Properly managed *in situ* leach operations are of course primarily concerned with groundwater quality management. In surface water quality management, we have seen several new developments:

(a) Batch release systems to replace flow-through systems for treated effluent;
(b) Dedicated collection and batch release/treatment systems for storm runoff waters;
(c) Routine effluent toxicity measurements to supplement chemical water quality management; and
(d) The addition of effluent toxicity treatment systems such as a reverse-osmosis system installed for the Key Lake dewatering effluent, and a combination of organic removal/cyanide and nitrite destruction along with boiler blow-down evaporation circuits installed at the Blind River refinery.

These are all new innovations and all have reduced the impact of uranium mining on the aquatic environment.

2.5. Water use

Reductions in the volume of fresh water used in uranium production are accomplished by using collected contaminated water for process use. For example, at McArthur River, treated effluent is returned underground to fulfil process needs and reduce fresh water make-up. Use of once-through cooling water systems, while not strictly water consumption reduction, do reduce process effluent discharges. What is particularly interesting from an environmental management perspective is the interrelationship between fresh-water consumption levels, effluent volumes, and effluent quality as measured by chemical concentration and end-of-pipe toxicity. At every opportunity, we have pursued reduction in water use.

2.6. Air quality management

Environmental controls at the mine and mill end of the uranium production spectrum tend to focus on water effluents, whereas air emission controls hold higher priority in the refining and conversion side of the fuel manufacturing process. We have made significant strides in reducing uranium, fluoride and nitrogen oxide emissions from these facilities, both by improving the efficiency of air pollution control equipment and better chemical recovery systems installed prior to emission control.

2.7. Chemical management

In uranium refining and conversion we use three main chemicals: nitric acid, ammonia, and hydrofluoric acid. For both nitric and hydrofluoric acid, we have large scale recovery circuits built into the processing circuits. About 97% of incoming hydrofluoric acid is shipped back out in the UF_6 product stream. In the case of ammonia, we generate by-product fertilizers (ammonium nitrate and ammonium sulphate), thereby minimizing environmental discharges. We also strive to convert refining and conversion waste into products that can be returned to the milling stage for uranium recovery. Cameco’s Blind River plant has an ongoing recycling programme for the recovery of nitric acid. Most of the acid used in the process is recovered and recycled to the digestion circuit of the refining process. As well, a liquid byproduct containing economically recoverable uranium content is treated within the plant and converted into a dry, calcined byproduct to recover even more nitric acid. This new process reduces the volume of byproduct by almost 75% and generates a material with more than 2% uranium. Because of these efforts, Cameco’s refining and conversion plants have successfully operated without the need for commercial radioactive waste disposal facilities since the mid-1980s. Not many other plants can claim ongoing operation without access to waste disposal facilities.

2.8. Enhanced environmental monitoring

Environmental monitoring programmes have substantially improved as well. The focus has shifted from effluent/emission monitoring to wider ranging, receiving-environment assessments. In northern Saskatchewan during the 1990s, much additional monitoring has been carried out. This monitoring is largely related to the assessment and licensing of new facilities, proposals to modify operations at existing facilities, or in the support of decommissioning efforts.

Federal and Provincial regulatory agencies have also been extensively involved in this area. While regulatory-mandated enhanced environmental monitoring (EEM) programmes are anticipated in the general Canadian mining sector, the uranium mining section has already adapted to the coming requirements and is a leader in the mining sector in environmental monitoring. In northern Saskatchewan, community-based environmental monitoring programmes were implemented as part of a larger impact management agreement with northern communities. As well, the Provincial government led a cumulative environmental monitoring effort to evaluate the potential for overlapping impact from multiple developments, and to study the accumulation of impacts since mine inception.

Another positive development is the advent of minesite State of Environment reports, required every five years. These reports go beyond the already extensive annual environmental and decommissioning reporting requirements. They look at long term trends, comparing actual performance to predevelopment EIS predictions. They also consider potential modifications to environmental monitoring programmes. For instance, the most recent report on Key Lake concluded that the facility is operating as predicted and within the environmental boundaries of the original EIS. It is satisfying to see that the original work done to predict environmental impact was accurate. This should instil confidence in the assessment process and its methodology.

2.9. Public consultation

In the 1980s, public environmental monitoring committees were established for the Blind River and Port Hope operations. In the 1990s, similar arrangements were made to develop routine public consultation on environmental matters at northern Saskatchewan mines. Environmental Quality Committees (EQCs) like the Athabasca Working Group in northern Saskatchewan act as a bridge between their communities, the government and uranium mining companies.

These public consultation initiatives have largely been successful, although it has proven difficult to maintain public interest in such activities in Blind River. As well, activities in Port Hope changed direction, so that public presentations are now made to a committee of local government. Along with these initiatives, full disclosure to regulatory agencies, public hearings associated with environmental assessment processes, and public licensing processes have all helped to meet public consultation needs. Our industry has become accustomed to and comfortable with providing the public with full disclosure and discussion of environmental aspects.

2.10. Environmental research

In recent years, our environmental research efforts have tended to focus on the uranium mining and milling portion of the nuclear fuel sector. Major areas of interest and external support are:

Waste Rock	—	Improved characterization and understanding of rock-pile hydrology and geochemistry, long term prediction methodologies, evaluation of various cover and liner designs
Tailings	—	Improved characterization – chemical nature, ageing characteristics, diffusive transport characteristics, sub-aqueous and tailings injection method development

Aquatic Impacts	—	Toxicity and bioavailability of nickel and molybdenum to indigenous fish species, sediment toxicity, fish-health surveys, site-specific validation of surface water quality objectives, and development of EEM programme study triggers.
Terrestrial Impacts	—	Primarily revegetation work using various native grasses, shrubs and trees.

In 1995, Cameco and the Natural Science and Engineering Research Council of Canada created an Industrial Research Chair in Environmental and Aqueous Geochemistry at the University of Saskatchewan.

2.11. Environmental management system (EMS) development

Over the past decade, much effort has been devoted to ecological risk assessment, particularly in northern Saskatchewan. This high level of analysis has undoubtedly been prompted in part by formal regulatory environmental assessment processes undertaken for the new generation of uranium developments. Modern environmental impact statements demand this type of analysis. We also embarked on a number of other assessment processes: environmental risk analysis, environmental aspects identification, and regulatory-mandated safety analysis using methodologies like the HAZOP studies. Risk identification leads to development of risk management programmes, emergency response planning, and auditing programmes. We are currently weaving these components into an overall formal EMS, based on the ISO 14001 principles of:

(1) Compliance with laws and regulations, and adherence to generally accepted industry practices.
(2) Prevention of pollution to levels as low as reasonably achievable.
(3) Continual improvement in overall environmental performance.

Formal environmental management systems will help promote ongoing efforts directed toward environmental performance.

3. CONCLUSIONS

Modern uranium and processing facilities are in the vanguard of sustainable development strategies in the energy production field. Environmental impacts associated with producing nuclear fuel are modest in relation to other energy fuels. Air and water emissions from these facilities are well controlled. Waste materials are subject to comprehensive management programmes, and the size of the impacted land area, or footprint, is small.

Sustainability's definition and the methods used to measure it continue to evolve. Regardless of the definitions applied, we have made substantive improvements in the areas most commonly associated with sustainability. This is not surprising, considering the extensive analysis required for the approval and permitting process for a new uranium development.

In 1991, the governments of Canada and Saskatchewan appointed an independent panel to examine several proposed uranium developments. What followed was an intense, six-year environmental review. Ministers of the Federal Government have been very pleased with the success of the review. Ralph Goodale, Minister of Natural Resources Canada, in particular praised the review. "The panel has played in important role in helping governments make informed decisions on ensuring that uranium mining projects bring economic benefits through a sustainable development approach," said Goodale.

In keeping with these values, projects submit extensive environmental impact statements. For the McArthur approval process, Cameco wrote what amounts to more than 38 kilometres worth of pages,

when placed end to end. For more than ten years, this information was under a microscope as it wended its way through both assessment and permitting processes. It is not possible to put this level of effort into assessment without a close examination of all aspects of sustainable development.

And all of this is taking place in the face of depressed commodity prices. Now, the improvements made did not lead to reduced commodity prices nor did they result from these price reductions. If there is an economic link, in fact, it is in our efforts to minimize future liability and to accelerate approval processes. I*n situ* leach techniques and resource extraction from the new high-grade uranium deposits offer even more opportunities to reduce operational and post-operational environmental impacts, further reducing the footprint associated with energy fuel production.

Effective 6 Oct.2000, Cameco will become part of the Dow Jones Sustainability Group Index, the world's first global sustainability index. The Index indicates that we were chosen, because "our analysis has shown that your company has an above average sustainablility performance compared to other companies in the same industry group."

As advances over the past three decades demonstrate, by any name sustainability is not only feasible for the uranium industry, but proven as well. We anticipate that these advances will continue and will manifest more in operational-phase risk reduction activities than in emission reduction activities. We anticipate programmes that will promote better understanding of current and future impacts associated with air and water emissions, programmes that focus on waste product stewardship, and programmes that minimize future liability. In other words, we will continue to do things ever smarter and better, despite ample evidence that we are already practising responsible environmental management.

Radioactivity of uranium production cycle facilities in the Czech Republic compared to the natural environment

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Abstract. Forty-five years (1946–1990) of intensive uranium exploration and exploitation in the Czech Republic led to mining at 64 uranium deposits. These mining and milling activities left numerous accumulations of waste rock material in the landscape. The radioactivity of these man-made accumulations was measured and compared to the natural radiation environment. Waste rock dumps at the uranium deposits Příbram, Rožná, Jáchymov, Stráž-Hamr and deposits in the Železné Hory area show surface gamma dose rates mostly in the range of 200–1000 nGy/h, with a uranium concentration 10–100 ppm eU. An extremely high radioactivity of 3000–4200 nGy/h was detected at the extensive uranium processing tailings impoundments at Stráž. Terrestrial gamma dose rate of regional geological units in the Czech Republic is in the range of 6–245 nGy/h. Reclamation and recultivation of dumps, control of their radioactivity and restriction of their accessibility are the major measures introduced to protect the public.

1. INTRODUCTION

Both natural and man-made sources of radiation contribute to doses absorbed by the populace. Protection against ionizing radiation, defined by the as low as reasonably achieavable (ALARA) conception, is based on knowledge, monitoring and assessmement of the environmental radiation. Radiological impacts on humans are stated in terms of absorbed dose. Doses to the public are related to activity sources, their pathways, form of irradiation and exposure time. Uranium mining and processing activities can significantly affect the local radiation environment and may result in some radiological impact on workers, the general public and the environment.

Uranium mining and milling involves disruption of the land surface, removal and transportation of large volumes of rock material, extraction of uranium from the ore and deposition of waste material. Waste rock dumps and tailings impoundments, which amount to millions of cubic metres by volume, are radioactive anthropogenic man-made/features at the earth's surface, which may pollute soil, surface and underground water and the atmospheric air. A joint NEA/IAEA publication [1] describes comprehensively environmental aspects related to the uranium production cycle.

The radioactivity of uranium cycle facilities is usually assessed by direct measurements. A comparison with the natural radiation sources gives an estimate of their radiological significance in the environment.

2. MONITORING OF THE ENVIRONMENTAL RADIATION

Airborne, carborne and hand-carried instruments, for the detection of gamma rays, are used for regional and local studies of the environmental radioactivity, which can be expressed in gamma dose rate (nGy/h). Radiometric data are affected by specific features, namely by the statistical character of radioactive decay, detectors and technical parameters of instruments, calibration standards and calibration procedures, sampling time and the geometry of field measurements. Climatic changes, precipitation, variation of atmospheric radon, and absorption of gamma rays by biomass, contribute to field radiometric data deviations. Comparison tests of various field instruments showed their mutual deviations in detected terrestrial radiation to be up to 20 nGy/h [2] and proved their capability to distinguish the environmental radiation sources at this level. Modern gamma ray spectrometers give in situ data of concentrations of the natural gamma ray emitting radionuclides, in particular of K, U and Th in the rock environment, and enable the specification of their accumulation in man-made features.

3. NATURAL RADIATION IN THE CZECH REPUBLIC

The territory of the Czech Republic (78 863 km^2) is formed by magmatic, sedimentary and metamorphic rocks differing in their radioactivity. Systematic airborne and ground radiometric measurements covered the whole country and resulted in the compilation of a Radiometric map of the Czech Republic 1:500 000 [3]. The range of terrestrial gamma dose rate 6–245 nGy/h, with a mean 65.6 nGy/h, indicates the regional radioactivity to be above the world average. Variscian granitoids in the Bohemian Massif exhibit enhanced radioactivity and are considered to be a potential source of uranium mineralization. The lowest radiation 15–30 nGy/h was observed over ultrabasaltic rocks, amphibolites, serpentines, quartzites, limestones and aeolian sands, while granites, granodiorites, syenites, porphyres and phonolites exhibit dose rate often exceeding 150 nGy/h.

Cosmic radiation, which is a component of natural radiation sources, is dependent on the altitude of the terrain above sea level, and corresponds to 32–38 nGy/h in the region.

4. RADIOACTIVITY OF URANIUM MINING FACILITIES

Forty-five years (1946–1990) of intensive uranium exploration and exploitation in the Czech Republic led to the discovery of thousands of radiometric anomalies. Out of the 16 846 uranium bearing mineralized zone, 164 uranium occurrences underwent a detailed investigation, and 64 uranium deposits were mined. Exploration and mining activities left about 1700 waste rock heaps, which include 350 bigger dumps, 874 exploratory and mining shafts and adits, 16 open pits and 16 tailings impoundments [4]. Uranium mining rock material deposited on the earth surface has been the subject of various radiometric measurements. Recent (year 2000) data on the radioactivity of uranium cycle facilities, measured by a portable scintillation gamma ray spectrometer GS-256, reflect the radionuclide contents in waste rocks and tailings and their radioactivity. The spectrometer GS-256 was calibrated at the calibration facilities in Bratkovice (Czech Republic) and Langenlebarn (Austria).

The Příbram uranium deposit (central Bohemia) is an endogenous vein type deposit in the Moldanubian metallogenic zone. Uranium mineralization occurs mostly in upper Proterozoic clay and sandy rocks in the exocontact of the central Bohemian pluton of Variscian age. The mineralization is controlled by tectonic features of the geological setting. Numerous waste rock dumps of the former major uranium production area in the Czech Republic indicate the dose rate 100–1000 nGy/h and the uranium concentration in the range 20–160 ppm eU. The waste rock dumps, of height 40–50 m, are a source of local enhanced radiation in closed, inaccessible areas.

The Rožná uranium deposit (central Moravia) is associated with a complex of metamorphosed sediments and effusive volcanics of Precambrian age. The host rock consists of migmatized gneisses and amphibolites of the Moldanubian zone, exhibiting a dose rate of 40–80 nGy/h and a concentration of 2–4 ppm eU. The uranium mineralization is of hydrothermal origin and occurs as veins and disseminations in mylonitized fault structures. Reclaimed waste rock dumps of the Rožná deposit area give a surface dose rate 80–150 nGy/h and uranium concentration in the range 6–18 ppm U, while ongoing uranium mining activities handle highly radioactive ore.

Uranium mining waste rock dumps of a series of uranium deposits along the Železné hory fault (E Bohemia) exhibit a dose rate of 100–600 nGy/h and a concentration of 10–100 ppm U, with local maximum 6000 nGy/h and 1000 ppm U, corresponding to a boulder of U ore, while numerous small exploration heaps are at the level of the regional radioactivity of 50–100 nGy/h.

The Jáchymov uranium deposit (NW Bohemia) is a vein type deposit in the Saxonian-Thuringian metallogenic zone. Uranium mineralization occurs in a mica schists complex and is tectonically controlled. The historical uranium deposit Jáchymov was abondoned in the 1960s, leaving numerous, large waste rock dumps which have been partly removed, or reclaimed and incorporated into the landscape. The recent measurement on the waste rock dumps showed the surface dose rate to be 120–

330 nGy/h and the uranium concentration 15–50 ppm U, while the surrounding rocks of the area exhibit a dose rate 60–120 nGy/h and a U concentration 4–8 ppm U.

The Stráž-Hamr uranium deposit is a sandstone type. The uranium mineralization was encountered in fresh-water sediments and shallow marine sediments of Cenomanian age, extending over Permo-Carboniferous phyllites and deeply weathered granites of the upper Proterozoic basement. At the Hamr mine, relatively low dose rate values of 120–220 nGy/h were measured on the waste rock dump, and high radioactivity spots were traced along the U ore transport road at the former uranium ore stock pile. Sedimentary rocks of the area, mostly Cretaceous sandstones, belong to low radioactivity rocks. The dose rate measured in the area was in the range of 20–60 nGy/h. Extremely high radioactivity of 3000–4200 nGy/h and more than 1000 Bq/kg of ^{226}Ra was detected at extensive uranium processing plant tailings impoundments at Stráž. Radioactive material in the tailings impoundment of the stage I has been partly covered by a 0.8 m thick layer of transported rock, reducing the surface dose rate to 260–350 nGy/h. Similar high radioactivity was referred over the extensive Mydlovary tailings impoundments (S Bohemia). Covering of tailings impoundments also prevents the environmental pollution by highly radioactive dust particles released from tailings. The dust particles show high specific activity on the order of 1 to 9 000 Bq/kg of ^{226}Ra. Typical levels of measured radioactivity in reported regions are summarized in Table I.

5. IMPACT OF THE URANIUM PRODUCTION CYCLE ON THE ENVIRONMENT

The waste rock material from uranium deep mining, which was used locally for road constructions in the 1950s, can be traced by airborne and ground radiometric measurements. In the Příbram area (central Bohemia), sections of exposed road surface have a dose rate of 70–600 nGy/h with a local maximum 1200 nGy/h, and a mean 290 nGy/h, leading to an estimated annual effective dose to population of 0.17 mSv [5]. Enhanced radioactivity was observed at river banks and sediments of river flows from the uranium mining areas. The Rolava and Ohře rivers (NW Bohemia), transported rock material and wastes from the former uranium processing plant Nejdek in the Jáchymov mining region (NW Bohemia) and enriched the bank sediments to 10 ppm U. The Ploučnice river contamination resulted from the long term mining activities at the Stráž-Hamr U deposits (N Bohemia) in the 1960s and 1970s. A relatively narrow, 20 km long, zone along the Ploučnice river, exposes a variable dose rate of 200–600 nGy/h with local maxima of 600–1000 nGy/h caused by increased concentration of U, Ra and other elements. A comprehensive study of contaminated zones resulted in the recommendation of their exclusion from agricultural use. A study of radon exhalation from vast tailings impoundments at Stráž, conducted by the state enterpise DIAMO in the 1990s, showed a low atmospheric radon concentration at various climatic conditions of 3–15 Bq/m^3, at a distance of one km from the tailings impoundments.

6. RADIOACTIVITY OF OTHER RADIATION SOURCES IN THE ENVIRONMENT

The quoted radiation data on the uranium cycle facilities can be compared to other industrial-based geological materials and other radiation data. The accumulation of natural radionuclides, especially of U, in coal beds and coal burning products, results in enhanced radioactivity. Coal mining heaps and slags in the Trutnov-Hronov area (NE Bohemia) showed the dose rate of 200–600 nGy/h with a maximum of 840 nGy/h, caused by the uranium enriched coal, currently containing an average of 10–20 ppm U, and up to 200 ppm U or more in individual samples. The average indoor radon activity concentration of 140 Bq/m^3 in the Czech Republic results in a personal annual effective dose 2.5 mSv. An identical effective dose would be generated by a year-long stay in an area with a 408 nGy/h dose rate. Natural sediments of the river Lužnice (S Bohemia), showing an enhanced concentration of Th rich heavy minerals monazite and zircon, transported from adjacent cristalline rocks, exhibit a gamma dose rate of 150 nGy/h. Laboratory analyses of these sediments indicated 2.6% K, 6.5 ppm U and 33 ppm Th.

TABLE I. CONCENTRATION OF K, U AND TH AND THE GAMMA DOSE RATE IN SOME AREAS OF URANIUM MINING IN THE CZECH REPUBLIC

Uranium mining area	Object	Concentration (% K)	(ppm eU)	(ppm eTh)	Dose rate (nGy/h)
Příbram	Bytíz				
	waste rock dump	2.3-3.3	82-162	8-15	521-996
	shaft 16				
	waste rock dump	2.3-2.7	8-74	7-17	120-479
	Háje				
	waste rock dump	2.9-3.1	26-37	9-11	214-346
	Brod				
	waste rock dump	2.8-3.1	26-37	10-12	213-275
Rožná	Rozsochy				
	recultivated dump	1.8-2.7	5-14	8-11	86-134
	shaft R4				
	recultivated dump	1.6-2.6	10-12	7-10	102-121
	Olší				
	dump	2.3-2.4	33-64	9-10	241-419
	recultivated dump	1.4-1.9	8-18	8-11	90-149
Železné hory	waste rock dumps		10-100		100-600
Jáchymov	Jáchymov				
	waste rock dump	3.9-4.4	16-31	14-17	180-265
	shaft Adam				
	waste rock dump	2.5-3.1	7-16	10-13	112-153
	shaft Svornost I				
	waste rock dump	1.8-2.4	5-39	8-12	80-280
	shaft Barbora				
	waste rock dump	1.1-3.8	23-48	9-13	175-332
Stráž-Hamr	shaft Hamr I				
	waste rock dump	1.3-2.4	14-29	7-11	115-223
	Stráž				
	tailings impoundment side	1.0-1.4	41-98	8-9	267-599
	tailings impoundment plateau uncovered	6.5	687	73	4164
	tailings impoundment plateau covered	2.8-3.9	32-52	11-13	264-355

7. RECLAMATION OF URANIUM MINING WASTE DUMPS AND IMPACT ASSESSMENT

The surface radioactivity on waste rock dumps and the escape of radioactive soil particles are usually reduced by covering the waste dumps with a non-radioactive rock or soil layer. Theoretical calculation of the decrease of surface gamma radiation, considering the source and the non-radioactive layer as a seminfinite space, and the absorption of gamma rays given by the integral exponential function of the second kind (E_2), show a substantial drop of radioactivity with increasing thickness of the shielding layer. For the gamma radiation of the uranium-radium decay series, represented by the gamma rays of ^{214}Bi of the energy 1.76 MeV, and the density of shielding soil material 1800 kg/m^3, a thickness of the shielding soil layer 5 cm, 10 cm, 20 cm and 50 cm would reduce the surface gamma radiation to 37%, 18%, 5% and <1% respectively, of the original value.

Since experimental data show a higher gamma radiation and lower shielding effect, migration of radon (^{222}Rn), a parent element for ^{214}Bi and ^{214}Pb, the major gamma emitting sources in the ^{238}U decay series, plays an important role. In addition to the thickness of the shielding layer, increased effectiveness can be achieved by using soils of low gas permeability, which prevent radon migration from the underlying rock or tailings into the shielding layer.

The medium and highly radioactive accumulation of waste material from the uranium cycle are periodically monitored under various programmes, supported by state funding, and gradually revegitated. The locally enhanced external radiation of isolated facilities, generally outside urban areas, has lower environmental impact than the possible escape of contaminated seepage water from tailings ponds and certain heaps. The recommended annual effective dose limit of 1 mSv for the public may be considered a standard for relative assessment of radiation sources and absorbed doses. Prioritization for the reclamation of uranium cycle wastes may be realized in accordance with estimated annual effective doses, corresponding to the level of measured radioactivity, its nature, and exposure time.

Results of recent measurements at uranium mining facilities in several chosen areas in the Czech Republic show the external radiation of waste dumps to be mostly in the range of 200–1000 nGy/h and individual cases of higher radioactivity. In comparison to the terrestrial radiation of regional geological units in the Czech Republic of the range 6–245 nGy/h, the enhanced radioactivity of the waste accumulation is evident. Since absorbed doses from external radiation are multiples of the dose rate, the exposure time and a conversion constant [6], the final product can be effectively reduced by limiting the exposure time. For the public, uranium mining heaps and dumps are mostly treated as closed areas and the use of waste material is controlled and restricted by governmental regulations and radiation limits. On the other hand, observed radiation levels at highly radioactive dumps emphasize the need for their control, documentation and application of radiation protection measures.

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Assessment of environmental impact of mining and processing of uranium ore at Jaduguda, India

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Abstract. Uranium ore from three underground mines located within a distance of 12 km is mined and processed by the Uranium Corporation of India Ltd (UCIL) in the mill at Jaduguda in eastern India. Management of mine water, mill tailings and the effluents from the tailings pond is given due importance during the mining and ore processing operations. Radon released from the mines exhausts and emanating from the tailings pile and liquid effluents released from the effluent treatment plant have a potential for environmental impact. Environmental surveillance has, therefore, been an integral part of the uranium mining and ore processing operations since their inception. The radiation exposure rate, atmospheric radon and radioactivity in surface and ground waters, as well as in soil, are monitored to assess the environmental impact of these operations. This paper gives a brief account of the mining, ore processing and waste management operations. The environmental monitoring results of the last few years are summarized in this paper. They indicate the radiological impact of these operations on the environment is only marginal and well within the regulatory limits.

1. INTRODUCTION

The first uranium ore deposit of economic importance in India was discovered at Jaduguda in the Singhbhum Thrust Belt in the eastern state of Bihar. After an initial phase of underground exploratory mining, the Uranium Corporation of India Ltd (UCIL) started mining and processing of 1000 tonnes of ore per day at Jaduguda in 1967. Subsequently two other deposits at Bhatin and Narwapahar, located 3 and 12 km northwest of Jaduguda, were taken up for underground mining in mid 1980s and early 1990s, respectively. The ore from these mines is also processed in the mill at Jaduguda, which has been expanded to a capacity of 2090 tonnes per day. A small quantity of mineral concentrate obtained by tabling of the nearby copper plant tailings, which contain about 0.005–0.009% U_3O_8, is also processed in this mill.

2. MINING AND PROCESSING OF URANIUM ORE

2.1. Underground mining

The Jaduguda mine developed to a depth of 900 metres, in three stages over the years, has a horizontal strike length of about 800 metres and production capacity of 1000 tonnes of ore per day. The central shaft serves as entry for men and material and as main ventilation intake route. The ore excavated from different stopes is brought to a central location and hoisted to surface and discharged on to a conveyor system leading to the mill. The Bhatin mine with a production capacity of 250 tonnes/day is a relatively small mine developed up to a depth of about 135 metres. It has entry through an adit, which also serves as intake route for ventilation air and transport of the excavated ore to surface. The Narwapahar mine designed to produce 1000 tonnes/day of ore is one of the most modern mines in the country. Trackless mining with decline is used as one of the entries to excavate the ore up to a depth of about 140 metres. A vertical shaft has also been sunk for mining of deeper deposits [1].

2.2. Ore processing

The initial ore processing operations briefly comprise of crushing, screening, wet grinding to the required size of –200 mesh and de-watering to control pulp density. This is followed by leaching with sulphuric acid in presence of an oxidizing agent (MnO_2) in air agitated vessels. Depending on the ore a temperature of 38–40°C or 50–55°C is maintained by using steam. The leachate is filtered, purified and concentrated using ion-exchange process. After precipitating sulphate and ferric iron by addition of lime slurry, magnesia slurry (MgO) is added to the pure liquor to precipitate uranium as magnesium diuranate [2].

3. WASTE MANAGEMENT

3.1. Mine wastes

(a) ***Solid waste*****:** Rocks below 0.03% U_3O_8 content are considered as waste. During ore winning operations care is taken to excavate a minimum quantity of waste. The waste rock is partly used as mine backfill material and the rest is used for land fill within the premises and for strengthening the tailings pond embankment.

(b) ***Liquid waste*****:** Large quantities of water are encountered in mines. As it contains dissolved uranium and radium the mine water is collected, clarified and reused in the mill process, after an ion exchange step since it also contains chlorides. Over 3700 cubic metre of the mine water is reused per day. Mine water from Bhatin and Narwapahar mines is brought through pipelines to the effluent treatment plant (ETP) at Jaduguda [2].

(c) ***Gaseous waste****:* The mine air from different operating levels, carrying radon and blasting gases, is let out through two return air exhaust adits located about 30 m above ground in isolated and unoccupied area. Similar exhaust air outlets are provided at the other two mines.

3.2. Mill wastes

(a) ***Mill tailings***: The bulk of the ore is processed in the mill in combination with reagents and emerges as waste or 'tailings'. It consists of the barren cake from the drum filters containing all the remaining undissolved radionuclides and the barren liquor from the ion exchange columns having some dissolved activity. Disposal of tailings in a permanent containment system is, therefore, an important aspect of the uranium ore processing.

(b) ***Run off water and other effluents***: Any runoff water from the ore storage yard is collected and used as a part of the process water in the mill. Overflow from the magnetite (a byproduct recovered from the tailings) settling pits is sent to the ETP for treatment. Effluents from storm water drains are treated for use as industrial water.

(c) ***Airborne pollutants****:* Air borne dust during ore handling, crushing and grinding operations are controlled at source by water spray, dry fog spray and dust extractor with water scrubbing system provided at appropriate stages. The slurry carrying the dust so extracted is also utilized in the milling operations. A series of pre-filters and high efficiency particulate air (HEPA) filters are provided in the final product area to retain the radioactive dust, only clean air is let out.

3.3. Tailings treatment, containment and consolidation

The barren liquor from the ion exchange columns is treated with lime stone slurry initially to a pH of 4.2–4.3 followed by addition of lime slurry to raise the pH to 10–10.5. It is then mixed with the barren cake slurry and a final pH of 9.5–10 is maintained. At this pH the residual uranium, radium, other radionuclides and chemical pollutants including Mn get precipitated. The treated slurry is classified

into coarse and fine fractions using hydrocyclones. The coarse material forming nearly 50% of the tailings is sent to mines for back-filling. The fine tailings or 'slimes' are pumped to an engineered tailings pond for permanent containment. The slimes along with the precipitates settle and clear liquid is decanted. A series of decantation wells and side channels are provided to lead the decanted liquid to the ETP.

There are three valley-dam types of tailings ponds at Jaduguda. The first and second stages of the tailings pond, which have about 33 and 14-hectare (ha) surface area respectively, are located adjacent to each other in a valley with hills on three sides and engineered embankments on downstream side of natural drainage. These two containment ponds are now nearly full. The third stage of the tailings pond having an area of 30 ha, which is currently in use, is also located nearby in a similar setting [3]. The underlying soil and the bedrock of these tailings ponds have very low permeability. The tailings ponds are fenced to prevent unauthorized access.

A vegetation cover of non-edible grass and plants such as *Saccharum spontaneum* (kansh), *Typha latifolia* (cat-tail) and *Ipomoea carnia* (Amari) has been provided over the used-up portion of the first two tailings ponds [3,4]. This vegetation cover helps in suppressing generation and dispersal of dust and consolidates the tailings besides merging it with the local landscape.

3.4. Water reclamation and effluent treatment

Though lime neutralization of tailings largely takes care of the dissolved pollutants in the process effluents, subsequent reduction of pH in the tailings pond due to oxidation of sulphide radicals, over a period of time, increases concentrations of some radionuclides and chemical constituents in the decanted effluents. Hence, these are further treated to meet regulatory discharge limits. The effluents coming from the tailings pond to the ETP are first clarified. A part of this discharge (about 800 cubic metre per day) is reused in the milling process. The rest is treated first with $BaCl_2$, and then with lime slurry, to precipitate the radioactive and chemical pollutants, especially ^{226}Ra and Mn. It is clarified and the settled sludge carrying the $Ba(Ra)SO_4$ and $Mn(OH)_2$ precipitates is sent to the tailings pond with the main tailings, and the clear effluent is discharged to the environment after pH adjustment [2].

4. ENVIRONMENTAL SURVEILLANCE

A comprehensive surveillance is maintained around the mines, mill and the tailings pond to evaluate the effectiveness of control measures, assess the environmental impacts and ensure regulatory compliance. Uranium tailings, being low specific activity material, are a source of low levels of gamma radiation and environmental radon. The mine exhaust air is also a potential contributor to atmospheric radon. The liquid effluents released after treatment may contribute to the radioactivity level of the recipient surface water system. Any underground migration of radionuclides from the tailings pond may show up in the local ground water. The environmental surveillance, therefore, includes monitoring of gamma radiation, atmospheric radon, and radioactivity in surface and ground waters and in the soil in the vicinity of uranium mining, ore processing and tailings disposal facilities.

(a) ***Radiation levels:*** The gamma radiation levels are periodically measured over the accessible parts of the tailings ponds and other areas in the vicinity using environmental radiation monitors. The ^{226}Ra content of 5.0 to 8.5 $Bq\cdot g^{-1}$ is expected to give a radiation level of about 2.5 to 4.0 $\mu Gy\cdot h^{-1}$ over the tailings surface. The radiation levels observed at different locations one metre above the tailings surface vary from 0.8 to 3.3 $\mu Gy\cdot h^{-1}$ averaging around 1.4 to 2.0 $\mu Gy\cdot h^{-1}$ at the three tailings ponds. This reduces to 0.5 $\mu Gy\cdot h^{-1}$at the embankment and to about 0.25 to 0.30 $\mu Gy\cdot h^{-1}$at about 20 m from the embankment. Background levels of 0.10 to 0.15 $\mu Gy\cdot h^{-1}$ are attained within in a short distance therefrom. These measurements are supplemented with deployment of environmental thermoluminiscent dosimeters at several locations up to about 25 km from the site to evaluate the cumulative radiation exposure [5]. The average annual exposure levels observed during the past five years are depicted in Fig.1. The annual radiation exposure levels at the surface facilities of the

Jaduguda mine and in the mill premises in general are about 1340 and 1030 μGy·y^{-1} while that at about 20 m from the tailings pond is 2440 μGy·y^{-1}. These are, however, within the work premises. It is observed that the annual radiation exposure levels in the public domain around the uranium complex are comparable to those of the natural background levels in the region and vary from 785 to 1862 μGy·y^{-1}, averaging around 1150 μGy·y^{-1}. The variations observed are due to differences in the geophysical characteristics of the local rocks and soils.

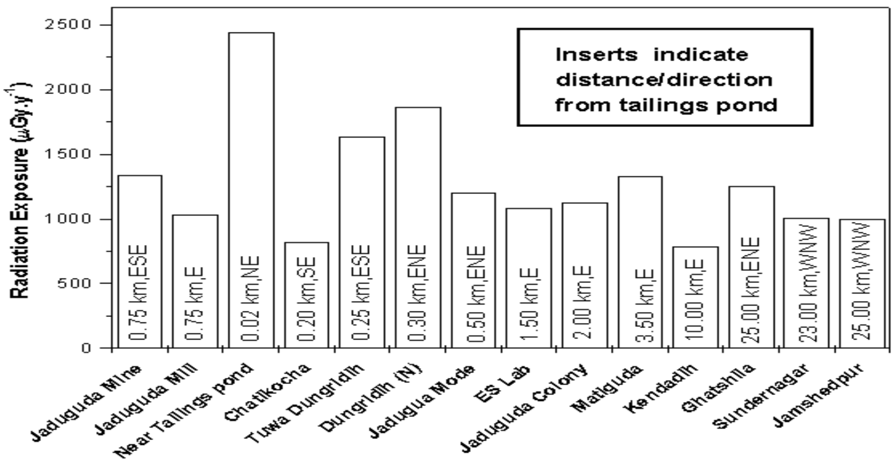

FIG. 1. Average radiation exposure around Jaduguda.

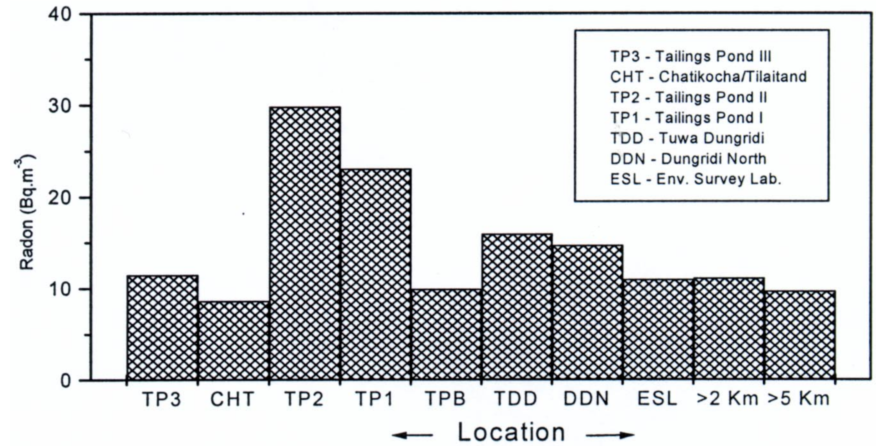

FIG. 2. Atmospheric radon levels around tailings pond.

(b) ***Atmospheric radon:*** The radon concentrations in the mine exhaust air measured at Jaduguda average 6.3 kBq·m^{-3}. At Bhatin and Narwapahar, these levels are 2.4 and 2.0 kBq·m^{-3}, respectively. The total radon released from Jaduguda is equivalent to 4.9×10^{10} Bq·d^{-1}. Considering complete emission during ore processing operations [6] the radon released from the mill is estimated at 1.1×10^{10} Bq·d^{-1}. Similarly, with an emanation rate of 1.53 Bq·m^{-2}·s^{-1}, the radon released from the two tailings ponds is also equivalent to 6.2×10^{10} Bq·d^{-1}. Thus the total radon released from the mine, mill and tailings pond at Jaduguda is about 1.22×10^{11} Bq·d^{-1}. The radon emanation rate from the local soil being of the order of 0.02–0.05 Bq·m^{-2}·s^{-1} [7], the same quantity of radon is likely to be contributed by a land area of 3–5 km radius. The atmospheric radon levels are periodically measured at the tailings pond and other locations in the region using a low level radon detection system [8]. The results of these measurements are summarized in Fig.2. The geometric mean of radon concentrations at the tailings ponds No. II and I are 30.0 and 23.0 Bq·m^{-3}, respectively, and fall to the local background of 10.0–15.0 Bq·m^{-3} close to the tailings pond boundary. Results of a detailed study on environmental radon in this region are published elsewhere [9].

(c) ***Surface water:*** The effectiveness of the ETP in controlling release of radioactivity in the aquatic environment is evaluated by measurement of U(nat.) and ^{226}Ra in the inlet and outlet effluents. Decontamination efficiency of the ETP for the past few years is shown in Fig.3 [10, 11]. The Gara River, a tributary of the Subarnarekha River, receives the treated effluents from the uranium mining and milling industry. The surface water system downstream of uranium industry is, therefore, regularly monitored. The U(nat) and ^{226}Ra concentrations observed in the surface waters in the public domain for the last five years are summarized in Table I. It may be noted that uranium and radium concentrations in water from the Gara and Subarnarekha Rivers downstream of UCIL operations are more or less of the same order as the respective background levels.

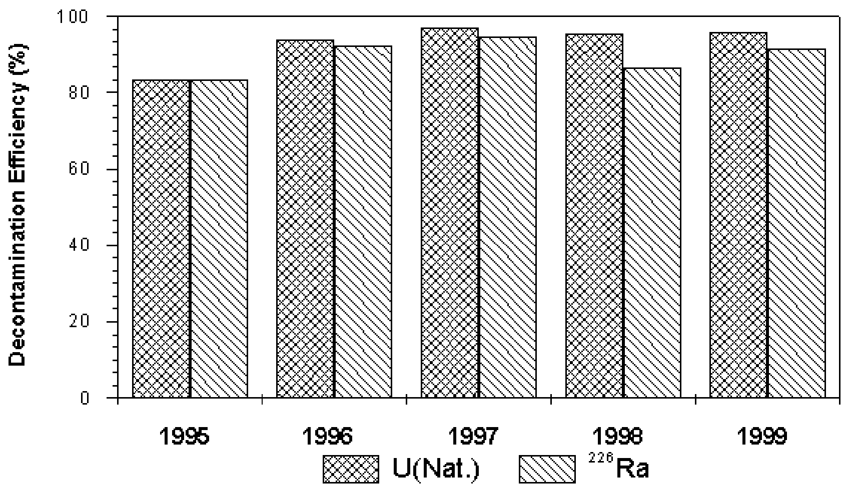

FIG. 3. Decontamination efficiency of ETP.

TABLE I. U(nat) AND ^{226}Ra CONCENTRATIONS IN SURFACE WATERS

Sampling locations	U(nat) Conc. (μg·l^{-1})		^{226}Ra Conc. (mBq·l^{-1})	
	Range	Mean	Range	Mean
Gara River (Narwapahar, U/S)	<0.3 – 4.4	1.5	1 – 18	9
Gara River (Narwapahar, D/S)	0.6 – 13.4	3.7	5 – 74	18
Gara River (Jaduguda,U/S)	0.5 – 34.3	3.5	3 – 61	12
Gara River (Jaduguda, D/S)	0.5 – 54.9	14.8	5 – 283	44
Subarnarekha River,U/S	0.5 – 5.4	1.4	4 – 48	18
Subarnarekha River, D/S	0.5 – 11.9	5.0	7 – 55	20
DWC (Limit)	100		300	

U/S – Upstream ; D/S – Downstream

(d) ***Ground water***: Ground water samples are periodically collected and analyzed from wells/bore wells near the tailings pond and other areas in the region [12]. The U(nat) and ^{226}Ra concentrations in the ground water obtained during past few years are summarized in Table II. It is observed that the uranium and radium levels in the ground water sources in the vicinity of the tailings pond are very similar to the regional average of 3.6 μg·l^{-1} and 23 mBq·l^{-1}, respectively, and are well within the derived limits for drinking water. It is interesting to note that average values of uranium and radium-226 in ground water at locations 20–25 km away are 2.1 μg·l^{-1} and 30 mBq·l^{-1}. Thus, there seems to be no movement of radionuclides from the tailings pond to the ground water in the vicinity.

TABLE II. U(nat) and ^{226}Ra CONCENTRATIONS IN GROUND WATER

Distance from tailings pond (km)	pH		U (nat.) ($\mu g \cdot l^{-1}$)		^{226}Ra ($Bq \cdot l^{-1}$)	
	Range	Mean	Range	Mean	Range	Mean
< 0.50	6.6 – 7.8	7.2	< 0.5 – 09.5	3.4	< 4 – 74	18
0.5 – 1.6	6.1 – 7.4	6.8	< 0.5 – 21.0	3.5	< 4 – 183	32
1.6 – 5.0	5.4 – 7.6	6.7	< 0.5 – 33.3	4.6	< 4 – 201	22
> 5.0	5.9 – 7.8	6.7	< 0.5 – 09.0	2.6	< 4 – 81	22
Overall	5.4 – 7.8	6.7	< 0.5 – 33.3	3.6	< 4 – 201	23
DWC (Limit)				100		300

TABLE III. U(nat) AND ^{226}Ra LEVELS IN SOIL

Distance from tailings pond (km)	U (nat.) ($mg \cdot kg^{-1}$)		^{226}Ra ($Bq \cdot kg^{-1}$)	
	Range	Mean	Range	Mean
< 0.50	0.8 – 39.7	4.4	5 – 285	84
0.5 – 1.6	0.5 – 13.0	5.8	23 – 150	69
1.6 – 5.0	2.4 – 08.5	6.6	44 – 256	115
> 5.0	0.9 – 09.1	4.1	5 –191	72
Overall	0.5 – 39.7	4.8	5 – 285	81

(e) ***Soil***: Soil samples are also collected from different locations and analysed for uranium and radium-226. Results presented in Table III indicate that natural radioactivity levels in soil from near the tailings pond are also of the same order as those found elsewhere in the region.

(f) ***Vegetation***: The uptake of natural radionuclides by the plants and grass, grown on the tailings surface for its consolidation, has been studied. The transfer factors observed were of the order of 10^{-4} to 10^{-2}. The wild grass, *Typha Latifolia* (cattail) indicated higher uptake of the radionuclides compared to the other plants [4].

5. CONCLUSIONS

Due importance is given to the safe management of low specific activity waste at uranium mining and ore processing operations of UCIL. The continuous environmental surveillance during mining and milling of uranium ore since the beginning of the operations have been effective in controlling the environmental releases of radioactivity. The impact of these operations on the local environment is only marginal. Recovery of small values of uranium from the copper plant tailings and recovery of waste water for reuse are other positive features, as they help in conserving the resources and considerably reduce the environmental impact.

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Uranium production and the environment in Kazakhstan

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Abstract. The production of uranium from open-pit and underground mines in Kazakhstan has terminated. Currently, uranium is extracted in Kazakhstan only by the In Situ Leaching (ISL) method. This method has a number of economical and ecological advantages. During a short period in the 70s-80s, Kazakhstan created a firm basis for developing uranium extraction by the ISL method. Now more than half of the world's uranium reserves amenable to the ISL method are located in Kazakhstan. By 2005, a significant increase in uranium production is planned. Thereby, Kazakhstan has the ability to grow into a world leader in uranium extraction through a lower cost and low environmental impact operations using the ISL method.

1. INTRODUCTION

As an integral part of the former USSR, Kazakhstan was an important part of the nuclear complex and possessed significant nuclear cycle capacities. Kazakhstan extracted uranium, fabricated fuel pellets and generated atomic energy at the power plant in Aktau. Kazakhstan was one of the main uranium producing regions of the former USSR and the main fuel pellet producer. Before the collapse of the USSR, more than 70 000 t U was extracted and the Ulba Production Centre provided 80% of the fuel pellets used by the USSR.

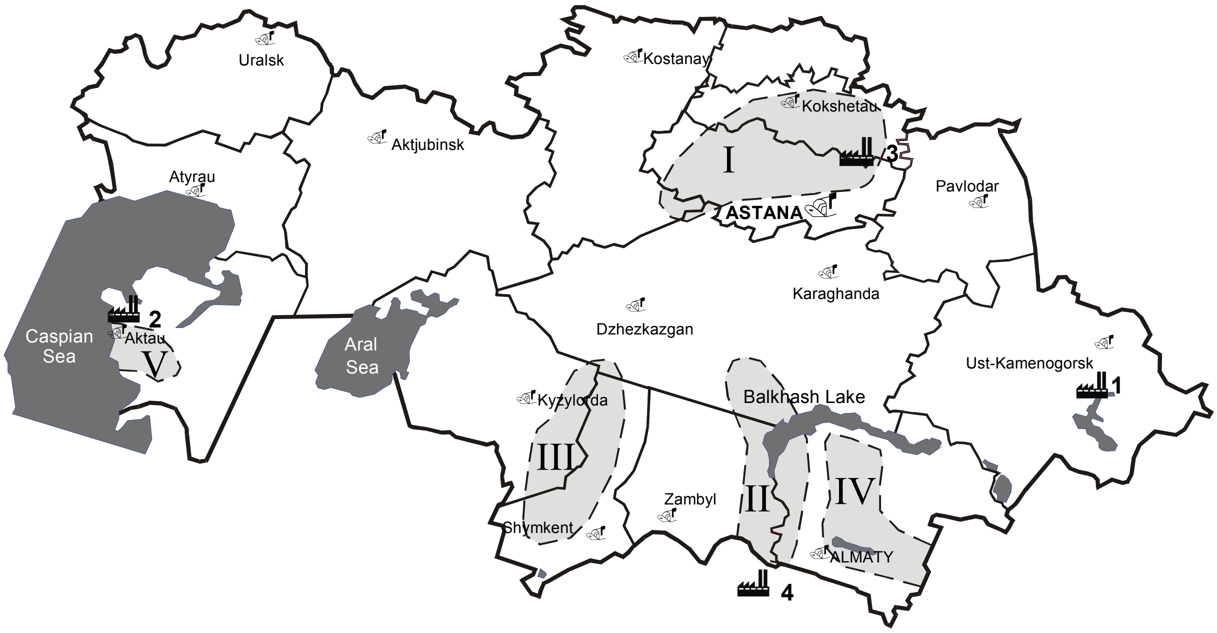
Before the 90s, Kazakhstan produced uranium primarily from open pit and underground mines. In the 70s-80s, large uranium deposits were discovered in Kazakhstan including deposits amenable to the ISL method. Since Kazakhstan possesses these large uranium reserves amenable to low cost and low environmental impact extraction using the ISL method, it has the potential to maintain and stabilize a position as the world's largest ISL uranium producer.

2. HISTORY OF THE URANIUM INDUSTRY IN KAZAKHSTAN

2.1. Formation of ore basis for uranium industry

Two stages and two directions can be identified in the history of uranium exploration in Kazakhstan: the search for deposits suitable for mining and the search for deposits in the friable sediments that amenable to the ISL method.

Implementation of the first stage began in the early 50s and was addressed the search for deposits at outcrop areas, using airborne, vehicle-mounted, and hand-held gamma radiometric systems as well as mining and drilling equipment. It can be said that the territory of Kazakhstan has been adequately explored. As a result of these explorations between the 50s-80s, about 30 commercial uranium deposits containing more than 1000 t U each were discovered. These deposits were located in the following three regions: Kokshetau, Betpakdala-Ili, and Pricaspian (Fig. 1). The largest is the Kokshetau region in the north of Kazakhstan. These deposits are of the vein-stockwork type in Silurian-Devonian folded sedimentary complexes and volcanics with low uranium grade (0.1-0.3%). The exception is located in the Pricaspian region where uranium ores with very low content (0.03-0.05%) are hosted in Tertiary sediments with the fish bones. This unique type is called organic phosphate.



Productions centres: 1 - Ulba, 2 - Pricaspian, 3 - Tselinny, 4 - Kirghiz

Uranium regions: I - Kokshetau, II - Betpakdala -Ili, III - Chu-Syrdarya, IV - Ili, V - Pricaspian

FIG. 1. Map of uranium regions of Kazakhstan.

In the 60s, exploration began for uranium deposits in friable sediments of the depression structures in the South of Kazakhstan. As a result, several uranium occurrences and the Uvanas deposit were discovered, but work on the occurrences was soon discontinued due to low uranium contents.

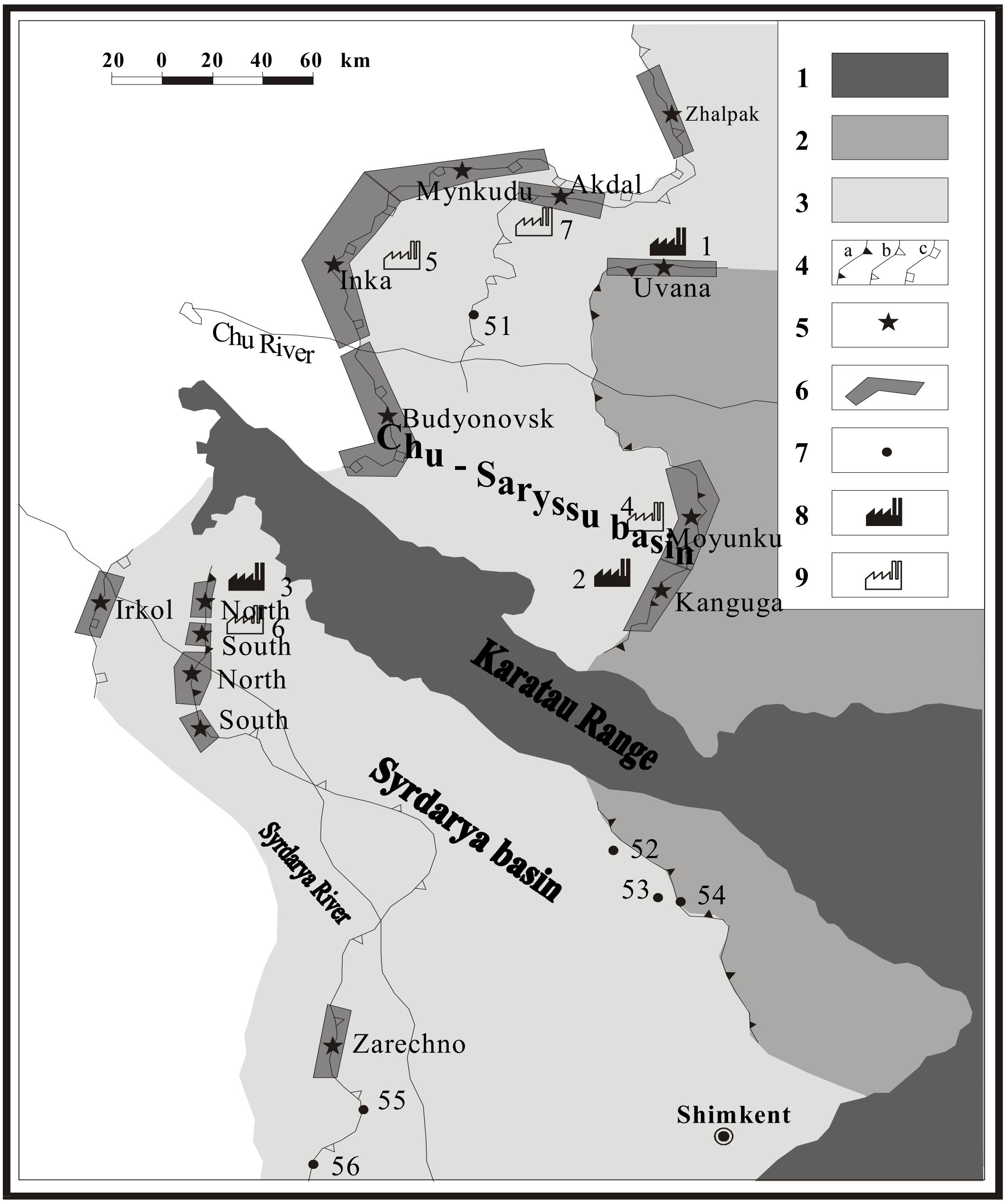
After the industrial use of the ISL method was proven and a successful ISL test at the Uvanas deposit was carried out in 1971, intensive search work was done by drilling in depression structures in the South of Kazakhstan. As a result, two ore regions were discovered: Ili and Chu-Syrdarya (Fig. 1). The Ili region located near Balkhash Lake includes mainly coal-uranium deposits and it is not of commercial interest for a number of reasons, mainly ecological ones. The Chu-Syrdarya region (ChSR) is now the most important uranium region in Kazakhstan (Fig. 2).

The Chu-Syrdarya uranium ore region was discovered and explored during the years 1971-1991. Exploration work in this region was carried out very intensively by three expeditions. Exploratory drilling efforts achieved up to 800 000 m per year. As a result, 15 large and unique uranium deposits in the permeable Paleogene-Cretaceous sand sediments were discovered and explored. The largest of them is the Inkay deposit, which contains 350 000 t U [1].

Exploration was accompanied by field tests for ore quality and different conditions of ore occurrence. In this case, the main emphasis focused on the following:

(a) uranium content in the ore;
(b) ore permeability;
(c) depth of the ore occurrence;
(d) existence of the confinement beds (especially in ecological importance in connection with solution excursion).

Primarily, the tests were carried out using sulphuric acid technology. Good results were obtained in practically every case. Uranium extraction reached more than 80% with acid consumptions of 50-80 kg per kgU. Several tests carried out using the alkaline method and various oxidants, showed significantly lower results on both extraction and solution productivity.



1 - Outcrop of Pre-Mesozoic rocks, 2 - Area of the bed oxidation zone development on whole thickness of Cretaceous-Paleogene sediments, 3 - Area of the bed oxidation zone development in Cretaceous sediments only, 4 - Redox-front a) in Paleogene sediments, b) in Zhalpak horizon of the top upper Cretaceous, c) in Mynkuduk-Inkuduk horizon of middle part of upper Cretaceous, 5- Commercial uranium deposits amenable for ISL, 6 - Ore-fields of the commercial uranium deposits, 7 - Unprofitable uranium deposits, 8 - Operating production centres (1-Stepnoe, 2-Tsentralnoe, 3-№6), 9 - Planned production centres (4-Katko, 5-Inkay, 6-South Karamurun, 7-Akdala)
Unprofitable deposits: 51 - Sholak-Espe, 52 - Kyzylkol, 53 - Lunnoe, 54 - Chayan, 55 - Zhautkan, 56 - Asarchik

FIG. 2. Distribution of uranium deposits in the Chu-Syrdarya ore region.

Therefore, acid technology of the ISL was selected as the main extraction method for practically of all deposits in the region. The low carbonate content of the uranium ores in Kazakhstan favoured such a decision. Thus, the unique Chu-Syrdarya uranium region, which has 15 commercial deposits with the reserves from 20 000 to 350 000 t U each, was discovered and developed for extraction within two decades as a result intensive exploration works in the South of Kazakhstan. Total resources of the region are estimated at 1.3 million t U, including about 0.6 million t U in proven and probable

reserves. Although the uranium content is relatively low (up to 0.07-0.08%), ores in the ChSR are characterized by quite considerable ore body thickness and favourable permeability coefficients (average of 6-8 m/day). In this case, the square productivity of the ore bodies reaches 7-10 kg/m^2 and solution concentrations of more than 150 mg/l are achieved. These circumstances show the strong possibility for the ChSR region of Kazakhstan to be an area for successful development in uranium production in the future.

2.2. Uranium mining and processing in Kazakhstan

2.2.1. Mining method

As uranium deposits were discovered in Kazakhstan during the 1950s, the mining complexes and the uranium ore processing centres were constructed. In 1956, the Kirghiz Production Centre was constructed for processing the first ore discovered in Kazakhstan in 1954 at the Kurday deposit (Fig. 3).

The Kirghiz Centre is located in territory of Kirghizstan. Through 1990, this centre also processed uranium ores of the Betpakdala-Ili region. In 1957 the Tselinny Production Centre in Stepnogorsk came into production, supported by the resources of the large Kokshetau ore region in the north of Kazakhstan. The unique ores of the Pricaspian region were processed at the Pricaspian Production Centre that came into production in 1959 in the West of Kazakhstan. In the East of Kazakhstan the Ulba Production Centre was constructed. Currently, fuel pellets are fabricated at this Centre. Thus, for short time the Kazakhstan power industry was created for extraction and processing of uranium ores and the uranium product fabrication. This industry included four large Production Centres. Before the USSR collapsed in 1991, these centres produced more than 70 000 t U from nine deposits using underground mines and open pits. The activities of the uranium Production Centres positively impacted the economies of the regions in which they were located. New settlements were built near the mines. Production Centres were accompanied by new town building.

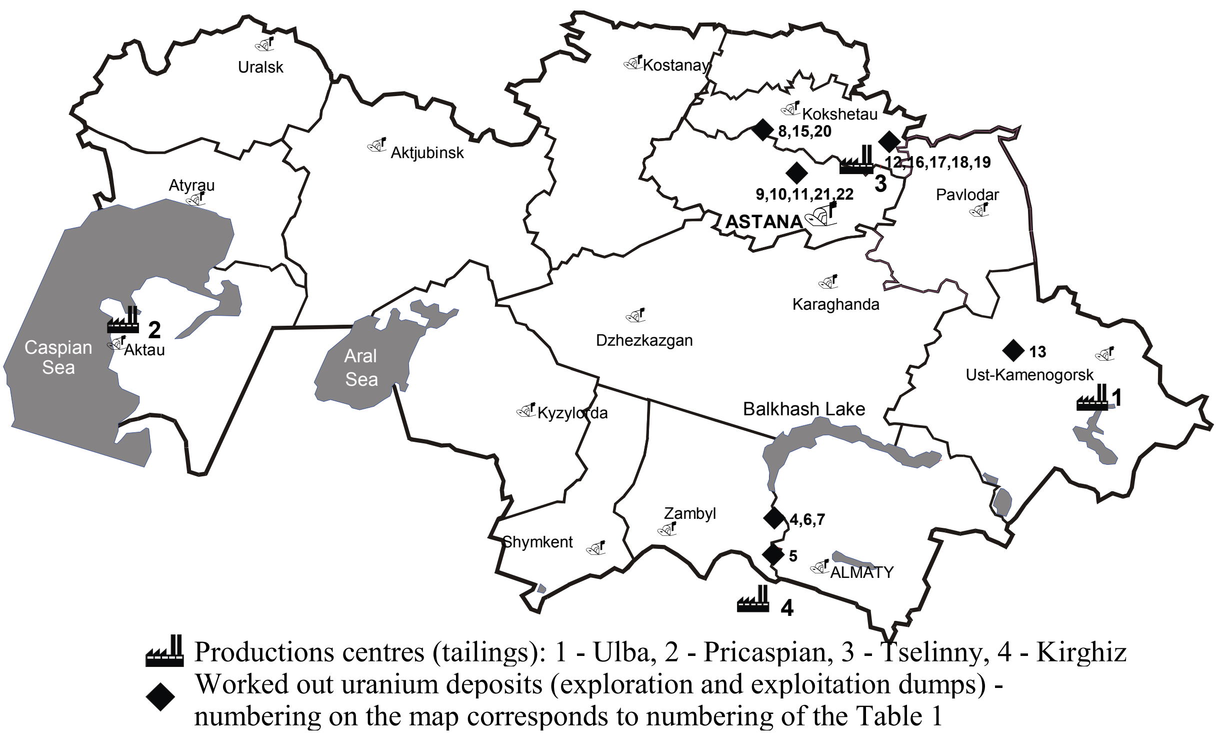


FIG.3 Distribution of Radwaste storages in Kazakhstan.

So Aktau city appeared on the map of Western Kazakhstan together with construction of the Pricaspian Production Centre. In the North of Kazakhstan the Tselinny Production Centre helped build Ctepnogorsk city. Ulba Production Centre was constructed near the existing city of Ust-Kamenogorsk. In the new cities with the uranium production other industries were created, such as oil industry in Aktau and biological and the other industries in Stepnogorsk. New roads and electrical lines were built. New regions of Kazakhstan were involved in this industrial activity.

Uranium production from underground and open-pit mining in Kazakhstan started to decline after the collapse of USSR. Several reasons caused this decline, such as the low uranium content of the Kazakhstan ores, falling prices in the world uranium market and the possibility to extract uranium by the more profitable ISL method. Currently, uranium production by conventional mining in Kazakhstan is practically non-existent.

2.2.2. ISL method

The discovery in ChSR of deposits amenable for the ISL method in the 70s, lead to the initial uranium production by this method at the Uvanas deposit (Stepnoe mine) in 1976. An additional two mines were put into operation very quickly: Tsentralnoe mine at the Moynkum deposit and Mine No. 6 at the North Karamurun deposit (Fig. 2). These mines are part of the National Atomic Company Kazatomprom and are producing more than 1500 t U per year. Kazatomprom is one of the world's largest producers of uranium by the ISL method. The company plans to increase uranium production. For this purpose, two satellite operations at the South Karamurun deposit (Mine No. 6) and at the Akdala deposit (Stepnoe mine) are being put into operation. In addition, two joint ventures: Inkay (together with Comeco) and Katco (together with Cogema) have received licences and have begun construction of their own ISL uranium operations. It is planned by 2005 to bring the uranium extraction in Kazakhstan up to 4500 t U per year. The reality of this plan certainly depends on the world uranium market.

The ISL operations are located in a semi-desert region, which is generally unsuitable for agricultural use and subsist through unique astrakhan farming. Activity of ISL mines as well as mining production has positively impacted the economy of this semi-desert region. Two small towns near Stepnoe and Tsentralnoe mines were built, new roads, electrical lines and water-pipe were constructed. At the same time, both mining production and ISL mines have had a detrimental impact on the environment.

3. ECOLOGICAL PROBLEMS CONNECTED WITH URANIUM PRODUCTION

3.1. Mining production

Uranium mining has had negative impacts on the environment. These impacts are seen in contamination of the soil and vegetation, hydrogeological and hydrochemical changes in surface and underground waters, and the formation of radioactive wastes. Due to the comparatively low uranium content of the uranium ore in Kazakhstan (especially in the Pricaspian region), a large quantity of Radwaste (about 235 mln. t) was formed during uranium extraction. The storage sites for this Radwaste have not yet treated for various reasons. One of the main reasons is the collapse of uranium enterprises after the USSR disbanded.

In 1996-98, special work was carried out on the inventory and characterization of the Radwaste storage sites in Kazakhstan [2]. As a result, about 100 storage sites were located but only 22 of these sites contained nearly 98% of all Radwaste. These sites are shown in Table 1 and Fig. 3. It has been determined that the dumps do not significantly impact the environment due to natural conditions in Kazakhstan (dry climate and limited population). The danger is primarily the uncontrolled use of dump material for construction purposes.

TABLE I. DISTRIBUTION OF THE WASTE ROCK DUMPS AND TAILINGS IMPOUNDMENT IN KAZAKHSTAN

№	Name of deposit or Productian Centre	Region	Type of waste	Volume (1×10^3t)	Nearest settlement (km)
1.	Ulba Centre	East Kazakhstan	Tailings	420	0.5
2.	Pricaspian Centre	West Kazakhstan	Tailings	120 000	6
3.	Tselinny Centre	North Kazakhstan	Tailings	88 330	5
4.	Deposit Botaburum	South Kazakhstan	Dumps	3 681	1.5
5.	Deposit Kurday	South Kazakhstan	Dumps	6 280	3
6.	Deposits Sections 2 and 4	South Kazakhstan	Dumps	2 130	6
7.	Deposits Sections 7 and 11	South Kazakhstan	Dumps	396	20
8.	Deposit Chaglinskoe	North Kazakhstan	Dumps	1 772	12
9.	Deposit Balkashinskoe	North Kazakhstan	Dumps	576	5
10.	Deposit Shokpakskoe	North Kazakhstan	Dumps	866	3
11.	Deposit Ishimskoe	North Kazakhstan	Dumps	568	6
12.	Deposit Manybay	North Kazakhstan	Dumps	6 340	0.5
13.	Deposit Ulken-Akzhal	East Kazakhstan	Dumps	19	27
14.	Deposit Panfilovskoe	South Kazakhstan	Dumps	13	0.1
15.	Deposit Kosachinoe	North Kazakhstan	Dumps	290	1.5
16.	Deposit Glubinnoe	North Kazakhstan	Dumps	123	0.5
17.	Deposit Zaozyornoe	North Kazakhstan	Dumps	568	6
18.	Deposit Shatskoe	North Kazakhstan	Dumps	430	2
19.	Deposit Tastykol	North Kazakhstan	Dumps	638	6
20.	Deposit Grachyovskoe	North Kazakhstan	Dumps	448	2
21.	Deposit Agashskoe	North Kazakhstan	Dumps	131	2
22.	Deposit Viktorovskoe	North Kazakhstan	Dumps	100	2

The tailings from uranium ore processing at the Pricaspian and Tselinny Production Centres became a significant danger due to the formation of dusting beaches after uranium production ceased. Tailings of Ulba Production Centre are also a significant danger due to infiltration of radionuclides into the ground water, which is used by the population of the Ust-Kanenogorsk. Currently, a programme for remediation of all the Radwaste storage sites, including the Ulba Centre, is being developed for approval by the government of Kazakhstan.

3.2. ISL method

Currently, an active interest is being paid to the ISL method by world uranium producers. Uranium extraction is already successfully carried out in several countries. Uranium production by the ISL method has considerable economic and ecological advantages. The main ecological advantages compared to conventional mining method are as follows:

(a) less surface damage,
(b) less Radwaste formation and radionuclide contamination,
(c) lower remediation costs.

Uranium extraction without surface damage is a very important factor for restoration of the land after cessation of ISL extraction. Large volumes of Radwaste are formed by conventional mining. The quantity of Radwaste depends on the uranium content in the ore and often reaches 1000-3000 kg per one kg of extracted uranium. With the ISL method, the amount of Radwaste does not exceed one kg per one kg U. By improving production techniques, there is a possibility that in the future, waste formation can be further reduced to 0.1 kg/kg U.

Remediation of the Radwaste storage sites after ISL operations includes surface rehabilitation and treatment of the ore bearing aquifer. Surface rehabilitation has no special problems. The problem of

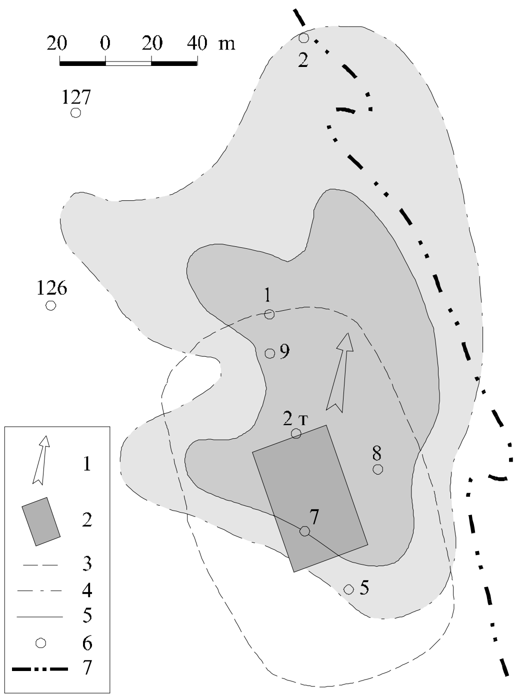
aquifer treatment costs deserves special consideration. We emphasize that there are now some data, which dispute a myth of the first years of ISL use about the economic impossibility of treating an aquifer contaminated by the ISL process using sulphuric acid.

4. ESTIMATION OF ENVIRONMENTAL IMPACT OF THE ISL URANIUM EXTRACTION IN KAZAKHSTAN

As mentioned previously, ISL uranium extraction in Kazakhstan is carried out using sulphuric acid. Uranium deposits are located in permeable Paleogene-Cretacious sand sediments. Ore bodies occur at depths from 100 to 800 m. Uranium extraction is mainly carried out in the sparsely populated semi-desert areas. Of course, during uranium extraction, there is radionuclide contamination of the aquifer, which has a detrimental effect on the environment. Kazakhstan Laws require reclaimation of the aquifer to pre-leach conditions after cessation of ISL extraction. Currently, there are effective methods of treatment. Treatment is commonly carried out during 2-3 years and incurs significant costs (up to $4 per one kg extracted uranium). Is it needed for Kazakhstan? The following facts should be kept in mind when considering this problem:

First, deposits of the Chu-Syrdarya region are largely located in areas of high salt content in the ore-bearing aquifers and where the underground water is unsuitable for use. Secondly, natural contamination occurs in these areas when radionuclides, heavy metal salts, and sometimes selenium form at the redox front (geochemical barrier) in the aquifer where there are uranium ore deposits. This natural occurrence renders the water unsuitable for technical uses and is undrinkable.

Further, enough evidence has been gathered from experience in Kazakhstan and Uzbekistan to assure that restoration of the groundwater to pre-leach conditions after ISL is possible. After cessation of ISL extraction, self-treatment and demineralization can offset the pollution formed in the aquifer during uranium extraction. This fact is convincingly shown by M. Fazlullin based on his observation of results at the uranium deposits worked out by the ISL method in Uzbekistan [3].



1 – movement direction of underground waters; 2 – test area; 3–5 – acid solution excursion boundaries: 3 – December, 1976; 4 – December, 1978; 5 – May, 1982; 6 – drill holes; 7 – redox front

FIG.4. Aquifer self-treatment at the Kanzhugan deposit for 6 years after the ISL completion.

Observations at the Kanzhugan test area in Kazakhstan [4], which were terminated due to commercial extraction beginning, also show a clear tendency of the acid solution halo decrease for six years (Fig. 4).

Currently, in connection with the licensing of uranium ISL projects, NAC Kazatomprom has been conducting investigations on the environmental impact of ISL extraction at four deposits in the Chu-Syrdarya region. The result of these studies will be presented in a special report, which will contain new data from these sites. This report will form the foundation for an official decision by the ecological authorities as to whether it is possible to leave the sites which have had uranium extracted by ISL method to natural restorative processes rather than treating the aquifer through other means.

5. FUTURE OF THE URANIUM PRODUCTION IN KAZAKHSTAN

The impact of extraneous influence on the uranium industry in Kazakhstan is reflected in the fact that Kazakhstan today produces only about 4% of world's uranium production although it has more than 20% of the world's uranium reserves. For comparison, Canada has about 11% of the world's reserves and about 32% of the production. In addition, Kazakhstan has more than half of the world's uranium resources amenable to extraction by the ISL method. This allows for NAC Kazatomprom to discontinue conventional uranium mining and, since 2000, to completely produce uranium by the ISL method.

Sulphuric acid ISL technology in Kazakhstan produces uranium with low costs and low environmental impact. NAC Kazatomprom has extensive experience using this technology in areas with various conditions of deposit occurrence, ore body thickness and ore body depths up to 750 m. These facts allow Kazatomprom to prepare plans for increasing uranium production up to 4500 t U per year by 2005. In the future, production could be even higher under favourable conditions in the world uranium market.

Main tasks for the future development of the uranium industry in Kazakhstan are as follows:
(a) updating and construction of new ISL operations to increase the production capacity;
(b) perfecting techniques and leaching technology, using new geotechnological systems and oxidants;
(c) completion of investigations for comprehensive estimation of the environmental impacts from ISL extraction and the approval by the government of aquifer self-treatment as the method of aquifer remediation after cessation of ISL extraction.

Thus, with the availability of a practically unlimited uranium base suitable for the ISL method, the use of this method instead of mining, will allow Kazakhstan to develop a successful uranium industry in the 21st Century with negligible negative environmental impact.

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Uranium production and environmental restoration at the Priargunsky Centre, Russian Federation

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Abstract. State JSK "Priargunsky Mining-Chemical Production Association" (PPGHO) has been the only active uranium production centre in Russia during the last decade. Mining has operated since 1968, and derives from resources in 19 volcanic-type deposits of Streltsovsk U-ore region, which covers an area of 150 km^2. The average U grade is about 0.2%. Ten deposits have been brought into production: eight by underground mines and two by open pits. Milling and processing has been carried out since 1974 at the local hydrometallurgical plant by sulphuric acid leaching with subsequent recovery by a sorption-extraction ion exchange scheme. The high level of total production (over 100 000 mtU through 2000) marks it as one of the outstanding uranium production districts worldwide. Significant amounts of wastes have been accumulated. The main sources of the environmental contamination are: 30 piles of waste rocks and sub-grade ores, mine waters, milling and sulphuric acid plant tailings. The following activities are performed to decrease the negative impact on the environment: rehabilitation of waste rock dumps and open pits utilization of waste rock for industrial needs, heap and in situ leach mining of low-grade ores, construction of dams and intercepting wells below the tailings, hydrogeological monitoring and waste water treatment plant modernization. Environmental activities, including rehabilitation of the impacted territories and also waste utilization will be realized after final closure takes place.

1. SITE CHARACTERIZATION

State JSK "Priargunsky Mining-Chemical Production Association" (PPGHO) has been the only active uranium production centre in Russia during the last decade. It is located in Chita region of Russia, 10–20 km from the town Krasnokamensk with about 60 000 population. Priargunsky Association is an integrated facility including uranium (mines, processing plant, mill tailings) and non-uranium (power plant, coal and manganese open casts, workshops etc) units, all of which require environmental activities.

Principal historical dates:

— 1968 - mining started;
— 1969 - plant for effluents treatment was built;
— 1973 - construction of acid and milling plants;
— 1974 - U milling and production started;
— 1977 - environmental laboratory was organized;
— 1988 - environmental department was organized.

Mining operations include two open pits (both are depleted) and three underground mines (Fig. 1). Milling and processing has been carried out at the local hydrometallurgical plant by sulphuric acid leaching with subsequent recovery by a sorption-extraction ion exchange scheme. Since the late 80's some amount of low-grade ore has been processed by heap and underground in-place (or block) leaching. The high level of total U production (about 100 000 t) marks Priargunsky as one of the outstanding production centres worldwide [1].

The production from the Streltsovsk U-ore region is based on 19 volcanic-type deposits with an average U grade about 0.2%. The area covers about 150 km^2 [2]. Uranium mineralization occurs to a depth of 1100 m and lower.

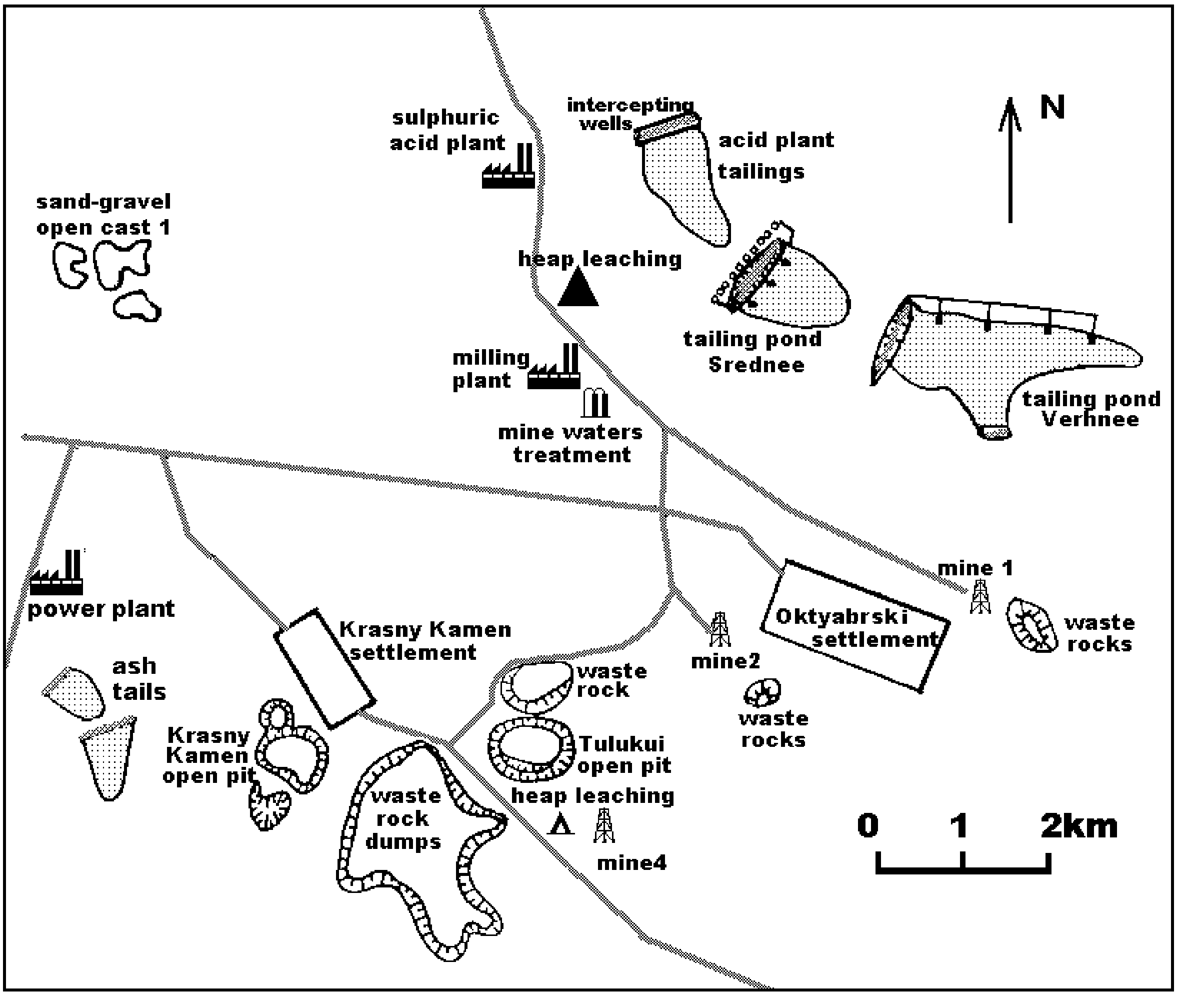

FIG. 1. Operation units of Priargunsky association.

Approximately 75% of the resources of the Streltsovsk district are in a depth interval from 200 to 600 m below surface where ore lodes are distributed at several levels in stratified sedimentary volcanogenic rocks. About 25% of the resources are situated at lower levels between 400 and 900 m deep. They are mainly contained in the two large and relatively high-grade deposits hosted by granite and with a marble basement.

Mineralization is largely controlled by structures reflected by predominantly vein and stockwork ore lodes. Monometallic uranium and polymetallic uranium-molybdenum ores are distinguishable. Since the discovery of the district in 1963, ten deposits have been brought into production, eight by underground mines and two by open pits.

Dominant production comes from underground mining of relatively high-grade ores (0.3 to 0.4% U). A limited amount of uranium (about 100 t U) is produced from the low-grade ores by heap leaching and in place (or block) leaching methods.

2. ENVIRONMENTAL IMPACT

Significant amounts of solid, liquid and gaseous wastes have been produced since 1968 (Table 1) [3, 4].

TABLE I. GENERAL CHARACTERISTICS OF WASTES

Type of waste	Area, ha	Amount, Mln. tn.	Volume, ths.m^3	U grade %	Radioactivity $\times 10^{-9}$ Ci/kg	Rn emanation $\times 10^{-3}$ Ci/m^2 y
Mill tailings	377		49 430	0.009	30-750	0.93-23.2
Acid plant wastes	125		6 180	Traces	30-250	-
Waste rock piles	340	153		0.002	27-80	0.84-2.50
Heap leaching sites		6		0.009	27-350	0.84-11.0

The aggregate area of radioactive contamination is 842 ha:

- 723 ha at the industrial site with the level 60 from to 240μR/hr,
- 119 ha in the sanitary protection and observation zones with the level below 60μR/hr.

The main risk for ground water contamination comes from the tailings of the hydrometallurgical operation and the sulphuric acid plants.

2.1. Mining waste piles

Mining activities produce the following contamination:

- emission of radioactive and blasting gases to the atmosphere;
- contaminated mine waters;
- waste and sub-grade waste rock accumulation.

Current uranium mining is carried out only by underground operations. About 0.2 to 0.4 tons of waste rock or sub-grade ore is generated for each ton of ore mined. Over 150 mln. tons of waste rocks and more than 2.7 mln. tons of sub-grade ores have accumulated in 30 waste rock dumps since 1968. Over 5.6 mln. tons of low and sub-grade ores have been placed for heap leaching. Total area of waste rock piles covers more than 340 hectares [5].

Waste rock dumps are generally not radioactive. Nevertheless, they can be a potential source for radionuclide migration to the atmosphere, soil and water. It is necessary to note that the radon and the long life alpha-nuclide concentration at 100 to 250 m from piles are close to background. The radioactivity decreases from 50–100 μR/h directly on a waste rock pile to 20–25 μR/h at a distance 200–250 m from it.

2.2. Mine waters

Mine waters are radioactive, bacterially infected and have a high dissolved mineral content. Their annual volume exceeds 8.5 mln·m^3. Since 1993, all mine and mill wastewater has been treated at the special water treatment plant. The flow sheet includes a precipitation circuit using chemical reagents (much of lime), a polyacrylamide as flocculent and green vitriol. The capacity is 1000 m^3/hour. The treatment process removes suspended matter, radionuclides, manganese, heavy metals and uranium. Effectiveness for U, Mn and radionuclides treatment is over 90% [5].

Normally, 5.4 mln·m^3 of treated mine water is used annually for milling plant needs and the remaining 2.6 mln·m^3 is discharged to the Umykei lakes. The water is also used to prepare the underground packing mix. The treated mine water, however, cannot as yet be used for other needs (agriculture, municipal services etc.).

2.3. Milling plant effluents

The milling plant, which processes up to 3500 tons of ore per day, produces significant amounts of solid, liquid and gaseous wastes. The plant consumes up to 3–4 m^3 of water per ton of ore leached. Only treated mine water is used in the milling operation.

Typically the concentrations of aerosols long life alpha nuclides, radon, its decay products and ore dust are low. More often the adverse environmental effect of non-radioactive harmful chemical substances such as ammonia and nitrogen oxides is more critical. The limits for each contaminant are established at the milling plant and controlled regularly.

2.4. Tailings

Two tailings impoundments enclose the milling plant wastes: Verhnee and Srednee (Table 2). During the past several years, the Verhnee tailing pond was the main impoundment, and Srednee was used only during pipelines repair. Table 2 shows tailing pond volumes [6]. Uranium grade in the solid mill wastes is about 0.010% U.

TABLE II. VOLUMES OF TAILINGS IMPOUNDMENT

Parameters	Mill tailing Verhnee	Mill tailing Srednee	Acid plant tailings
Upper level of embankment, m	706	660	648.8
Water table, m	697.8	656.7	642.3
Permitted level, m	698	658	646.1
Level of protection cover, m	699	659	347.7
Volume of impoundment, ths. m^3	46 055	3 377	6 179
Square of impoundment, ths. m^2	3 025	741	1 251
Square of liquid table, ths. m^2	1 775	384	1 021

Tailings impoundments are a significant source of potential environmental contamination. Milling tails contain appreciable amounts of radionuclides such as ^{226}Ra, ^{230}Th, ^{210}Po and ^{210}Pb. The principal emanation comes from ^{222}Rn and its short-life decay products as the result of beaches dusting.

Probable liquid waste seepage through tailing pond beds can affect underground waters and contaminate them. Continuous monitoring of observation wells shows that in 1997, after new intercepting wells were constructed, the water table decreased and contaminated aureole migration was stopped. However, high concentrations of sulphate-ion, manganese, copper and nitrate ion are noted in the wells located close to mill tailings.

3. WASTE MANAGEMENT

Waste management is carried out by an environmental survey organization according to the state laws and instructions. The environmental survey departments of PPGHO include the following:

- an environmental department to co-ordinate environmental activities of all services and divisions;
- environmental service facilities for controlling atmosphere pollution and harmful chemical substances concentrations in liquid wastes;
- a radiation and radiological safety service, for controlling industrial wastes and radioactive emissions to atmosphere, soil and water.

Annual limits for solid and liquid wastes at Priargunsky include: uranium sub-grade ores 150 000 tons/year; waste rocks 300 000 tons/year; treated mine water 2800 ths.cub.m/year; and a total wastewater discharge of 22 500 ths.cub.m/year.

The following activities are performed to decrease the negative influence of **waste rock** on the environment [5,7]:

- rehabilitation of waste rock piles;
- irrigation of dusty waste surfaces and roads;
- utilization of waste rock for industrial needs, i.e. for tailing pond dam, road and hydraulic engineering construction;
- development of heap leaching mining for low- grade ores.

The problem of waste rock utilization and dumps rehabilitation is urgent and requires immediate action. The project of Tulukui and Krasny Kamen open pits rehabilitation has been adopted.

One of the main environmental problems is **water supply**. All water sources (technical drains, power plant effluents, and treated mine waters) are confined to the system of Umykei inland lakes. Normally, 69% of the treated mine waters is used for milling and processing and remaining 31% is discharged to Umykei lake [5]. Further development of recycling water supply systems as well as clarification of mining and technical waters will allow the PPGHO to:

- stop completely technical water supply from Argun river and to preserve the storage pond;
- return the surplus of treated sanitary and technical waste waters to the Argun river;
- reduce waste water discharge to the Umykei lakes.

The **tailing pond** is considered as most dangerous unit, because of the large amount of accumulated radioactive wastes and possible overfilling. The potential threat of a dam accident together with waste seepage to Urulungui and Argun rivers exists at the mill tailings pond. Environmental activities [5,7] include:

- monitoring of the tails neutralization operation to reduce the toxic substance content in clarified tailing water;
- strengthening of dam bodies and building protective dams around the potable water wells;
- construction of new intercepting wells below the tailing pond dam and effective operation of existing wells;
- hydrogeological monitoring through special wells.

However, the construction of a special plant for liquid wastes treatment is considered to be the most desirable approach.

The following activities are performed to reduce **radionuclide emissions**:

- closure of old or stand by mine drifts, bore pits and ventilating shafts;
- isolation of underground mines by special crosspieces and concrete;
- complete water saturation of tailing ponds surfaces and beaches for dusting prevention;
- increasing efficiency of power plant filters to reduce ash emission in atmosphere.

4. MONITORING

Laboratories for radiation safety, waste testing and radiochemistry perform systematic monitoring [5,7].

4.1. Atmosphere

The integrated atmospheric protective zone exceeds 100 km^2. A number of permanent atmosphere monitoring stations are located within the zone to measure the concentration of most toxic chemical elements, ^{222}Rn, long life alpha nuclides, natural uranium, ^{226}Ra, ^{230}Th, ^{210}Po and ^{210}Pb. The emission of toxic substances must not exceed the limits that come from non-uranium facilities. Radiation monitoring of the personnel and the environment in mines and the mill show that the level of harmful factors (latent energy, radon emanation, alpha-contamination, dose rate etc.) generally meet the required standards.

Atmosphere monitoring is generally performed for sulphuric dioxide, nitrogen oxide, carbon dioxide, ammonia and dust content. Their amount varies from 9 to 74% of the estimated limits. The maximum concentrations of nitrogen oxide and sulphur dioxide are found in the effluents from the power plant and the sulphuric acid plant.

About 500 annual air samples from Krasnokamensk show that only minor ammonia and sulphur dioxide elevations are present.

The toxic substance contents (dust, NOx, NH_3, SO_2) are also monitored at the uranium heap leach sites, in the mill and in the sulphuric acid plant tailings. Toxic concentrations in the dust exceed the limits in only some samples.

Annual radiation doze rate for population does not exceed 1 msv. Environmental radiation and toxic chemical concentrations now basically meet the State regulators norms and requirements.

4.2. Ground waters

Monitoring for ground water quality is performed through a system of 111 wells and local monitoring wells around tailings, heap leaching sites, slag heaps etc. During 1998, 326 water samples were analysed for 7800 element-measurements. Portable water quality satisfies the regulatory norms except for the fluorine content, which is naturally present.

4.3. Solid wastes and soil

Monitoring of mill and acid plant tailings (42 observation points), power plants tailings (eight observation points) and waste rock piles is performed to prevent contamination in the protective zones. The principal activities include chemical composition and physical property measurements, estimation of the impoundment areas and volumes, etc. Special monitoring for soil and grass was performed in 1999 to evaluate the contamination in the protective zone near tailing ponds.

5. CONCLUSION

Significant amounts of uranium and wastes have been produced at Priargunsky for more than 30 years. The results of monitoring show that the impact of mining and milling on the environment is generally similar to that of other conventional uranium producing centres in the world, and it is minimized by proper environmental activities and waste management. Isolation of mill tailings, treatment of mill wastes, reclamation of mine waste rock piles and rehabilitation of closed mines – are the most important tasks for further activities and studies. The total rehabilitation of all impacted territories will be carried out after closure of the mining and milling operations.

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Acid rock drainage in the uranium mining and milling site of Poços de Caldas, Brazil — duration assessment, pollutant generation modelling and remediation strategies

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Abstract. This geochemical modeling work was carried out to simulate the acid drainage generation from one of the waste-rock piles at the Poços de Caldas uranium mining site. The mathematical code STEADQYL was used. The estimated results were in good agreement for sulphate and uranium concentrations and the duration of the acid water generation was estimated to be about 500 years. The effect of covering the dump with a material that minimized oxygen diffusion was assessed. Projections indicated that covering the dump with a 1.0 m thickness of a material (like clay), which had an oxygen diffusion coefficient of $10^{-9} m^2.s^{-1}$, would reduce the pollutant concentrations to acceptable values. The estimated cost, when using this strategy, would be about US $10 million.

1. INTRODUCTION

Open pit mines involve moving large amounts of overburden that are subsequently disposed in waste rock piles. If pyrite is present, acid drainage may result. The disposal site for the waste rock is typically determined by convenience and the accessibility of the site to the mining operation; usually the choice is not based on considerations that facilitate environmental management and remediation. If the mine operator has a fair understanding of how the design of the waste pile can mitigate acid drainage generation, improved layout and design of waste rock piles may be achieved.

The chemical composition of the acid drainage is controlled by the pyrite oxidation rate, which is a function of temperature, pH, oxygen concentration, composition and amount of infiltrating water and the population of micro-organisms [1]. The proportions of different oxidation and reaction zones in a waste rock pile will depend on the rate that the pile is being oxidized and also on the rate and pathways of water transport through the pile. The region under oxidation can encompass the whole dump or may embody a thickness of only few meters. Moreover, due to the heterogeneity of the material forming the pile, the oxidation regions may differ in size throughout the dump.

Oxygen transport into the dump is governed by three major processes:

(1) Transport as dissolved O_2 in the infiltrating water;
(2) Diffusion of O_2 gas through rock pore spaces and;
(3) Advective transport of O_2 gas through rock pore spaces.

Because the leach solutions cannot carry significant oxidant with them as they move through the dump, air infiltration is the main source of oxidant. Diffusive transport is the major process of oxygen transport in the vast majority of cases. Oxygen removed from the dump pore space in the process of pyrite oxidation will establish a concentration gradient in the pore space. Despite the fact that gas removal will set up a pressure gradient, the gradient will be rapidly dissipated by mass transport of air.

Intrinsic Oxidation Rate (IOR) is a key parameter for understanding how oxidation is taking place in a dump. It is merely the rate of oxygen consumption by the material deposited in the dump under the conditions applicable to the particular case and is a function of a large number of variables including pore-gas oxygen concentration, particle-size distribution, mineral surface area, bacterial population, temperature, pH, and ferric ion concentration. If one considers the possibility of including the

functional dependence of the IOR on these variables, numerically intensive calculations will be generated.

The IOR in pyritic waste rock is a critical parameter for estimating the acid-drainage potential and its probable duration. The IOR parameter should be of a form that is physically reasonable and that allows the following goals to be achieved:

(a) identification of the mechanisms controlling the global oxidation of the pyritic material in the pile;
(b) planning the appropriate remedial actions;
(c) assessing the rehabilitation schemes to be applied;
(d) assessing the building construction techniques
(e) quantification of pollutant loads, with emphasis on the peak values and the related time for its occurrence.

Values of IOR in the range of 10^{-8} to 10^{-9} kg $(O_2)m^{-3}.s^{-1}$ are typical for a large number of waste rock piles [2]. Values greater than 10^{-7} can be considered extremely high, whereas values around 10^{-10} are related to marginal acid drainage environmental problems.

Temperature and oxygen profiles can be analysed both to define the oxidation rate in a region of pyritic material and to determine the dominant gas-transport mechanisms. With this information and data on bulk physical properties of the dump material, the primary pollution-production rate can be calculated; from this result an estimate can be made of the time dependence of pollution load in drainage from the base of the waste rock dump.

A sequence of lined drill holes can be used to obtain pore-gas oxygen concentrations and temperature profiles within the dump. Enough probe holes should be installed to obtain profiles through the various types of material present in the pile. In situ measurement of oxygen concentrations and temperature profiles in a waste pile is the best way to assess the IOR and subsequently predict the potential for generating acid drainage and its duration. It should be pointed out, however, that other techniques are available to deal with the problem.

The waste rock pile (WRP-4) of Poços de Caldas mining site, the object of the present study, was chosen because most of the infiltrating water is collected in a single holding pond. This situation represents a particularly unique opportunity that is not generally available and has not been previously exploited. This allows for checking the accuracy and internal consistency of the geochemical modelling predictions.

The objective of the present work was to study and investigate the rate and degree of acid drainage generation in the WRP-4 waste pile by means of geochemical modelling and to recommend possible remediation strategies.

The results from this work are expected to contribute to the study of problems associated with acid mine drainage prediction and management and should also support the decisions concerning the remedial actions to be implemented by the mining operator.

2. DESCRIPTION OF THE STUDY SITE

The uranium mill site and mine are located on the Poços de Caldas plateau, in the Southeast region of Brazil. The alkaline complex corresponds to a circular volcanic structure that began forming in the upper Cretaceous (87 ma) and evolved in successive steps until 60 ma. This intrusion is rounded by the levelling of bed rocks consisting of granites and gneisses. These rocks are frequently cut by diabase dykes, amphibolites and gneisses.

These igneous-policyclic activities, of alkaline nature, associated with intense metassomatic processes and strong weathering, gave rise to a variety of rock types belonging to the Nepheline-Syenite family and to uranium mineralization.

The uranium enrichment in Poços de Caldas mine is related to hydrothermal events (primary mineralization) and to latter weathering processes (secondary mineralization).

The mine covers an area of about 2.5 km^2 and is divided into three mineralized units designated as ore bodies A, B and E for mining purposes.

The mining and milling facilities began commercial operation in 1982. However, the original intended production of 500 ton of U_3O_8 per year was never reached. As of 1995, 1172 tons of U_3O_8 were produced. During development of the mine 44.8×10^6 m^3 of rock were removed. From this amount, 10 million ton was used as building material (roads, ponds, etc). The rest was deposited into two major rock piles, waste rock pile 8 (WRP-8) and 4 (WRP-4). In contrast to WRP-8, all the drainage from WRP-4 is collected into a single holding pond.

3. RESULTS AND DISCUSSION

Geochemical processes can be divided into three groups based on their rates of reaction. Fast processes are assumed to proceed to equilibrium and can be modelled using equilibrium chemistry. Slow processes are assumed to proceed at a rate, which is *quasi-steady-state*, and therefore, can be modelled using chemical rate equations. Very slow processes are assumed to be slow enough that they have a negligible effect on the geochemistry.

The main purpose for using the kinetic modelling code, STEADYQL [3, 4] was to assess the value of the Intrinsic Oxidation Rate. Secondly, we aimed to develop a feeling for the equilibrium pollutant concentrations in the drainage. The model combines slow reaction kinetics with empirical rate laws and depicts rapid reactions as speciation equilibrium. The dissolution kinetics of primary and sulphide minerals are treated as irreversible processes far from equilibrium, and secondary phases are maintained in equilibrium with the aqueous phase. Speciation equilibrium is defined by the mass action equation where $C_{(i)}$ is molar concentration of species i; $K_{(i)}$ is the conditional stability constant; $X_{(j)}$ is free concentration of component j and $a_{(i,j)}$ is the stoichiometry coefficient j in species i:

$$C(i) = K(i) \prod X(j)^{a(i,j)} \qquad (1)$$

The equation for defining the kinetics of a process in terms of its constituent components has the general form:

$$R = \frac{\partial C_A}{\partial t} = k[C_A]^a [C_B]^b ... [C_N]^n \qquad (2)$$

Where R is the rate of reaction, t is time and k is the rate constant C_N is the concentration of the n-th component and a,b,c...n are the stoichiometric coefficients. The rate of each process is converted to a flux, J, of material entering or leaving the system. The general form of the flux equation is given by:

$$J_{l,j} = s_{l,j} \prod_m P_m^{wl,m} \prod_i C_i^{ni,j} \qquad (3)$$

Where $\mathbf{J_{l,j}}$ is the flux of component **j** due to process **l** (the units are mol per unit area per unit time), $\mathbf{s_{l,j}}$ is the stoichiometric coefficient of component j in process l,

$$\prod_m P_m^{wl,m}$$

Captures all modifying or normalising parameters for the $J_{i,j}$ flux (these may include the rate constant, reactive area constraints, porosity and moisture content) and

$$\prod_i C_i^{nl,j}$$

Captures all concentration terms related to the flux. Under the conditions of quasi-steady-state, the sum of influent and effluent fluxes of the system must balance.

The chemical equilibrium/steady state problem is solved iteratively as follows: 1) The free concentrations of the components at steady state are estimated; 2) The corresponding concentrations of all of the species are computed from the mass-action equation; 3) The fluxes are calculated taking into consideration the concentrations of the species; 4) The concentrations of the species and the fluxes are then substituted into the mole-balance equations; 5) If all of the difference functions for the components are equal to zero, the mole balance equations are satisfied, and the problem is considered to be solved; and 6) If some of the differences functions are not equal to zero, the value of the difference functions and their derivatives with respect to the free concentrations of the component, are used to calculate improved values for the free concentration of components with the Newton-Raphson method. The process is repeated with the improved values until the mole-balance equations are satisfied.

The reactive surface area of the waste rock, $A_{r,tot}$ [$dm^2.dm^{-3}$] was treated as a dependent variable. The reactive surface area for a specific mineral $\mathbf{A_i}$, is assumed to be related to mineral volume abundance, v_i, and the calibrated total reactive surface area:

$$A_i = \chi_i A_{r,tot} [dm^2 / dm^3] \qquad (4)$$

$$\chi_i = \frac{v_i}{\sum_{j=1}^{n} v_j} \qquad (5)$$

$$A_r = \chi A_s 0.006 [dm^2.dm^{-3}] \qquad (6)$$

Where the figure of 0.006 stands for the accessibility factor [5, 6]. Differences in grain sizes and surface roughness between different minerals that could effect the distribution of surface area are neglected.

Physical surface area is approximately constant per volume rock and independent of the particle size distribution [6]. This value would be approximately equal to 100 $dm^2\ g^{-1}$, with no dependence on the size of the fraction between 0.1 to 4.7 mm. One can consider that this range is greater than the geometric area of the particles.

At an estimated bulk density for the waste rock of 2.8 $kg.m^{-3}$ and an assumed porosity for the heap of 15% [7] the physical surface area is on the order of 2000 $m^2 \cdot dm^{-3}$.

The infiltration rate [8] for the undisturbed rock at the mining area is 0.1 $mm^3\ m^{-1}\ year^{-1}$. This figure is 5% of the local precipitation rate. However, the dump surface is completely altered in relation to the original surface. It is suggested that 40 to 60% of the precipitation will infiltrate into the dump [9]. It is also reported [11] that infiltration in different dumps averages 50% of the total precipitation. Stromberg and Banwart [6] had reported an infiltration rate of 70% for a waste dump in Sweden. Since the infiltration rate for the current site is not known, we elected to use the value reported by these authors since the amount of water collected in the holding pond suggest the occurrence of high infiltration rates.

Based on the work of Cross et al. [7, 8] who used a kinetic approach to model the redox front movement in the Poços de Caldas mine and that of Nordstrom et al. [11] who modelled rock-water

interaction in the mine of Poços de Calda and Morro do Ferro, we estimated an average mineralogical composition for the WRP-4 waste pile (Table 1).

This mineralogical data could then be used, together with the kinetic rate and equilibrium constant data within the STEADYQL modelling code to estimate the composition of the drainage. The reactions considered in the modelling exercise and the associated expressions are shown in Tables 2 and 3 respectively.

TABLE I. ESTIMATED AVERAGE MINERALOGICAL COMPOSITION OF WASTE ROCKS IN WRP-4

Mineral	Volume Fraction
K-Feldspar	50%
Kaolinite	20%
Muscovite	20%
Fluorite	0.42%
Uraninite	0.12%
Pyrite	2%
Mn-Oxides	0.17%
Secondary Fe-Oxides	2%

The reaction constants and parameter terms (Tables 4 and 5 respectively) have been corrected by the Arrhenius expression to the estimated average temperature of the dump (45°C). The estimated equilibrium concentrations are given in Table 6 along with the average concentrations in the drainage from WRP-4.

TABLE II. REACTIONS CONSIDERED IN THE PRESENT STUDY

Mineral	Dissolution Reaction
K-Feldspar	$KAlSi_3O_8 + H^+ + 9/2\ H_20 \rightarrow K^+ + 2H_4SiO_2 + 1/2Al_2Si_2O_5(OH)_4$
Kaolinite	$Al_2Si_2O_5(OH)_4 + 6H^+ \rightarrow 2^Al^{3+} + 2H_4SiO_4 + H_20$
Muscovite	$2KAl_2[AlSi_3O_{10}](OH)_{2(s)} + 2H^+ + 3H_2O \rightarrow K^+ + 3Al_2Si_2O_5(OH)_4$
	$3Al_2SiO_2O_5(OH)_4 + 18H^+ \rightarrow 6Al^{3+} + 6H_4SiO_4 + H_2O$
Pyrite by O_2	$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$
Pyrite by Fe^{3+}	$FeS_2 + 14\ Fe^{3+} + 8H_2O \rightarrow 15\ Fe^{2+} + 2SO_4^{2-} + 16\ H^+$
Oxidation of Fe^{2+}	$4\ Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$
Hematite	$Fe_2O_3 + 3H_2O \rightarrow 2Fe^{3+} + 6OH^-$

TABLE III. EXPRESSIONS FOR PROCESSES

Reaction	Rate Equation
Kaolinite	$J_{ka} = K_{ka}\ P_{ka}$ (mol dm^{-2} s^{-1})
Pyrite by O_2	$J_{PyO} = K_{PyO}\ P_{PyO}\ [O_2]^{0.5}$ (mol$^{0.5}$ dm$^{0.5}$ s^{-1})
Pyrite by Fe^{3+}	$J_{PyF} = P_{PyF}\ [Fe^{3+}]$ (dm s^{-1})
Oxidation of Fe^{2+}	$J_{FeO} = K_{FeO}P_{FeO}[Fe^{2+}][O_2][OH^-]^2$ (mol^2 dm^{-7} atm^{-1} s^{-1})
K-Feldspar	$J_{Kf} = K_{Kf}\ P_{Kf}$ (mol dm^{-2} s^{-1})
Hematite	$J_{He} = K_{He}P_{He}$ (mol dm^{-2} s^{-1})
Muscovite	$J_{Musc} = K_{Musc}\ P_{Musc}[H^+]^{0.37}$
J_{in}	$J_{in} = vC_{in}$ (mol dm^{-3} s^{-1})
J_{out}	$J_{out} = vC_{out}$ (mol dm^{-3} s^{-1})

TABLE IV. REACTION CONSTANTS

Reaction	Constant
Kaolinite	$K_{ka} = 1.8 \times 10^{-15}$ (mol dm^{-2} s^{-1})
Pyrite by O_2	$K_{PyO} = 2.3 \times 10^{-2}$ (mol$^{0.5}$ dm$^{0.5}$ s^{-1})
Pyrite by Fe^{3+}	$P_{PyF} = 5.5 \times 10^{-9}$ (dm s^{-1})
Oxidation of Fe^{2+}	$K_{FeO} = 9.6 \times 10^{-13}$ (mol^2 dm^{-7} atm^{-1} s^{-1})
K-Feldspar	$K_{Kf} = 1.6 \times 10^{-15}$ (mol dm^{-2} s^{-1})
Hematite	$K_{He} = 5.0 \times 10^{-14}$ (mol dm^{-2} s^{-1})
Muscovite	$K_{Musc} = 3.24 \times 10^{-14}$ (mol dm–^{2}s–^{1})

TABLE V. PARAMETRIC TERMS

Reaction	Parameter Term
Kaolinite	$P_{ka} = 7.90 \times 10^4$
Pyrite by O_2	$P_{PyO} = 1.32 \times 10^4$
Pyrite by Fe^{3+}	$P_{PyF} = 1.10 \times 10^1$
K-Feldspar	$P_{Kf} = 1.78 \times 10^5$
Hematite	$P_{He} = 1.38 \times 10^4$
Muscovite	$P_{Musc} = 7.39 \times 10^4$

TABLE VI. ESTIMATED CONCENTRATIONS X OBSERVED CONCENTRATIONS OF CHEMICAL SPECIES IN THE WRP-4 DRAINAGE

Chemical Species	Estimated Concentration, (ppm)	Observed Concentration, (ppm)
SO_4	943	1010 ± 234
Al	53	118 ± 41
Fe	340	-
SiO_2	25	-
K (*)	63	7.73 ± 1.07
pH	4.34	3.3 ± 0.13

The model's prediction of sulphate concentration is very close to what is actually observed. This observation suggests that the derivation of the IOR by this method will be a valid approach. However, the model underestimates Al concentration by a factor of 1.8 and overestimates the pH value as well as K concentration by one order of magnitude. The aluminium concentration in the drainage results from the dissolution of muscovite, K-feldspar and kaolinite. The total Al production rate was predicted as being 2.25×10^6g.ha^{-1}.yr^{-1} with 72% of the Al load in the drainage coming from K-Feldspar dissolution, which also accounts for 90% of the produced silica. The production of K is mainly maintained by K-feldspar dissolution and to a lesser extent by muscovite dissolution. Both processes are acid consuming reactions along with kaolinite dissolution. K-feldspar dissolution alone accounts for 61% of H^+ consumption. The model overestimates the pH by one pH unit that represents one order of magnitude in terms of H^+ concentration. Thus the K-feldspar dissolution may be in charge both for the overestimation of K concentration and the pH. It is possible that the process of K-feldspar is not being well represented by the model and thus must be calibrated. It is important to observe, however, that the inconsistency between the predicted and observed values of pH and K concentration does not impact the estimation of the sulphate production rate.

It has been shown [12] that the uranium variations in the acid drainage follow the same pattern as sulphate. If the observed ratio between uranium and sulphate in the acid drainage were applied to the estimated sulphate concentration, a value of 160 Bq.L^{-1} would be obtained which is very close to the average uranium activity concentration of 175 Bq.L^{-1} in the drainage of WRP-4.

Pyrite oxidation by atmospheric oxygen is responsible for 99% of the generated sulphate, implying that oxidation by ferric iron is negligible. This finding supports the assumptions made earlier during

the mass balance calculations. The model also estimates an oxygen consumption of 7.2×10^5 moles ha^{-1} $year^{-1}$. If this value is converted to IOR units a figure of 3.3×10^{-9} $kg.m^{-3}.s^{-1}$ is obtained.

Finally, the estimated sulphate production is equal to 4.12×10^5 moles $ha^{-1}.a^{-1}$. This corresponds to a total production of 1.98×10^6 kg per year. It can be estimated that the total content of pyrite in WRP-4 is 6.20×10^8 kg. If this amount of sulphide is converted to sulphate stoichiometrically an amount of 1.0×10^9 kg would be produced. As a result, approximately 500 years would be necessary to consume all the sulfidic material in the dump.

One of the recommended remediation strategies is to cover the dump with a layer of an appropriate material that has an oxygen diffusion coefficient lower than the assemblage of rocks forming the dump. This would allow a reduction in the global oxidation rate by a significant factor. The reduction factor will depend to a very large extent on the cover properties rather than on the waste rock pile properties themselves [14]. The practical problem is to design a cover that remains relatively intact over a long period of time. The Global Oxidation Rate of the entity may be related to the cover thickness Xc and oxygen diffusion coefficient of the cover Dc by equation (7):

$$GOR = \sqrt{2C_0DS^*}\left(\sqrt{\alpha+n}-\sqrt{\alpha+n-1}\right) \qquad (7)$$

where:

$$\alpha = \sqrt{\frac{X_c}{D_c}\left(\frac{S^*D}{2C_0}\right)}$$

If it is required that the cover show adequate efficiency, α will have to be greater than unity. With the aid of equation 7 the sulfate concentration and load arising from the dump drainage was simulated for different cover thickness and oxygen diffusion coefficients. The infiltration rate was assumed to be equal to 50% of the total precipitation rate. The results are shown in Table 7. It can be observed that from the coefficient option 4 on, the reductions in the sulphate and uranium concentrations begin to be negligible.

It has been mentioned that the long term integrity of the covering system must be assured. As a result, a three layers cover system is usually employed. The system comprises a lower granular layer, an intermediate one of low gas permeability and an external one of sand and gravel to avoid the erosion of the system by rain and wind. The costs of a system like that adapted to the dimensions of the WRP-4 are represented in Table 8.

TABLE VII. EFFICIENCY OF THE DIFFERENT REMEDIATIONS APPYED TO THE DUMP

Dif. Coef. (m)	1×10^{-8} (1)	1×10^{-8} (2)	1×10^{-8} (3)	1×10^{-9} (4)	1×10^{-9} (5)	1×10^{-9} (6)	1×10^{-10} (7)	1×10^{-10} (8)	1×10^{-10} (9)
Thick.s. (m)	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
GOR kg/m^2s	1.8×10^{-8}	2.2×10^{-10}	1.1×10^{-10}	2.0×10^{-9}	1×10^{-9}	2.0×10^{-11}	2.0×10^{-10}	1.0×10^{-10}	5.0×10^{-11}
Load t/ano	139	75	38	15	7.7	3.9	1.8	0.76	0.34
$[SO_4]$ mg/l	287	154	78	32	16	8.0	3.7	1.58	0.79
$[^{238}U]$ Bq/L	49	26	13	5.4	2.7	1.3	0.63	0.27	0.13

TABLE VIII. COVERING SYSTEM ASSOCIATED COSTS

	US$/m^2	m^2	Total (US$)
Lower Layer	3.5	56.5×10^4	1.98×10^6
Intermediate Layer (low permeability)	11	56.5×10^4	6.22×10^6
External Layer (gravel and sand)	3.0	56.5×10^4	1.70×10^6
Total			9.9×10^6

It can be seen that approximately US$ 10 million would be necessary for the installation of a 3-layer covering system. Other possibilities were considered such as covering with a plastic material or the backfilling the open pit with the waste rock. The first option would cost US$ 12.7 million while the second one would amount to about US$ 70 million. It must be emphasized that these cost refer to only one of the existing waste rock piles at the site.

4. CONCLUSIONS

Acid drainage generation is a long term problem at mining sites where sulfidic material is present in the rock. We demonstrated that geochemical modelling could predict the rates of pyrite oxidation and concentrations of pollutants in the acid drainage. It was also demonstrated that pyrite oxidation is mostly through reaction with oxygen and that oxidation by Fe^{3+} is of minor importance.

Remediation should concentrate on the reduction of oxygen diffusion into the dump. This may be attained by covering the dump with some sort of material (e.g. clay or compacted clay) that has a lower coefficient of diffusion for oxygen and lower permeability to water than assemblage of the rocks at the surface of the dump. Future monitoring of the dump should aim to improve understanding of the actual infiltration rates applicable to the site and of the distribution of oxygen in the dump. These data may be obtained by installation of lysimeters (work in progress) and installation of oxygen probes to measure oxygen concentration at different depths in the dump (work to be developed).

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Problems of radiation safety at mined out uranium properties in Uzbekistan

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Republic of Uzbekistan was one of the main uranium production areas in former Soviet Union for more than 40 years. About 150 uranium production facilities have been constructed for that time in connection with hydrothermal and sedimentary-metamorphic deposits of the fold basement and stratal-infiltration deposits of the sedimentary cover. 18 of these facilities are located in Tadzhikistan and Kyrgyzstan along the boundary with Uzbekistan.

Exploration and operation activities in the deposits located in the fold basement were in general in form of mining. It was resulted in essential violation of landscape, development of various underground excavations, damps, tailing impoundments, lower grade stockpiles. All these need large volume of radioactive decontamination and restoration activities. 54 sites from 67 (80%) located in the territory of Uzbekistan need radioactive decontamination and restoration now.

Very serious radiation settings have occurred in some of these sites nowadays. Radioactive dumps of Cherkesar-I and Cherkesar-II mined out uranium deposits are out of any control in Fergana valley in Pap region of Namangan province. The radioactive materials are collected in dumps covered with neutral ground. The cover is washed out in some places by rains. Intensity of gamma radiation is 300 to 450 μr/h, radon exhalation is up to 7 Bk/m^2*sec (while the normal level is up to 1 Bk/m^2*sec). Water runs out from mothballed mines and its microelement composition is close to the composition of the technological solution. The water contains a number of very toxic elements (beryllium, manganese, iron, and aluminum). Water concentration of radionuclides is uranium - 23.4 Bk/1 (the normal level is 9.6), radon - 1433 (80), radium - 15.9 (0.94). The same set of the toxicants has been found in bottom sediment of a stream, its total alpha-activity reaches 35 to 81 KBk/kg. The spring water runs to a small valley and then to a village where the water is used for cattle watering and irrigation, that is hazardous for the local people health. Living in stone houses is also hazardous as they have been built of damp material and plastered with sand from Uigursai uranium deposit located in vicinity with the village. 250 living and public buildings have been examined. Gamma-activity level of 60 to 120 μr/h was observed in 50% of them, radon exhalation is 200-500 to 3000 Bk/m^3 (normal level is 100). The village habitants suffer from increasing rate of disease of blood, circulation and respiratory organs, urogenital system and oncologic diseases. Similar situation can be seen in other mined-out uranium facilities of the Republic (Yangiabad, Rezak, Shakaptar and others).

Radiation setting is happier in the cover mined-out facilities because the underground leaching (UL) technique, which is much more environmentally safer, was used there. However, local contamination of surface of the UL sites and, mainly, underground water of ore-bearing horizon occurs and preserves for a long time using this technique. Main reasons of the contamination are: technologic solution spillings, disbalance of pumping-in and pumping-out, solutions remained in leaching areas, running out of these solutions into neighbouring horizons. Sulphuric acid underground leaching has lead to essential deterioration of environmental condition of ore bearing horizon underground water in the site under operation. The underground water was assayed for 27 components. Major of them noticeably exceeds the ultimate permissible concentrations. These are, before all, the solvent components - sulphate-ions and ions of hydrogen, leached elements - uranium, iron, aluminum, manganese, some heavy metals and other toxic elements, products of technological processing -

nitrates and others. The highest contamination rate was observed for sulphates - 20 times and more, aluminum and uranium - hundreds times, iron and beryllium - thousand times.

In spite of the fact that areas of contamination in case of underground leaching are rather small and, as a rule, not exceed 100 m - 150 m radius from the UL site, the contamination is hazardous enough if the underground water is used in economics. As regime observations during 8-10 years have shown, the composition of technological solutions in the UL sites does not change essentially within the contour of lower oxide formation, at the same time, areas of underground water contamination expand to some extent. These date do not allow to hope the underground waters will be self-restored soon.

So, many tens of the mined-out UL sites in the territory of the Republic need to be reclaimed to restore initial quality of water, especially if water of ore-bearing horizons is fresh one.

The underground water reclamation provides restoration of the remaining solutions using to different extent a mechanism of sorption-capacity properties of the ground. The mechanism comprises 3 methods of decreasing underground water contamination within a mined-out block: by pumping out the remaining solutions and replacing them with stratal water ("washing" technique), by displacement of the remaining solutions with compressed air ("displacement" technique), or by intensifying natural demineralization using of increased rates of filtration of contaminated water in local volumes ("drawing" technique).

IMPACTS

Impact Assessment

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Environmental assessment in the uranium industry

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Abstract. The paper examines the subject matter to be dealt with in environmental impact assessments for uranium production facilities, the development of environmental impact statements and the processes used for assessing projects. Different types of regulatory process used to assess projects are described, using Canadian and Australian examples. Some of the techniques used in developing environmental assessments are described. Public participation, including that of special interest groups, is discussed. Some examples of assessments are examined, particularly looking at recent assessments for uranium mining projects in Canada. Trends in environmental assessment are described, using examples from a number of different projects over the past 25 years. Some recommendations for the future are offered.

1. INTRODUCTION

Although uranium ore was mined in the early 20th century, the primary interest was in the radium found in the ore, rather than in the uranium itself. The first great uranium boom came after the Second World War when the demand was for defence purposes. Environmental issues were clearly a secondary concern. By the late 1950s and early 1960s environmental agencies were starting to monitor uranium and other types of mining. The practice of formal environmental assessment has grown out of the increasing environmental awareness of the 1970s. The public concern over radioactivity accelerated the process, making uranium mining a leader for environmental assessment in the mining industry.

2. PURPOSE OF ENVIRONMENTAL ASSESSMENT

An environmental assessment examines the physical, biological and human environment in which a project is proposed to be sited, the nature of the project and the anticipated impacts on the environment, with a view to determining mitigating measures for significant impacts and ultimately judging the acceptability of the project, balancing the potential impacts against the benefits. The assessment process generally includes the production of an environmental impact statement (EIS), a document that describes the project, the environment, the anticipated impacts, potential mitigating measures and the costs and benefits of the project. This is followed by some procedure for reviewing the EIS and coming to a decision on whether or not the project should proceed and under what conditions it should proceed. Modern environmental assessments generally include some from of public input, but the details of how this is managed vary with the jurisdiction under which the assessment proceeds.

It should be recognized that all impacts and benefits of a project might not accrue to the same area or population. A mine may have local impacts that a small group of people may consider unacceptable, but the uranium from that mine may fuel a nuclear power programme that provides a greater benefit to the entire population of a country. In such a case the decision may be to proceed with the project and negotiate some reasonable compensation for the local population who may be directly affected by the project.

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3. PARTICIPANTS IN ENVIRONMENTAL ASSESSMENT

The participants in an environmental assessment fall into three groups: proponents, regulatory authorities and public. The proponent is the legal entity that is putting forward the proposal to develop the project, be it a new mine or a significant change to an existing operation. The proponent will make the applications for the necessary approvals, perform the necessary fieldwork, produce the environmental impact statement, conduct the public information programme, defend the project in the assessment process, respond to any requirements arising from the assessment, and initiate the project when the approvals are obtained.

The regulatory authorities are those authorities in a country that assess environmental impacts, issue licences for the operation of uranium mines and mills, monitor the operations and approve the decommissioning. Depending upon the location of the project, more than one level of government may have an interest in the development, resulting in more than one regulatory authority being involved and more than one assessment process being invoked. For greater efficiency most countries try to combine these interests into a single assessment process.

The public may comprise only the local inhabitants of the site of the proposed project, it may be the regional population, or it may be the entire population of the country. Public input may occur at several stages of the process. In some countries public meetings are held at the beginning of the process to solicit views on the issues to be addressed in the assessment. Whether or not this is a requirement, the proponent is well advised to seek the views of the public. After the EIS is issued, public comment is generally invited. In assessing the weight to be given to public input, proximity to the site is an obvious factor; however, the impacts on a small local population must frequently be balanced against the greater good of the country.

Some special interest groups use the public participation aspects of environmental assessment as a means of putting forward their particular views, whether or not they are directly relevant to the specific assessment. A second tactic is to use unfounded environmental arguments against a project. In both situations, the person in charge of the assessment, be it the chairman of a public hearing or a bureaucrat managing a less formal process, must exert strong control to ensure that submissions are relevant to the terms of reference of the assessment and that the process is not high jacked by over attention to matters of little or no importance. However, the proponent must also recognize that there are legitimate environmental groups who have a genuine interest in the project and their questions must be answered.

4. SCOPE OF ASSESSMENTS

Reference [1] gives detailed information on the contents of environmental assessments for uranium projects with examples and case histories from several countries. This section briefly summarizes the material in Reference [1].

Any proposed mining project is usually started with a feasibility study, which assesses whether or not the deposit can be economically developed. The feasibility study entails a definition of the ore reserves, a preliminary design of mining and milling methods, and the estimate of capital, operating and decommissioning costs, to be compared with the revenue that the sale of the product could generate. It is vital for a proper evaluation of a project that regulatory requirements and environmental impacts be considered. The cost of impact mitigation must be factored into the economic evaluation of the project. The environmental information to be considered at the feasibility stage is similar to that in the environmental impact assessment, but at a lower level of detail. The feasibility study should focus on those issues that could seriously affect the economics of the project.

The initial environmental impact assessment of a uranium mining project in a country may involve an examination of a broad range of moral and ethical issues, such as the potential for weapons

proliferation and the problem of used reactor fuel management. However, once these issues have been considered and the initial decision has been made to proceed with the programme, there should be no need to re-examine these policy issues for every new development that is proposed.

Material to be included in the assessment will vary with the type of project and the regional environment. For this reason, many jurisdictions start an assessment process with some type of scoping exercise to develop relevant guidelines for the assessment.

The location, type and size of ore body are important considerations in any assessment. General regional information must be developed on seismology, vulcanism, major fault zones, regional climate, etc. The environmental baseline must be described, including topography, geology, surface hydrology, hydrogeology, flora, fauna (in particular identifying any rare or endangered species), and background concentrations of trace metals and radionuclides in local air, waters, sediments, soils and biota. The data collection should focus on those environmental elements that that are likely to be affected by the proposed project. Generally data collections should be extended over four seasons, because local conditions and biological activity can vary widely (rainy *versus* dry season, hot summer *versus* frozen winter). Good environmental baseline data are important, not only for the assessment, but also as a record of initial conditions, which can be used to guide decommissioning activities.

The details of the ore body and local geology will usually dictate the type of mining method to be used. General mining considerations include mine de-watering, waste rock management, ore stockpiles, dusting, radon exhalation, infiltration of precipitation, acid generation, metals leaching, surface and groundwater contamination, management of contaminated equipment, and radiation protection. Additional underground mining factors are mining methods, ore and waste transport methods, use of back-fill, subsidence and mine ventilation. Open-pit mining must also consider slope stability. *In situ* leaching may be appropriate in some particular geological conditions, eliminating many of the issues related to waste rock management and ore stockpiles, but putting much greater emphasis on groundwater contamination control and liquid waste disposal.

The type of mineralization will generally dictate the milling process to be used. Particular issues here are hazardous chemicals, fire hazards, dusting, radon exhalation, radiation protection, tailings management, effluent treatment, air emissions and contaminated equipment management.

The transportation of mined material (ore and waste rock), chemical reagents and uranium product all have potential environmental impacts that must be considered. Spills and the attendant potential for air and water pollution, highway traffic accidents and public safety are all important considerations.

Socio-economic issues have become increasingly important in recent years. Impacts on local populations may disrupt current local lifestyles but there may also be positive impacts by providing employment in an otherwise depressed area. Current resource use, such as agriculture, wildlife harvesting, fishing, and tourism are important. Cultural issues must be considered, including both current conditions and archaeology and history. The costs and benefits of the project must be carefully weighed.

A conceptual decommissioning plan is needed, which will lead to an assessment of long term impacts after the project has completed its productive life and been shut down.

In some circumstances, where multiple projects are operating in a single region, cumulative impacts must be considered.

5. IDENTIFICATION OF SIGNIFICANT IMPACTS

After the baseline environmental data have been collected and the project description developed in detail, the probable impacts can be identified. These include impacts on the physical and biological

environment and also socio-economic impacts. The level of effort and detail devoted to baseline data collection and impact identification should be commensurate with the planned activities in the project. Both short and long term impacts during each phase of the project must be considered, e.g., construction, mining, decommissioning and post-decommissioning.

A useful tool for evaluating the importance of the various factors is ecological risk assessment [2]. This process identifies potential undesirable impacts, estimates the probabilities of their occurrence and evaluates the ecological consequences of these impacts, should they occur. Valued Ecosystem Components (VECs) are first identified, with their importance arising from their function in the ecosystem, their use as a food source, or their cultural, medicinal or scientific significance. End points for defining risks to these VECs in terms of chemical toxicity or radiation dose are established. Environmental pathways modelling is used to estimate environmental concentrations of contaminants emitted by the project. A screening index is established by dividing the estimated exposure from the pathways modelling by a benchmark toxicity level (generally from the literature), which would result in known effects. Where this index exceeds one, a potential risk exists that requires more detailed investigation. The modelling deals with uncertainties in the emission rates and the degrees of toxicity by performing Monte Carlo calculations to determine probabilities of impacts. It is important to remember that not all environmental factors are amenable to the quantification necessary to handle them by such computer modelling.

6. MITIGATION AND PREVENTIVE MEASURES

Having identified the probable impacts from the assessment, it remains to consider the significance of these and possible means of mitigation where the impacts are considered unacceptable. Some impacts may be so minor that they will be acceptable to all parties without further effort, but there are other situations where it is imperative to prevent or mitigate the predicted impacts. In some cases, the unacceptable impact may be avoided at the design or construction stage with relatively minor modifications to the original plan. However, some impacts may demand a major change, for example, the elimination of a particular milling reagent. It is important that the design and operating departments work closely with the environmental department at the planning stage to develop cost-effective mitigating measures.

Monitoring programmes generally flow from the findings of the assessment. The proponent proposes monitoring programmes based on the identified potential impacts and sensitive areas in the local environment. Regulatory agencies generally must approve monitoring programmes and often will make certain monitoring requirements a condition of the operating licence or permit. While early monitoring programmes tended to concentrate on emission monitoring, the trend has been towards more extensive programmes of monitoring contaminant concentrations in the natural environment around the operation. Most recently environmental effects monitoring has come into vogue, whereby effects of the discharges on identified important components of the local biological community are monitored. As these monitoring programmes become more complex, their cost rises dramatically. It is vital that the assessment identify good marker biota, if this type of monitoring is to be undertaken; otherwise, the costs of the monitoring programme could become an unsupportable burden on the project.

7. ASSESSMENT PROCESSES

The details of the assessment process will vary, depending upon the jurisdiction conducting the assessment. In Australia, environmental assessments may be required by the local, state or Commonwealth governments, or a joint process may be invoked [1]. In Canada, both the provincial and federal governments may require assessments [1]. Since local, state and federal legislation is usually not identical, the processes vary in detail. Unless special efforts are made at the beginning, it is quite possible that an assessment completed under one jurisdiction will not meet all the requirements of another jurisdiction. This could result in a project being subjected to more than one

assessment, which wastes money and consumes time, resulting in unnecessary delays in the project. The costs of environmental assessment are usually borne primarily by the proponent, but there are costs to the jurisdictions conducting the assessments. As environmental assessments have become more complex, and the processes more time-consuming, the risks increase of placing an overwhelming burden on the development of new projects. It is vital that agreement be obtained at the start that a single process will serve all interested jurisdictions, modified as necessary to meet the requirements of local, state and federal legislation.

Assessment processes generally require some form of public information programme or public input. This may take the form of information meetings, actively soliciting public comment, or holding public hearings. Hearings may be informal or quasi-judicial, with sworn testimony and legal counsel. Hearings are clearly more complex, time-consuming and costly than information meetings and simple requests for public comment. Less formal proceedings generally get broader public participation and are more apt to receive views from more people, because people are often awed by formal, judicial proceedings that are more like courtroom proceedings. On the other hand, sworn testimony with cross-examination eliminates a lot of unsubstantiated claims. Environmental assessments in Canada have been conducted under all three approaches: meetings but no hearings, informal hearings, and judicial inquiries. Aside from the costs of the EIS, the timing and costs of the processes have varied by two orders of magnitude, with meetings costing a few hundred thousand dollars, informal hearings a few million dollars and judicial inquiries costing over $10 million.

The Ranger Uranium Environmental Inquiry in Australia [3] was a federal quasi-judicial process with sworn testimony and cross-examination. In Canada, the Cluff Lake [4] and Key Lake [5] Boards of Inquiry were similar processes, but constituted by the Saskatchewan provincial government, rather than the federal government, and the expansion of the Elliot Lake uranium mines [6] was assessed by the Environmental Assessment Board by a similar process in the province of Ontario. In contrast, the original development and the recent expansion of the Olympic Dam Project in South Australia [7] and the first two phases of the Rabbit Lake Project in northern Saskatchewan underwent public review but without hearings. The third phase of the Rabbit Lake Project was initially assessed under the Saskatchewan process, with federal agreement, without a hearing, but the federal Atomic Energy Control Board, recently reconstituted as the Canadian Nuclear Safety Commission (CNSC) later demanded a public hearing and the project was re-assessed through the federal process [8]. More recently, five uranium mining projects in northern Saskatchewan (McClean Lake, Midwest Project, Cluff Lake Expansion [9], McArthur River [10] and Cigar Lake [11]) have been assessed through informal public hearings by a joint federal-provincial panel.

8. TRENDS IN ENVIRONMENTAL ASSESSMENT

It becomes apparent in reviewing 25 years of environmental assessment in the Canadian uranium industry, that the assessment process is becoming progressively more arduous. The level of public participation has increased dramatically, from the initial public information meetings to direct public involvement at several stages of the assessment. Intervenor funding is now made available to individuals and to organizations to enable them to conduct independent studies and compile presentations for the hearings.

The guidelines for EISs have become increasingly complex. For example, the guidelines for Cigar Lake and McArthur River [12] were drafted after input from public meetings in 12 communities, then given a 30-day public comment period before finally being issued. They comprised 78 single-spaced pages of issues to be dealt with by the proponents plus 22 additional pages of information requests to government agencies. With guidelines this complex, the EISs themselves have grown by an order of magnitude and the level of effort required has grown similarly. Field work to develop the necessary information for McArthur River had actually started before the project was referred to the Federal Environmental Assessment Review Office and continued through the assessment process. Before these studies were complete, 17 different consulting firms were used with specialties ranging from air

dispersion analysis, through aquatic biology, environmental pathways analysis, hydrogeology and radiation protection, to socio-economic impact assessment. In the 1970s, an EIS would consist of two or three volumes, numbering less than 500 pages. The McArthur River EIS occupied 15 volumes totalling 12 000 pages. After two days of information sessions for the panel, the panel issued a request for further information, which was supplied in an addendum of two volumes totalling 800 additional pages. The topics covered in the EIS included the expected ones, such as the baseline aquatic and terrestrial environment, rare and endangered species, regional geology and mineralogy of the ore body. Because this is an extremely high-grade ore body, mining methods, radiation protection and waste management were also of prime importance. An economic assessment was required to demonstrate that there would be a net public benefit from the development. However, in addition to these topics, impacts on community health and community vitality, and cumulative impacts also had to be assessed, despite the fact that the nearest community is well over 100 km away and the nearest other development is some 50 km away. The assessment of the operation included a regional ecological risk assessment to identify those factors of greatest significance, and environmental pathways analysis to predict the impacts during operations and on potential future occupants of the area long after the operations are decommissioned.

To accommodate this increased effort in production of EISs and the increased level of public involvement, the time to complete an assessment has greatly expanded. The most efficient assessment process was probably the 1978 assessment of the Eldorado Nuclear uranium refinery/conversion plant in Ontario [13], which took just nine months from the initiation of the project to the issuance of the panel report. This included the writing of three EISs for the three alternative sites under consideration; however, these sites had been considered in a previous assessment, so most of the information was readily available in a useful format. In contrast, the McArthur River environmental assessment took six years from the initial referral to issuance of the panel report. The Phase 1 construction licence took an additional six months for approval and the Phase 2 construction licence was approved a further nine months later. In total, the process from initial notification of the regulatory agencies to the final construction approval took seven years and four months. Production started one year and seven months later.

9. DISCUSSION

Although in the end the Joint Federal-Provincial Panel approved all five Saskatchewan projects in the 1990s, one must question the need for such a microscopic examination of what are really relatively small mining projects. It appears that the environmental assessment process has become so detailed and so all-encompassing that only extremely rich ore bodies could afford to support the costs that this work entails.

Northern Saskatchewan is an area of some 250 000 km^2 with a population of only 35 000. At the start of the process there were three producing uranium mines and four others planned. The nearest community to any of these mines is Wollaston Lake, which is 35 km from the Rabbit Lake mine. In many cases there is no road access between the mine sites and the communities. The uranium is generally found at the contact between the Archaean basement rock and the overlying Athabasca Sandstone. The Athabasca Sandstone Basin is not very productive, being sandy with low rainfall and low nutrient levels in the soil, and frozen for half the year. Hence, the Basin does not produce abundant food and there are no permanent settlements in the middle of the Basin. Despite this situation, great concern was expressed about the impacts of mines on communities and the cumulative impacts of the mines. The EIS guidelines required detailed examination of these issues.

In the past, the feasibility study and financial analysis that a company would do to satisfy its board of directors was considered sufficient justification for the economic basis of a project. A company was unlikely to invest money in a project that was not going to be profitable, and directors due diligence would not permit this to happen. However, for McArthur River and Cigar Lake an extensive economic analysis was required to publicly demonstrate that a market existed for the uranium, that the projects

were going to profitably recover that uranium, and that all interested parties would get their share of that profit. It was pointed out by more than one intervenor that the panel asking these questions had no one with business credentials in its membership to provide the necessary financial assessment. Fortunately, these projects had such clear economic benefits that it did not take a high level of business acumen to reach a proper conclusion. The problem that this type of analysis presents for the proponents is that much of their business is opened to public scrutiny, which can be very detrimental in a highly competitive market.

Socio-economic issues are getting much more attention. The examination of these issues has gone far beyond what has traditionally been required. Because of the remoteness of the mine sites and the lack of roads, all the northern Saskatchewan mines operate fly-in camps. Workers are picked up from small communities all over the north, flown to the mine sites, work for one week, and return home for a week off. These communities have grown beyond the capabilities of the local environment to support them by a traditional hunter-gatherer lifestyle, but because of their remoteness, there is little opportunity for wage earning. The mines are one of the few sources of employment and (quite rightly) the provincial government through its surface lease agreements with the mines encourages the preferential hiring of northern residents. However, in assessing the McArthur River and Cigar Lake projects, the panel asked that extensive information be gathered on the impact of hiring northerners for mine jobs. Naturally it was known and expected that fly-in camps were disruptive to family life and do not work well for everyone. However, when one considers that the traditional lifestyle required a trapper to be away from home for days, even weeks, at a time, there is little difference, except that the transportation to the mine is more reliable and the camp accommodation more comfortable than a trap line affords. Nevertheless, the impacts of this type of employment had to be examined, with questions even being raised as to whether or not it is a good idea to create economic divisions within the community by giving some people the well-paid mining jobs.

Questions such as the advisability of building roads were debated. Without exception the northern communities want roads to improve communication with the south and reduce the cost of bringing in supplies. But others, frequently not from the north, complained that building roads would open the north more and result in increased hunting and fishing pressure on limited resources. They also questioned the impact that easier communication would have on northern lifestyles. This debate did point out the generation gap, with many elderly people preferring the old ways (although recognising that these would no longer support the larger community), while the youth clearly wanted the modern lifestyle that they see on television.

The net effect of all this social policy examination has been a number of panel recommendations for monitoring socio-economic impacts, community health and community vitality. This has resulted in the formation of several committees to examine these issues and develop monitoring protocols for matters that the committees themselves do not fully understand.

For all its value to the uranium business, McArthur River is a very small mine. At full production, it will produce only 125 tons of ore per day, compared with 1000 to 2000 t/d at earlier Saskatchewan mines such as Rabbit Lake and Beaverlodge and up to 8000 t/d at some of the Elliot Lake mines. Unless the material being mined has some particularly nasty properties, the environmental impact of a mine is primarily a function of the mine production, both ore and waste rock. Ore transport impacts are also in proportion to production. An underground mine produces proportionately much less waste rock than does an open pit mine. In the case of McArthur River, much of the waste rock will be used as back-fill underground, further reducing the amount of waste rock to be left on surface at the end of the operation.

In situations where a mineral zone spawns several mines on adjacent properties, cumulative impacts are a serious consideration, e.g., the Sudbury nickel-mining area in Ontario. The impacts of several operations discharging effluent into a single stream can be significant and should be considered in the environmental assessment. However, in the northern Saskatchewan context, where mines range

from 40 to 300 km apart and are generally discharging effluents into different water bodies, although possibly part of the same drainage basin, the concept of cumulative impacts is overworked. Yet, this seems to have become another essential part of modern environmental assessment; companies are asked to assess the cumulative impacts of operations that are hundreds of kilometres apart with no reasonable expectation of having anything other than a very localized impact. Cumulative air emissions had to be examined, despite the fact that no changes can be measured in airborne radionuclides at more than a couple of kilometres from any operating site. The cumulative impacts to air and water then had to be translated into dose and risk estimates for the distant northern communities.

The additional employment is small. Because Key Lake was running out of ore, McArthur River ore is being processed there, meaning no new mill is required. The cessation of mining at Key Lake reduced the work force there. McArthur River supplied new jobs to replace those lost, but the net additional employment is only about 125 jobs.

Certainly McArthur River will have an economic impact which is far out of proportion to its physical size and environmental impact. It will generate large amounts of revenue for the federal and provincial governments in the form of taxes, royalties, and lease and licence fees. But these are positive impacts, which were more than adequately dealt with in the economic analysis.

Not only was the McArthur River assessment process long, but the requirements changed over the period with the net result that the hurdles continually got higher. Some of this change was as a result of the panel process itself (through recommendations in the earlier reports of the panel) and some was from normal regulatory/political evolution. We started the McArthur River process believing that we were providing more information than was required by any regulation. This was a conscious decision to produce the best EIS possible in order to minimize negative regulatory impact. Because of the changes in regulatory and panel perception, in the end we had done just enough work to meet regulatory and panel expectations.

From the perspective of nearly 25 years of participation in environmental assessments and public hearings, it becomes apparent that the public involved is a very small group indeed. The same individuals appeared as intervenors in the 1996–1997 hearings as appeared in the 1977 Cluff Lake Board of Inquiry and all the hearings in between. They are a small but vocal group of dedicated environmentalists who are philosophically opposed to industrial development generally and to the nuclear industry in particular. One of their strategies would appear to be to make the assessment process so onerous as to discourage proponents from proceeding. One must question the wisdom of catering the entire environmental assessment process to this small group.

Interested members of the public do attend sessions of the hearings but generally not for more than one evening or afternoon. Certainly there are people in the north of the province, closer to the mine sites, with genuine concerns and questions that should be answered. However, it is questionable whether a formal process conducted at the level of detail of these hearings is really necessary. Most of the questions could be answered in meetings without the formality and cost of the hearings.

The role of the regulatory agencies seems to have been forgotten in the zeal to promote public participation. Government agencies such as the CNSC and the Saskatchewan Department of Environment and Resource Management exist to protect the public interest. If the public had no interest in the matters being regulated by these agencies, there would be no need for these agencies to exist (nor would there be any need for hearings). If the agencies are performing their assigned tasks, then there is no need for others to act on behalf of the public.

In cases where there is a government agency that regulates the matter under review, we question the justification for intervenor funding. The argument put forward in support of intervenor funding is that the public, which is not expert in technical matters, needs the funds to hire consultants, etc., to assist it

in examining the issues under review by the panel. Yet the government agencies exist for the sole purpose of protecting the public interest. By handing money to the public to independently analyse the issues, the assessment agency is suggesting that the government agencies are doing their job very badly. That being the case, the first issue to be addressed by any panel should be an assessment of the relevant government agencies. If these agencies are doing their jobs effectively, then there should be no intervenor funding. Taxpayers and proponents should not have to pay for both intervenor funding and an agency looking after the public interest.

The proponent faces a constant struggle over the level of detail required in describing the project and its impacts. Recent experience with the licensing of the McArthur River and McClean Lake projects has shown that the regulatory agencies are demanding more detailed analysis than they have ever demanded before. It is apparent that the agencies regard much of the information presented at hearings as superficial. The panel members are attempting to make an honest assessment of the project but they cannot be expected to bring the level of expertise of someone whose full-time occupation is studying the details of these projects. On the other hand the proponent is criticized for not making his documentation simple enough to be easily understandable to the public present in the hearings.

Environmental panels should not be turned into instruments of research. Many of the questions which proponents are being asked to address go far beyond what is reasonable and necessary to assess the projects. Public health studies in northern native communities may be worthwhile, but they should not be carried out under the guise of vital information required to assess a small mining project located over a hundred kilometres away from any community, and they should not be done at the expense of the proponent.

In Canada, there is a fundamental difference between the federal and provincial processes. The provincial hearings are quasi-judicial, with sworn testimony and cross-examination. The federal process is informal, with no sworn testimony and very limited opportunity to question a witness. The latter process is designed to elicit opinion rather than scientific truth about a project. The proponent must submit an environmental impact statement, which is subjected to intense scrutiny by the panel and any experts it cares to employ. On the other hand, intervenors can make any sort of irrational statement about the supposed impacts of the project without the need to present proof. The more extreme cases are so transparent that even without cross-examination it is clear that the statements are wrong; however, a clever intervenor can sow the seeds of doubt in the panel's collective mind without going to extremes.

The judicial process certainly discourages indefensible statements being made about the project. Over all it is a better process for eliciting scientific truth and controlling the more extreme statements that opponents of a project may be prone to make. The value of the informal process is that it is less intimidating for the participants. However, that lack of formality and the inability to elicit the truth make it less valuable as an assessment process. If the objectives are to familiarize the public with the project, listen to their concerns and answer their questions, this could be better and more economically accomplished in community meetings.

As an educational process for the public, Canadian hearings are, with few exceptions, an abject failure. Most opposition groups and opposed individuals appear only to present their briefs and to support each other's presentations. Aside from panel and proponent staff, only a few individuals who could be termed public actually remain present to hear the majority of the presentations by the proponent. Those who wish to be recognized in the hearings, to present written or oral briefs, should be required to attend some minimum amount of time, in particular listening to the presentations by the proponent and by any experts on those issues that the intervenor plans to address.

The increasing detail required in the assessment process is reducing flexibility for the proponent in subsequent dealings with the regulatory agencies. There is a growing tendency for panel

recommendations to be treated as inviolate, rather than advisory. In Saskatchewan a ministerial approval is granted to carry out the project as described in the EIS with such modifications as may have been recommended by the panel. Any change in detail, even if it is an obvious improvement, must be formally reviewed and approved. This may be a workable mechanism, but with the CNSC, there is the added complication that a change from what was assessed must be screened for potential referral back to the assessment agency.

In addition, the Canadian Environmental Assessment Act and regulations require that any project subject to a licensing decision by the CNSC shall be screened for potential referral for environmental assessment. In the case of a project that has already undergone a public hearing, such a referral would be redundant and the Canadian Environmental Assessment Agency is drafting protocols to ensure that a project only undergoes a single environmental assessment.

10. CONCLUSIONS AND RECOMMENDATIONS

Environmental assessment of uranium projects is a valuable process and one that should be continued.

Public participation in environmental assessment is vital and should be promoted. However, the specific vehicle for that participation warrants further examination. While judicial hearings are excellent for separating scientific truth from hearsay, they are intimidating to most of the public. In most cases public information meetings would be a more useful tool for public participation.

Where more than one regulatory regime is in place, the principle of one assessment for one project must be upheld. The terms of reference must include the agreement among the various agencies that one process will suffice.

The opponents of nuclear power have frequently seized upon environmental issues as a way of stopping or delaying uranium projects. The conduct of the environmental assessments must be tightly controlled to ensure that relevant issues are examined and that undue amounts of effort are not wasted on minor issues.

Intervening in an environmental assessment should demand some responsibility of the intervenor. He should have read the parts of the EIS related to his concerns and he should attend the sessions at which these concerns are discussed, rather than merely appearing to present his views and immediately leaving.

The issue of intervenor funding is really one of credibility of the regulatory agencies. Public distrust of government is rampant. Regulatory agencies must be apolitical. They must conduct their affairs openly and based on sound science. And they must educate the public to restore that lost credibility.

Intensive environmental assessment is a phenomenon of the late twentieth century. Some factions of our society are demanding ever more stringent examinations of new developments. If major impacts are not identified, then the assessment effort is blamed and additional examinations are demanded. Canada is a wealthy country, blessed with mineral resources rich enough to support this level of effort, but this may not be true in other countries. Under the present assessment approach, small ore bodies, which would have been economical to develop 20 years ago, are no longer viable, because they cannot support the level of effort required to go through environmental assessment and licensing.

We must temper our environmental ardour and make assessment effort commensurate with the size of the project and its ability to do damage. We must more severely limit the matters that can be opened in an environmental assessment. Some consideration of socio-economic issues is justified, but a project which is going to create 125 new jobs in an area with 35 000 people, most of whom are unemployed, is not capable of an enormous impact and does not justify the depth of study that has been employed.

Although some of these comments refer specifically to the Canadian regulatory regime, in general they would apply elsewhere. The case for public hearings is best made for completely new technology, for which there are no regulations and no industrial or regulatory experience. The uranium industry is a mature industry, regulated by agencies that have long experience and detailed knowledge of the industry. Recent developments have been in areas where there have already been uranium projects, which have been assessed in detail and are closely monitored. Under such circumstances it is difficult to justify a full-blown environmental assessment, as conducted for McArthur River and Cigar Lake. The licensing of such projects should be allowed to proceed through the normal regulatory process, without the need for extended studies and public hearings.

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Natural background radioactivity of the earth's surface — essential information for environmental impact studies

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Abstract. An environmental impact study is basically a study of change. This change is compared to the pre-existing conditions that are usually perceived to be the original one or the "pristine" stage. Unfortunately reliable information on the "so called" pristine stage is far from adequate. One of the essential parts of this information is a good knowledge of the earth's chemical make up, or its geochemistry. Presently available data on the geochemistry of the earth's surface, including those related to radioactive elements, are incomplete and inconsistent. The main reason why a number of regulations are judged to be too strict and disproportional to the risks that might be caused by some human activities, is the lack of reliable information on the natural global geochemical background on which environmental regulations should be based. The main objective of this paper is to present a view on the need for complete baseline information on the earth's surface environment and in particular its geochemical character. It is only through the availability of complete information, including reliable baseline information on the natural radioactivity, that an appropriate study on the potential effect of the various naturally occurring elements on human health be carried out. Presented here are a number of examples where the natural radioactivity of an entire country has been mapped, or is in progress. Also described are the ways these undertakings were accomplished. There is a general misconception that elevated radioactivity can be found only around uranium mines, nuclear power reactors and similar nuclear installations. As can be seen from some of these maps, the natural background radioactivity of the earth's surface closely reflects the underlying geological formations and their alteration products. In reality, properly regulated and managed facilities, the levels of radioactivity associated with many of these facilities are generally quite low relative to those associated with some natural geological formations.

1. INTRODUCTION

An environmental impact study is basically a study of potential changes in the environment that may be caused by industrial or human activities. These studies, however, tend to focus on very small geographic areas that may be anticipated, will be altered through these activities, often neglecting the broader natural environmental background that surrounds the areas of interest. These broader regional perspectives more often than not are essential for understanding the environment as a whole and the potential influence on the public's health and safety of the areas under investigation. Geologists or geochemists perceive the earth's environment as rocks of different composition and their alteration products. Abnormalities that might occur are known as anomalous areas and might have been caused by geological or anthropological processes. Therefore, a good understanding of the geology of the earth and the variable geochemical compositions of these formations will provide information on the general natural environment of the earth's surface. The objective of this presentation is to show that the environment of the earth's land surface varies greatly because of the geological and thus varying geochemical make up. It is only through the use of complete information that defined limits for levels of contaminants on the surface environment and our understanding of the potential hazards caused by variations of these elements or substances to the living organism, including human, can a realistic evaluation be carried out with an improved perspective.

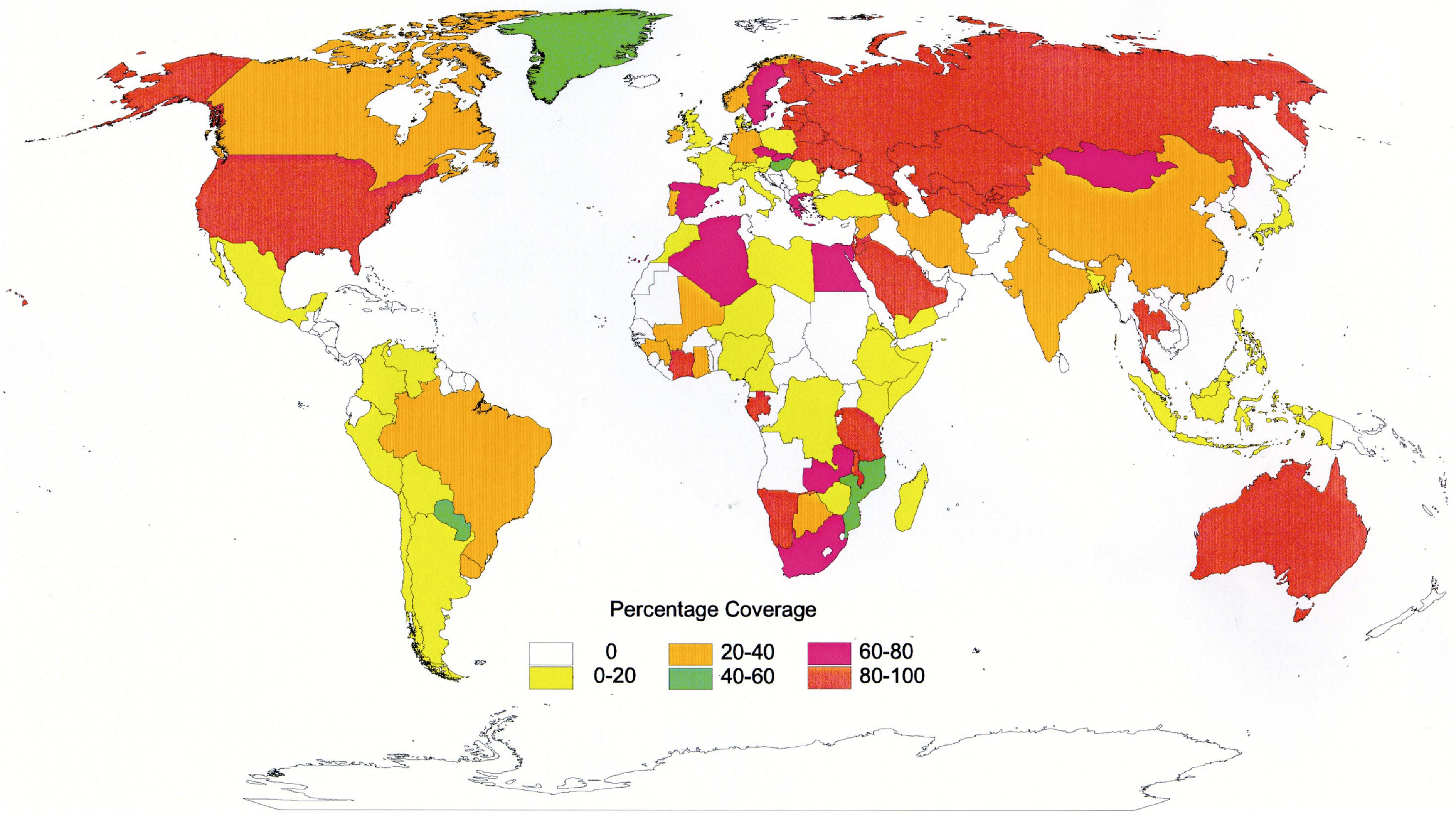


FIG. 1. A map showing the estimated extent of world airborne gamma ray survey coverage, modified from the IAEA database [1].

2. CURRENT KNOWLEDGE

It is probably safe to state that at the world level, our information on the earth's surface radioactivity is poor to very poor. Only a small percentage of countries in the world have good quality information on the natural background radioactivity of their landmass. The best information available, with sufficient regional coverage that it can be used to produce natural background radioactivity maps are the result of airborne gamma ray spectrometric surveys carried out for mineral exploration, uranium in particular (Fig. 1). These surveys have been conducted in many parts of the world. This vast source of gamma-radiation data is potentially valuable, not only to the geologist, but also to the health physicist for assessing background radiation levels. Some of the examples cited below took advantage of the availability of airborne survey data, collected over 10 years ago to produce the natural background radioactivity maps of their countries.

As these airborne surveys were carried out at different times, often over a 30 year span and using different systems, the greatest problem is standardization of the old data. This standardization, commonly called "back calibration"[1], is basically a procedure to compare the count rate derived from the old airborne survey with the ground level radiation flux as measured with a calibrated portable gamma-ray spectrometer (Fig. 2). To assure that the maps to be produced will have comparable values that correlate reliable calibration facilities are needed. Shown in Fig. 3 are the locations of transportable calibration pads in the world. Similar calibration pads for portable instruments can also be found in Ottawa and Calgary (Canada), San Rafael (Argentina), Rio de Janeiro (Brazil), Palindaba (South Africa), Príbram (Czech Republic), Denmark, Malå (Sweden) and in Sydney (Australia). Calibration facilities specifically constructed for aircraft are known in Ottawa (Canada), Grand Junction (U.S.A.), Borlange (Sweden), Helsinki (Finland), Ankara (Turkey), Israel, Tehran (Iran), Nagpur (India), Bangkok (Thailand) and Johannesburg (South Africa).

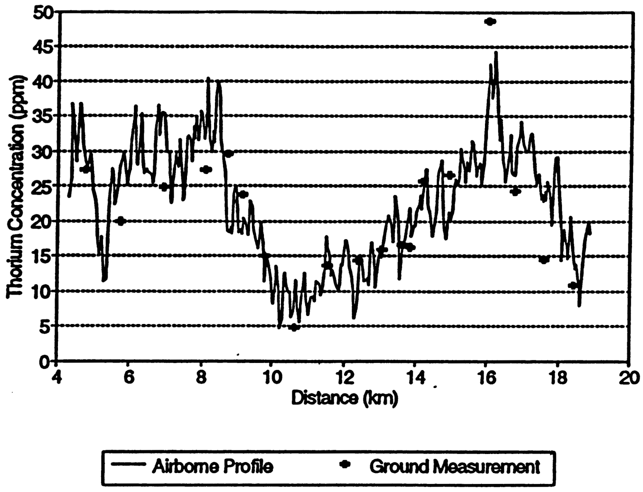


FIG. 2. The relationship between the thorium ground concentration and the calibrated airborne measurements in Malaysia.

A number of areas in the world have long been known to have high levels of natural radiation. These are areas with beach sand deposits that contain appreciable amounts of monazite as in southern India, the eastern coast of Brazil, Madagascar (also containing thorianite), Sri Lanka, Bangladesh, Malaysia, Indonesia, the southeastern coast of U.S.A., and Egypt. Other areas with high levels of natural radioactivity are those that are underlain by large alkalic and carbonatite intrusive complexes such as in Poços de Caldas in Brazil, Oka and St. Honore of Canada, as well as large areas in the world underlain by phosphate deposits. Numerous hot springs in the world are also known to have elevated levels of radon and/or radium. Some of these areas have been the subject of several epidemiological investigations by those interested in the relation between cancer related mortality and high radiation levels [2].

FIG. 3. Location of transportable calibration pads in the world.

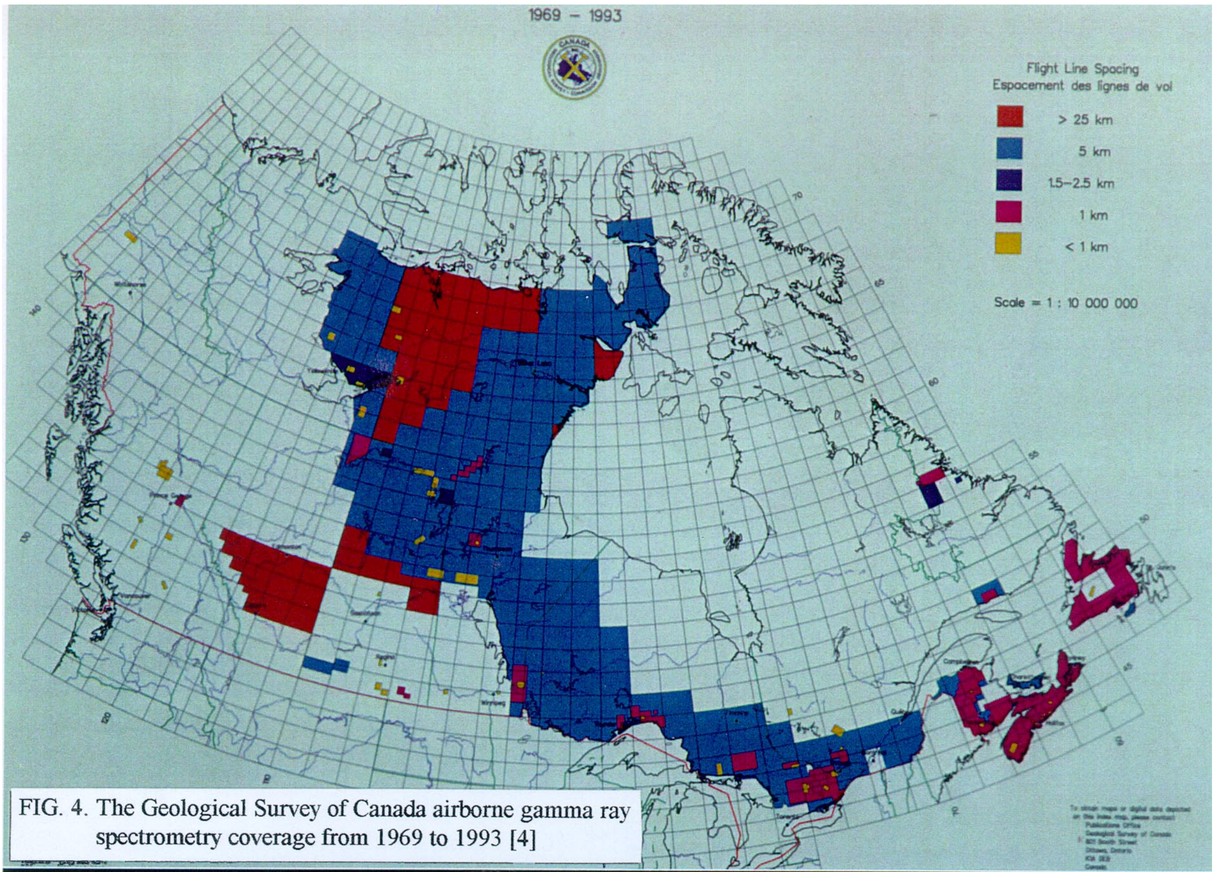


FIG. 4. The Geological Survey of Canada airborne gamma ray spectrometry coverage from 1969 to 1993 [4]

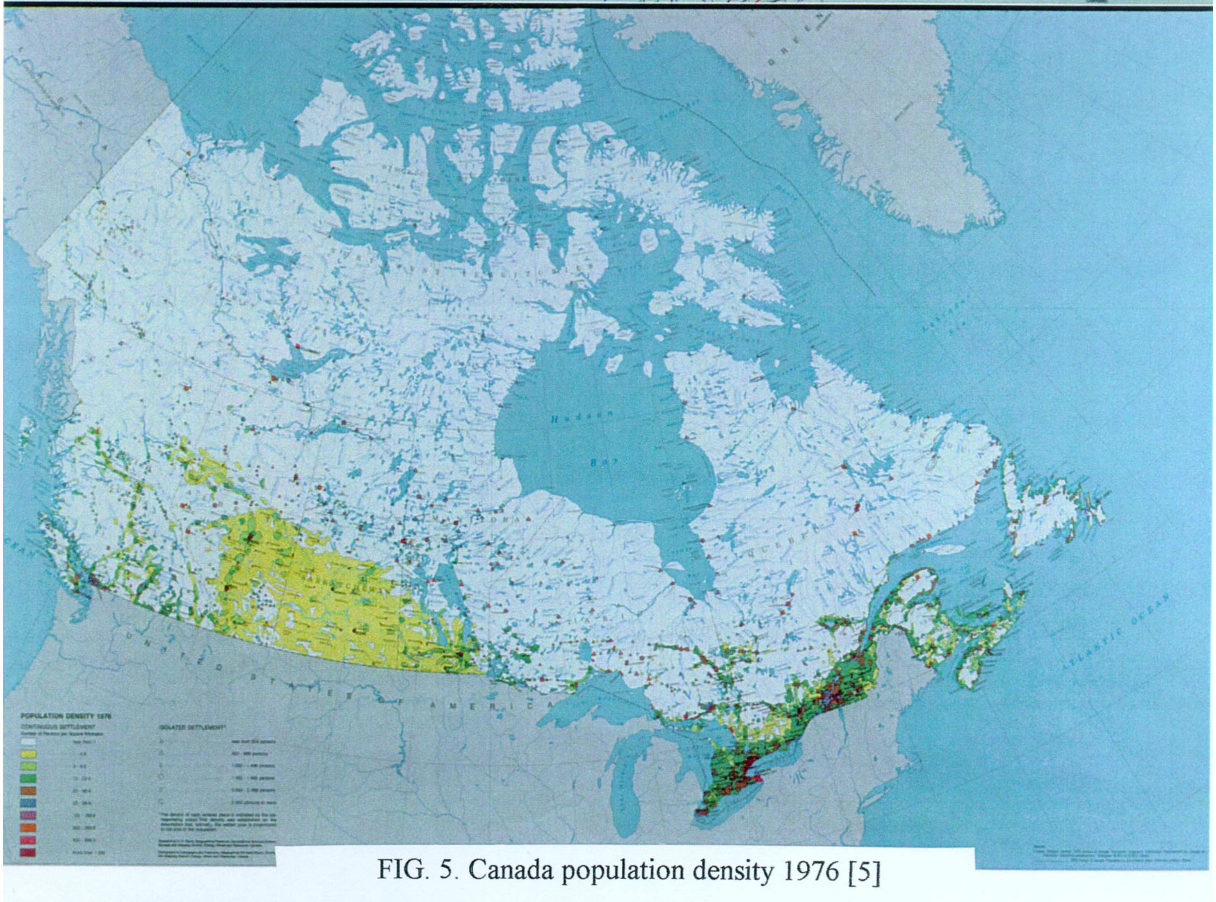


FIG. 5. Canada population density 1976 [5]

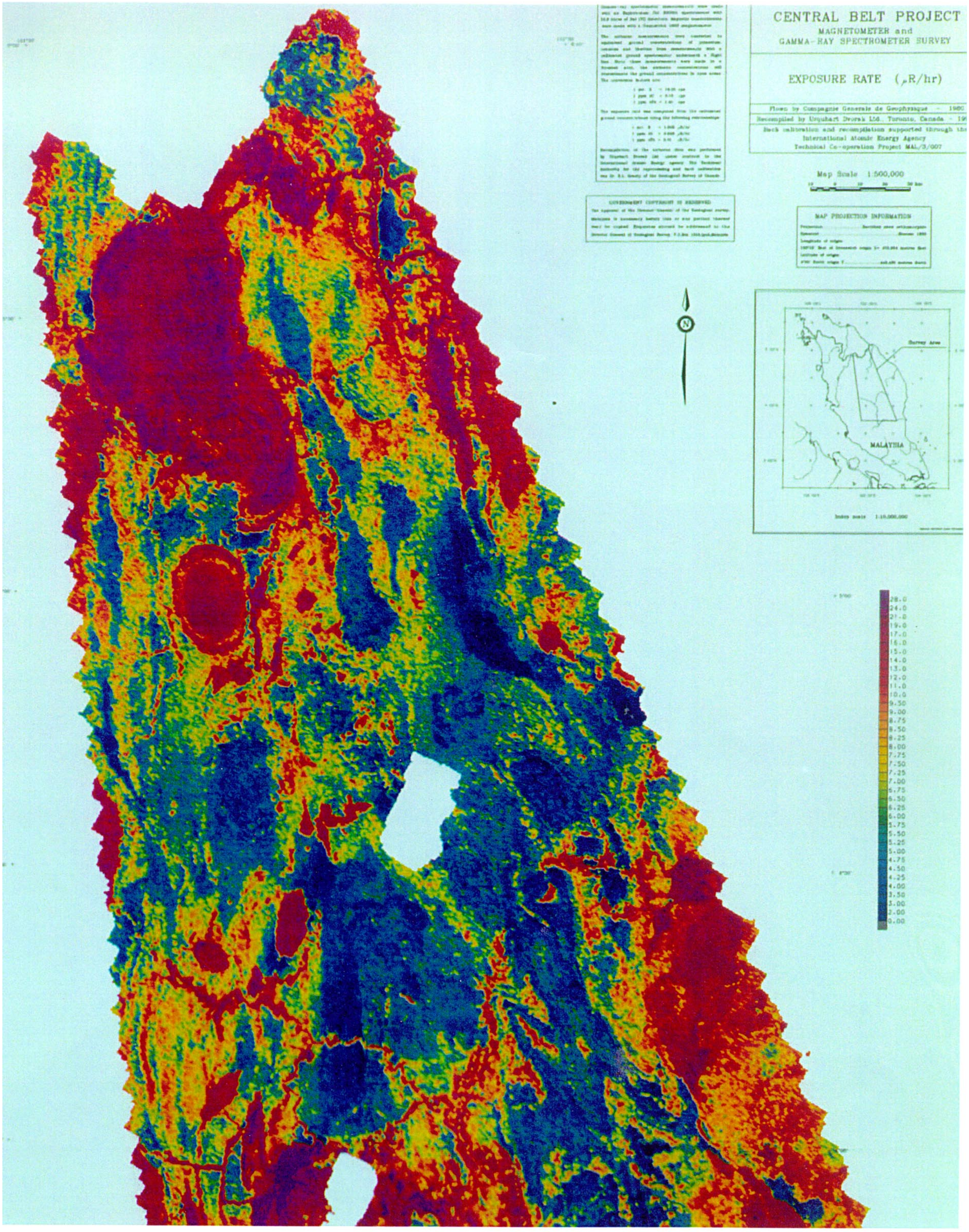


FIG. 6. Exposure rate map of parts of Peninsular Malaysia, reprocessed from old airborne survey data [1]

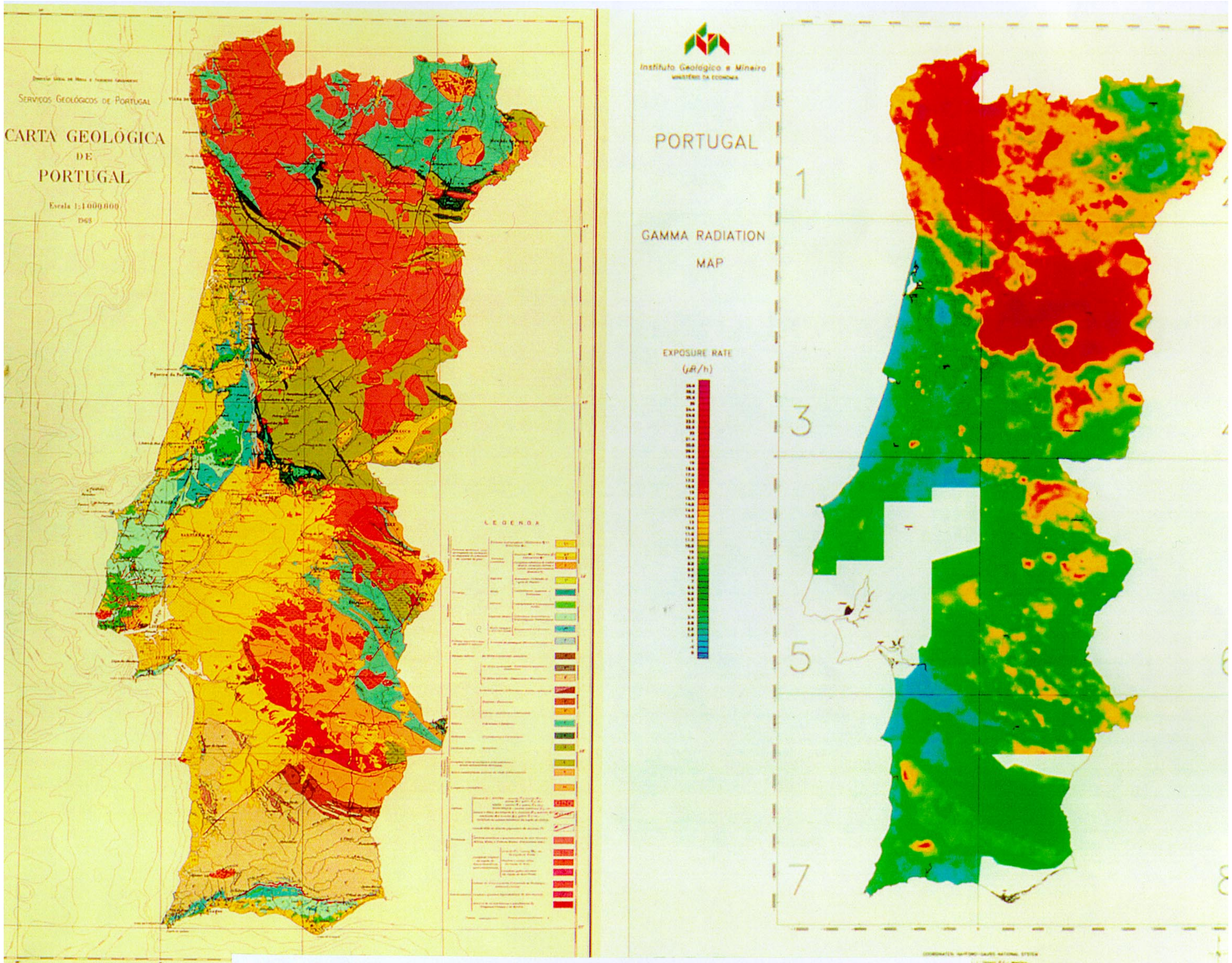


FIG. 7. Relation between natural gamma radiation and geological maps of Portugal [9]

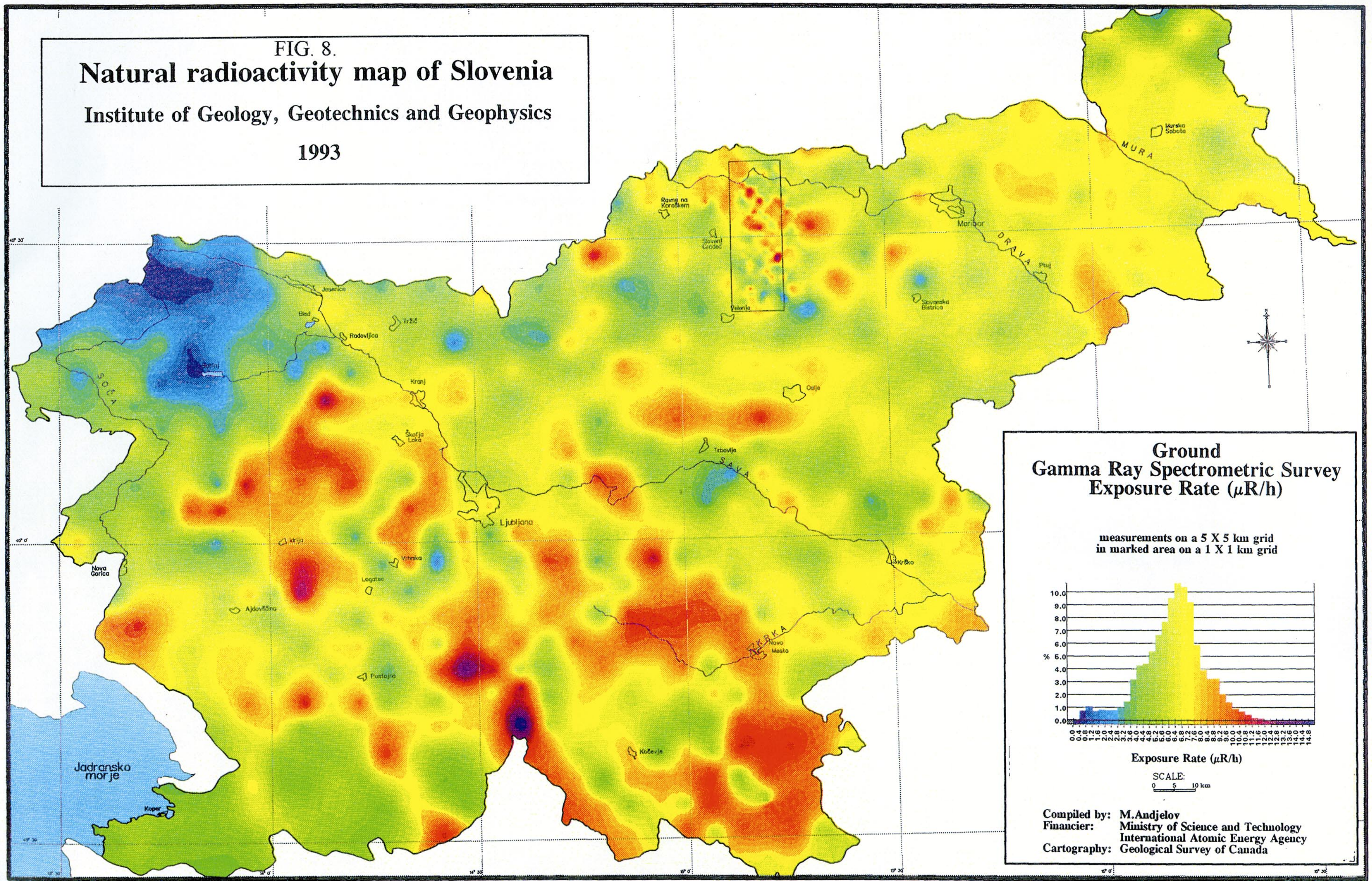
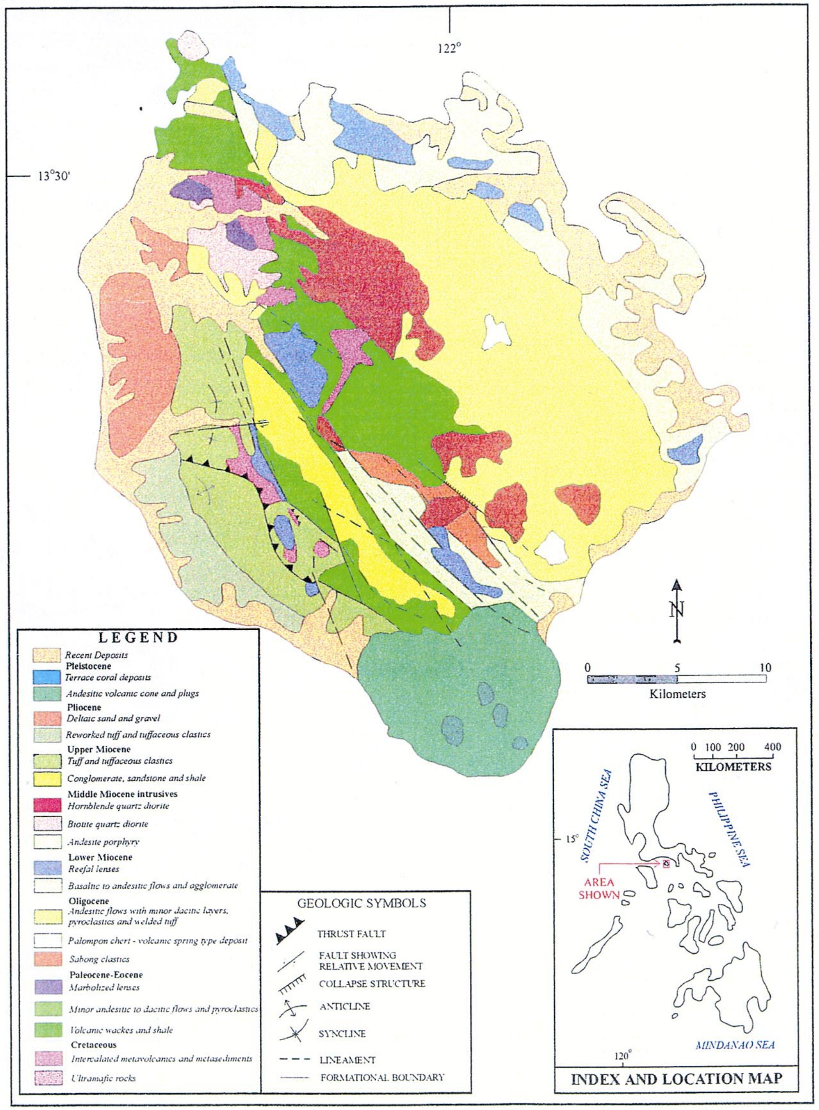


FIG. 8.

Natural radioactivity map of Slovenia

Institute of Geology, Geotechnics and Geophysics

1993



Generalized geologic map of Marinduque Island (modified from the Bureau of Mines, 1970).

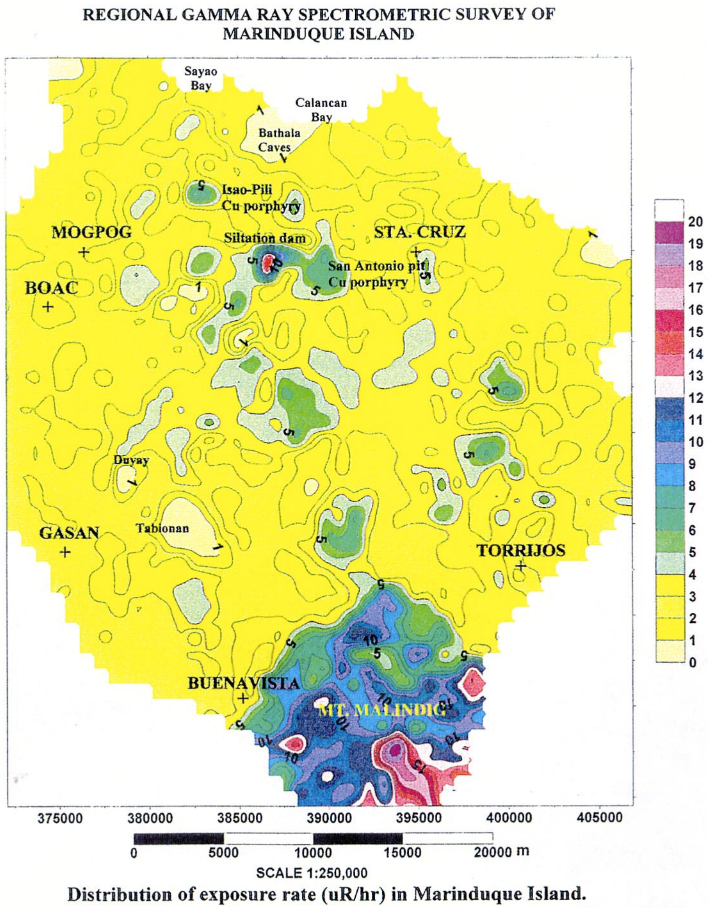


FIG. 9. Exposure rate map of Marinduque Island, Philippines, a product of carborne survey, in relation to the local geology [12]

It is worth noting that during the past five years, a number of countries, particularly in western Europe, Brazil, China, and Russia, have carried out country wide geochemical baseline mapping as a contribution to the Global Geochemical Baseline program following the recommendations of the International Geochemical Mapping (IGM) project. The IGM was organized under the International Geological Correlation Program (IGCP) Project 259, sponsored by UNESCO and the International Union of Geological Sciences (IUGS) [3]. The IAEA, with its interest in the radioelements and the natural radioactivity of the earth's surface, also acted as one of the co-sponsors.

3. NATIONAL EXAMPLES

Increasing public concern on matters related to radioactivity and radioactive accidents has prompted a number of countries to prepare a map of the natural radioactive background of their countries. It is also a way to detect and map the extent of any man made contaminants that might have been generated from within and/or outside their political boundaries.

These maps have been prepared using many different methods. Unfortunately, out of haste or lack of understanding of the potential complexity of the earth's environment, some of these maps are too general. They may, for lack of control points, be too general and hence portray a somewhat distorted picture of the real natural environment. Noted below are some examples that were produced using old uranium exploration data generated during the 1960's, and particularly from the exploration boom of the mid 1970's to the early 1980's. The first three examples noted below (Canada, Malaysia, and Portugal) were produced using old survey data to make high quality maps. The other two examples, from Slovenia and the Philippines used new approaches to produce the maps at relatively low cost.

Canada: *- Systematic Coverage Using Airborne Gamma Ray Spectrometry*

One of the main products of the Geological Survey of Canada's Uranium Reconnaissance Program (URP) started in the mid 1970's, is a systematic coverage of much of the Precambrian shield by good quality airborne gamma ray spectrometry. URP was prematurely terminated in 1979. Regardless, the Geological Survey of Canada (GSC) continued with its systematic airborne radiometric surveys at a much reduced pace as compared to the late 1980's. However, even this reconnaissance airborne survey program was stopped a number of years ago. The Canadian territory covered by airborne gamma ray spectrometry is shown in Fig. 4 [4]. The GSC is at the moment in the final stage of compiling and digitizing all these data to produce digital maps of the nation wide radioelements and the natural background radioactivity. As the main objective of these programs was for mineral resource assessment, the airborne surveys covered regions of the country considered most prospective for mineral commodities, primarily the Precambrian shield. Unfortunately these areas are generally less productive for agriculture and therefore the least populated parts of the country (Fig. 5). If one is concerned that radioactivity might influence the health and safety of the general public, adequate coverage for this type of information, at least for Canada, will never be sufficient if one is to rely solely on surveys that are motivated by the search for mineral resources.

Malaysia: *- Back Calibration of Airborne Survey Data*

At the request of the Government of Malaysia, the IAEA assisted the Geological Survey of Malaysia to evaluate the quality of earlier (1980) airborne survey results. Since the primary purpose of the survey was for mineral exploration, the explorationist is generally concerned with only the relative concentrations of the radioactive elements (in count rates) rather than their absolute values. A back calibration program was carried out to enable conversion of the airborne data to the ground concentrations of potassium, uranium and thorium. This conversion was necessary for the production of a background exposure rate map [1]. The resulting map is shown in Fig. 6. The reprocessed maps have been successfully used to improve the geological map of highly inaccessible areas, to better assess their mineral potential, and to identify areas that are affected by former mineral exploitation activities.

The IAEA also assisted Argentina and Thailand in the reprocessing and/or back calibration of older airborne radiometric survey results to produce exposure rate maps. Other countries known to have done back calibration and recompilation of old airborne survey data are Brazil, the Czech Republic [6], Namibia [7], Spain [8] and U.S.A. It is obvious from Fig. 1 that there is still a vast source of airborne gamma ray survey data that can be used to produce standardized, hence correlatable, radioelement and natural background radioactivity maps for a good percentage of the earth's surface.

Portugal: *- Back Calibration of Carborne Survey Data*

The example from Portugal as it used very old total count radiometric data commonly collected in the early years of uranium exploration. The natural background radioactivity map was prepared using a vast amount of records from ground surveys, particularly carborne, total count radiometric surveys carried out from the late 1950's to the 1970's, combined with recent data from carborne and airborne gamma ray spectrometric surveys that cover a large part of southern Portugal [9]. The work started with back calibration of selected old survey areas using a calibrated portable gamma ray spectrometer followed by very tedious work of recovering, plotting and eventually digitizing the corrected information. The result was a high quality natural radioactivity map of the country at a scale of 1:200 000. As noted in Fig. 7, this map reflects much of the geological character of Portugal. It should be noted that the project was also a direct result of an IAEA technical co-operation programme.

The next two examples differ from those described earlier because they are from new surveys with the objective, among others, of producing natural background radioactivity maps. These examples are selected to demonstrate that this type of survey can be carried out at very modest cost.

Slovenia: *- Low Cost Ground Gamma Ray Spectrometry*

In 1990, under a Research Contract agreement with IAEA, the Inštitut za geologijo, geotechniko in geofiziko of Geološki Zavod Ljubljana prepared radioelement geochemical maps of Slovenia using ground survey methods[10]. The survey was carried out using calibrated portable gamma ray spectrometers on a 5 × 5 km grid. Soil samples were also collected at each survey location and each sample was analyzed for 33 elements. With this modest approach, the first country wide multi-element geochemical maps of the country were prepared. One of the products is the natural radioactivity map of Slovenia shown in Fig. 8. One should note that in Poland, a similar approach has also been used [11].

The Philippines: *- Low Cost Carborne Gamma Ray Spectrometry*

Taking advantage of a well developed road network, the Philippines Nuclear Research Institute (PNRI), with IAEA assistance, carried out a carborne gamma ray spectrometer survey over the small island of Marinduque (959 km^2) [12]. This pilot study was carried out in preparation for the planned countrywide survey using the same approach. However, because of inadequate road density in many parts of the country the carborne survey must be combined with ground measurements. The objective of the project was to produce information that could be used in general mineral resource assessment, geological mapping and most importantly, to provide baseline information for environmental studies and monitoring. Fig. 9 shows the relationship between the produced exposure rate map and the local geology. This pilot study has demonstrated that for areas with sufficient road density, high quality carborne gamma ray spectrometry surveying can be easily and rapidly carried out at a very low cost.

4. DISCUSSION AND COMMENTS

It has to be stated that what is presented here is not a complete picture of the world situation. A number of approaches are being used to prepare outdoor gamma ray dose rate maps in several parts of the world. More studies have also been made in relation to the radon concentration in the environment. What is presented here is an approach normally used by exploration geologists,

geochemists and/or geophysicists for producing regional maps. The most important principle is to have sufficient data over regularly distributed points, to produce maps that adequately represent the surveyed areas. It is known that distorted information may be produced where the control point density is inadequate. The important role of airborne surveying for rapid and accurate production of radioelement and natural radiation maps is well established. However, the high cost of such a survey may then make them prohibitive for many countries, particularly if the objective is to cover the entire territory. Examples from Slovenia and the Philippines offer alternative procedures of how these maps can be prepared with modest resources and low operating costs.

There is a general misconception that elevated radioactivity can be found only around uranium mines, nuclear power reactors and similar nuclear installations. In reality, for properly regulated and managed mines and nuclear facilities, the associated radioactive emissions from many of these facilities are generally quite low relative to those produced by some geological formations. Of course, this is an oversimplified statement when one accounts for all of the possible negative impacts that may be generated by this type, or any other type of industrial operation.

As may be seen from some of the maps, the natural background radioactivity of the earth's surface closely reflects the underlying geological formations and their alteration products. In fact, with some understanding of the geochemistry of different rock formations, one can look at the general geology map of the world and estimate what the natural background radioactivity of the earth's surface may look like.

The main objective of this paper is to present an explanation of the need for complete baseline information on the earth's surface environment and its geochemical make up in particular. The effort made by the Working Group on the Global Geochemical Baseline under the auspices of the International Union of Geological Sciences (IUGS) and the International Association of Geochemistry and Cosmochemistry (IAGC) in achieving its objective, represents a good start. However, it is more likely that the radioactivity component of the program will not receive equal attention. The IAEA is the only international organization that can act as a coordinator for the establishment of a Global Baseline on Natural Radioactivity. As indicated by some of the examples discussed above, through its Technical Cooperation Program, the IAEA can further assist its Member States in the realization of this important task, in particular at the interregional scale.

It is necessary to stress that only through the use of more complete information, including reliable baseline information on the natural radioactivity, that appropriate studies on the potential effects of the various naturally occurring elements on human health can be carried out. There is an increasing amount of information available for the study of the potential benefit or harm of various major and trace chemical elements on the human body. Probably the most important information needed for this type of study is the knowledge of what concentration of a given substance is beneficial and what amount is considered toxic. Do we need a certain level of radioactivity to be healthy? The answer is probably yes.

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The environmental impact assessment of uranium mining in Australia

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Abstract. Federal environmental impact assessment legislation has existed in Australia since 1974. A number of uranium mines have been developed in this time, utilizing a range of mining techniques, including opencut, underground and in-situ leach. Projects have also been undertaken in a variety of geographical areas requiring consideration of diverse biodiversity, cultural heritage and social impact issues. Assessment of uranium mining proposals in Australia is also conducted in a climate of political opposition from a cross section of the Australian community. This paper outlines some of the key issues that arose during recent assessments and which provide a lead to the role of environmental impact assessment in environmental policy development. Issues are also relevant to recent assessments on a replacement nuclear reactor, shipments of waste for reprocessing and proposed assessments on proposals for low and intermediate level nuclear waste facilities.

1. FRAMEWORK FOR ASSESSMENT

Although the Australian constitution provides for State and Territory Governments to exercise the primary role in land use management, including mining, uranium mining and nuclear matters generally involve the Commonwealth Government directly in the decision making. Since 1974, Commonwealth involvement in environmental assessment has occurred under the *Environment Protection (Impact of Proposals) Act 1974* (EPIP Act). The object of the Act is to ensure that environmental matters are fully examined and taken into account in the Commonwealth's decision making process. Under the EPIP Act, "the environment" is broadly defined as "all the aspects of the surrounds of man", and the Act applies to matters that affected the environment to a significant extent. Administrative Procedures established by statute under the Act specify the major elements of the assessment process including determination of the level of assessment, scoping of guidelines, public consultation, and the provision of advice and recommended conditions to Ministers giving approvals. The Act does not provide an approval power directly for the Environment Minister.

Under this system, the environmental assessments generally inform approval decisions relating to either foreign investment in Australia or statute based export approvals, the latter providing the primary means for the Commonwealth to impose and manage any environmental conditions of approval.

Australia has no significant domestic demand for uranium and almost all production is exported. Export permits are required for shipments of uranium, and are issued by the Minister for Industry Science and Resources under the *Customs (Prohibited Exports) Regulations.* Stringent controls have been placed on exports by the Australian Government to ensure that the uranium exported is only used for peaceful purposes. These nuclear safeguards require customer countries to allow international inspectors from the International Atomic Energy Agency (IAEA) to verify that the uranium is not directed into weapons programs. The Australian Safeguards Office (Department of Foreign Affairs and Trade) monitors compliance with these requirements. The guidelines for the peaceful uses of uranium developed by the International Atomic Energy Agency (IAEA) and are incorporated into agreements that Australia requires with purchasers of Australian uranium.

All environmental assessments required by the Commonwealth government are integrated with assessments required by the State governments. Under a joint assessment process, proponents are required to prepare only one set of documents to satisfy the requirements of both governments. Assessment reports are prepared jointly but with recommended conditions reflecting each government's requirements and priorities.

Australian environmental impact assessments must be undertaken prior to approvals being given, with public consultation being required at an early stage. Although the Minister determines the level of assessment, the responsibility for preparation of assessment documentation and associated costs is borne by the proponent. The role of governments in environmental assessments is to establish the guidelines for the assessment, ensure that the process is properly undertaken, particularly the public consultation, and that on completion all impacts have been identified and fully assessed to ensure fully informed decisions can be made. The Commonwealth legislation provides that assessments on non- complex projects or those which are not controversial can be based on assessments already completed within State or Territory jurisdiction without further public consultation. However major projects, including all uranium mining and other nuclear projects are generally required to be assessed at the highest level a requiring preparation of an environmental impact statement (EIS). Public Inquiries may also be directed.

For projects requiring an EIS, public consultation is generally undertaken on the scoping of the assessment and preparation of guidelines for an EIS. A draft EIS is also issued for public consultation when Environment Australia is satisfied that issues have been adequately identified and are being published in a manner that would be understood by the general public. All public comment must be considered by the proponent in preparing a final EIS which must be submitted to the Environment Minister. Environment Australia is then required to prepare an assessment report for the Minister. These reports generally review the impacts and proposed mitigation measures and identify key issues for consideration by Ministers. Environment Australia also advises the Minister on the adequacy of the public consultation and the responses by the proponent. The Environment Minister is then required to consider all matters and provide advice and recommendations for conditions to the relevant Minister(s) responsible for issuing approvals. Whilst there is no provision for merit appeals, all decisions taken by Ministers under the EPIP Act are subject to appeal in the Federal Court. Whilst appeals through the courts may be expensive it is not unusual for controversial projects including the Jabiluka assessment to be appealed in this manner.

In July 2000 the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) came into effect. By agreement between the State, Territory and Federal governments, this new legislation provides for the first time in Australia, a clearly identified role for the Commonwealth on environmental management. It introduces a system in which Commonwealth interest in environmental assessment and approval of proposals is focused on matters of national environmental significance. There are six matters of national environmental significance contained in the EPBC Act including nuclear actions. As such all significant nuclear actions, including uranium mining and nuclear waste facilities will require approval of the Environment Minister in future. The Act also establishes an integrated regime for biodiversity conservation and for the management of important protected areas.

The new environmental assessment and approvals regime under the EPBC Act has a number of significant differences to the system it replaces. The EPBC Act eliminates the use of indirect triggers unrelated to environmental matters and Commonwealth involvement in environmental assessment and approval is now triggered by actions that have a significant impact on matters of national environmental significance. In addition projects affecting Commonwealth land or actions taken by the Commonwealth agencies anywhere in the world are subject to the approval provisions of the Act.

2. MINING AND EXPLORATION HISTORY

Australia has some of the largest uranium deposits in the world, occurring in a variety of geological and biophysical environments. Many of these are estimated to be economically viable low-cost deposits. At present Australia is the sixth largest producer of uranium and there is significant potential for an increase in production in the short to medium term.

The first uranium mining for radium products was conducted at Mount Painter in South Australia between 1910 and 1931. Exploration for uranium in its own right began in late 1940s resulting in

discovery and development of deposits at Rum Jungle, Mary Kathleen, Radium Hill and several smaller deposits in the Alligator Rivers Region in the Northern Territory. Mining of these deposits was undertaken throughout the 1950's and 60's without any direct environmental controls.

Encouraged by Australian Government and in response to predictions of increasing world demand for uranium, exploration activity increased again in the late 1960s. Important new deposits were discovered at Nabarlek, Ranger, Koongarra and Jabiluka (also known as North Ranger) in the Alligator Rivers area of NT; at Beverley and Honeymoon in the Lake Frome area of SA; and at Yeelirrie and Lake Way in WA. The Olympic Dam (SA) and Kintyre (WA) deposits were discovered in 1975 and 1985 respectively.

Mary Kathleen mine was re-opened in 1975 and operated until 1982. The Nabarlek deposit was mined in 1979 and the stockpiled ore was processed from 1980 to 1988 and the pit rehabilitated.

2.1. Ranger mine

The Ranger mine is located about 220 km east of Darwin in the Magela Creek catchment between the South and East Alligator Rivers. Two large ore bodies were discovered about 2 km apart, designated Ore body No.1 and Ore body No.3, containing an estimated total of 100 000 tonnes of uranium oxide. Ore body No.1 contained approximately 20 million tonnes of uranium ore at an average grade of 0.25% yellowcake. Sixty million tonnes of waste rock was extracted with the ore, leaving a pit 700 metres in diameter and 175 metres deep.

Ore body No. 3 was slightly larger at 23 million tonnes and a slightly lower grade. Production at Ranger began in 1981 and to date some 56 000 tonnes of uranium oxide had been produced. The processing plant has a capacity of 3000 tonnes per year of uranium oxide.

The Ranger Uranium Environmental Inquiry was established by the Commonwealth Government in July 1975 under the provisions of the *Environment Protection (Impact of Proposals) Act 1974* (EPIP Act) in response to significant public opposition to uranium mining. The presiding Commissioner was Mr Justice Fox.

The terms of reference required the Commission to inquire into the development by the Australian Atomic Energy Commission (AEC), in association with Ranger Uranium Mines Pty Ltd, of uranium deposits in the Alligator Rivers Region of the Northern Territory. The Commission was specifically to inquire into the environmental aspects of works, operations or expenditure by or on behalf of the Australian Government and the AEC and other authorities. The terms of reference were wider than an examination of the Ranger proposal alone and encompassed the Nabarlek, Jabiluka and Koongarra prospects, as well as an examination of nuclear development and the generic issue of whether uranium mining should be allowed to proceed anywhere in Australia.

The first report of the Fox Inquiry addressed the generic issues and was presented to the Government on 28 Oct. 1976. The Report concluded that the hazards of mining and milling uranium, if those activities are properly regulated and controlled, are not such as to justify a decision not to develop Australian uranium mines. The report stated: “We are quite satisfied that, if properly regulated and controlled according to known standards, these operations do not constitute any health hazard which is greater in degree than those commonly accepted in everyday industrial activities”.

The second report was presented on 17 May 1977 and dealt with the specifics of uranium mining in the Northern Territory, particularly the Ranger mine. It recommended that uranium mining could proceed subject to strict conditions regarding water management, tailings disposal, rehabilitation and monitoring. The Fox report also recommended the establishment of a national park (Kakadu) to protect the unique flora, fauna, landscape, material cultural values and habitats of the area, as well as the establishment of a Commonwealth agency to oversee uranium mining in the Alligator Rivers

Region. The Office of the Supervising Scientist (OSS) established in 1978, was the response to this latter recommendation.

In June 1977, then the Commonwealth Department of Environment, Housing and Community Development advised that, subject to proper safeguards, there were no environmental reasons why uranium mining and milling in the Alligator Rivers region should not proceed.

2.2. Jabiluka

The Jabiluka (North Ranger) mine is yet to be developed. The site is located 230 km east of Darwin, approximately 20 km to the north of the Ranger mine. Although the lease area is over 7000 ha, the total area of disturbance would be less than 100 ha. The depth of the orebody together with topographical and heritage constraints have dictated that the Jabiluka No.2 Orebody be developed as an underground mine. There is a total ore reserve of 20 million tonnes at a grade of 0.2% uranium oxide. The project owners intend to extract around 90 000 tonnes of uranium oxide over the life of the mine.

A Commonwealth EIS for the Jabiluka mine was prepared and assessed in 1979, but the mine did not proceed at that time. A change of Government in 1983 saw the incoming Government adopt a policy to limit the uranium industry in Australia to those three mines already in operation. The Government changed again in 1996 and the "Three Mines Policy" was abandoned.

A new EIS for the Jabiluka project in 1996 examined ERA's preferred option for an underground mining operation, with the ore to be processed at the Ranger mill with the tailings disposed of the mined out Ranger pits. Following approval of this proposal, the Traditional Owners of the Jabiluka area indicated their unwillingness to consent to milling Jabiluka ore at Ranger. Consequently, further environmental assessment was undertaken of the alternative development proposal, namely the construction of a mill at Jabiluka to process the ore. A public environment report (PER) was produced for public review. Following this assessment, the Jabiluka Mill Alternative was also cleared to proceed, subject to a number of stringent environmental conditions.

The matters of greatest significance during the assessment of both Jabiluka mine proposals were impact on living Aboriginal culture, social impacts of mining in the Kakadu region, tailings technology and management, water control in a sensitive and high rainfall area and perceptions of potential long term environmental damage to the unique biological resources of the Kakadu region.

The Jabiluka proposal was closely examined by the World Heritage Committee during 1998-1999. Kakadu National Park, a World Heritage Area, surrounds the mining lease and the WHC examined the potential threats the mine might pose to the values of Kakadu. In July 1999, the World Heritage Committee confirmed that the Jabiluka project would not cause Kakadu's world heritage status to be placed in danger. Nevertheless the project proponent has agreed to limit Jabiluka production until the Ranger orebody is exhausted. This concession was in response to concerns held by some WHC members that Kakadu would be adversely affected if two mines were in full-scale operation simultaneously.

2.3. Olympic Dam

Olympic Dam is primarily a copper deposit with significant commercial levels of gold, silver and uranium. The orebody is one of the largest polymetallic orebodies in the world. Total estimated reserves are 11 million tonnes of copper, 300 000 tonnes of uranium, 400 tonnes of gold and 2800 tonnes of silver. Production began in 1988 and annual production is now 200 000 tonnes of copper, approximately 4600 tonnes of uranium oxide, 2050 kg gold and 23 000 kg of silver.

An Environmental Impact Statement was undertaken prior to the development of the mine and a new EIS was undertaken in 1996 for a major expansion of the project. Although the mine had been operating for a number of years there was considerable community interest in the expansion. Following the assessment approval was given for the expansion project subject to conditions relating mine technology, water usage from the Great Artesian Basin, tailings management and radiation management.

2.4. Beverley and Honeymoon

Beverley and Honeymoon are aquifer deposits suitable for mining using the In Situ Leaching process. The Beverley site is located on an arid plain between the northern Flinders Ranges and Lake Frome, 600 km north of Adelaide in South Australia. There is an estimated uranium resource of 16 300 tonnes, of which at least two thirds is estimated to be recoverable. Over a projected mine life of 15 years, production of 600-1000 tonnes per year of uranium oxide is anticipated.

The Honeymoon uranium deposits are located south of Lake Frome, 200 km from Beverley, and about 300 km north east of Adelaide in South Australia. An estimate of the uranium reserve has not been published, but is thought to be comparable to Beverley. The processing plant is being designed for production of 1000 to 1500 tonnes of uranium oxide per year.

The assessment process for Beverley involved the preparation of an EIS and was finalized in 1998. Concerns about excursions of mining and waste liquids into surrounding aquifers was the primary issue dealt with in the assessment. In order to obtain environmental clearance of this project, including permission for disposal of waste mining fluids into this aquifer, the proponent had to demonstrate that the northern section of the aquifer was effectively isolated.

An Environmental Impact Statement has been directed for the Honeymoon project. At the time of writing, the public consultation phase of the assessment has been completed and the proponent is preparing a supplementary report addressing issues arising for public comment.

2.5. Prospective uranium mines

In addition to Ranger, Jabiluka, Olympic Dam, Beverley and Honeymoon projects there are many other significant uranium deposits with prospects for development. These include Koongarra and Angela (Northern Territory) Maureen, Ben Lomond and Westmoreland (Queensland) Manyingee, Turee Creek, Kintyre, Lake Maitland, Yeelirrie, Lake Way, Mulga Rock and Oobagooma (Western Australia).

3. ISSUES

Whilst every project has factors that are unique, there are some general themes that are common to the environmental assessments of uranium mines in Australia. Details of the assessments can be found in the references to this paper and the Environment Australia Website. Some of these issues are discussed in detail in other papers being presented at this Symposium and it is not intended to duplicate that work here. In particular, the impact of uranium mining on the aboriginal people and World Heritage values in the Alligator Rivers Region is addressed elsewhere. Some key issues that rose in recent assessments and which may be relevant to international considerations are set out below.

3.1. Management of overseas impacts

The environmental assessments require that all impacts that might arise from the projects are assessed. Because all the uranium oxide produced in Australia is exported, potential impacts from transport, use of fuel in reactors and long term storage and disposal of nuclear waste had to be taken

into account in the assessment. As detailed consideration of many of these downstream matters is beyond the legal responsibility individual mining companies, Environment Australia requested the Department of Foreign Affairs and Trade to prepare a report on these overseas impacts in co-operation with the relevant industry Department. The report focussed on the management regime for the peaceful use of Australian uranium established under the Treaty on Non-Proliferation of Nuclear Weapons. The report also noted that Australia has entered into bilateral agreements with countries which purchase Australian uranium to reinforce control over the peaceful use of this material. Whilst there was a high degree of confidence in the management regimes for use of the uranium, there remained a concern with the long term storage and disposal of nuclear waste. The issue of nuclear waste was central to much of the public comment. Nevertheless Commonwealth Ministers accepted that progress was being made and that technological solutions were likely in the forseeable future. The issue remains a major concern for the community and will no doubt be a major consideration of future projects.

3.2. Tailings management

The long-term management of tailings is a major concern with uranium mines. Although there is a legacy of poorly managed tailings from most of the earlier uranium mines, recent mines generally manage tailings in an environmentally acceptable manner. The tailings from Ranger and Nabarlek are being disposed into the mine pits at Ranger. Eventually these pits will be covered and rehabilitated to a standard that will enable the area to be incorporated into Kakadu National Park. The Ranger Mill Alternative for the Jabiluka project also proposed that the tailings would be disposed of in the Ranger pits. With the rejection of this option by the traditional owners, ERA proposed to mill the ore at Jabiluka and place the tailings in cement paste in two specially constructed pits. The environmental assessment highlighted concerns with this option because of the untried technology in a tropical climate and the potential for seepage into groundwater. Although the risk was low, this option was rejected by the Commonwealth because of the concerns of perceived risk to traditional hunting and gathering and the ecological risk to the downstream wetlands. In the final stages of the assessment, ERA agreed to the option of disposal of tailings into specially constructed deep underground cavities. Whilst many modern mines, including Olympic Dam, use some tailings to fill underground stopes the Jabiluka project will be the first in Australia where all tailings will have to disposed of in this manner. Barren rock will be brought to the surface and used in the eventual rehabilitation of the site.

3.3. Radiation management

Radiation exposure in underground mines was a significant issue during the assessments of both the Olympic Dam expansion and Jabiluka although actual experience with the Olympic Dam operation provided valuable information on which to make initial judgements. As part of the assessments, expert reviews were conducted by the Supervising Scientist and the Australian Radiation Laboratory of the modelling forecasts of radiation exposure. Whilst there were differing views between experts on some of the assumptions used in the modelling of exposure, sufficient information was available on which to make judgements about the radiation management regime that would apply for these underground mines. The expert reviews confirmed that it was not possible to predict exposure any better than the estimates provided by the project proponents. The validity of the modelling forecasts would nevertheless have to be confirmed through comprehensive investigation into the actual radiation environment during development and operation of the mines. Final approvals for these underground mines required a radiation management regime that included measures to establish baseline radiation levels, finalization of the modelling and development of ongoing monitoring programs. Other management requirements affected the design of ventilation systems, shielding of surfaces and enclosure of workers in mobile equipment.

3.4. Water management

The high environmental sensitivity of the Jabiluka area required detailed consideration of the water management regime. High monsoonal rainfall and proximity of the mine to the wetlands required the development of a total containment zone to ensure that runoff from any catchment containing material with more than 0.02% uranium was stored in a retention pond for recycling or evaporation. Other areas on the mine lease were also managed to minimize impact on streams and the wetlands. At Olympic Dam which is located in an arid region, water management was focussed on water supply and impact on groundwater rather than runoff. Modelling was undertaken to enable predictions to be made of the impact of the mine on groundwater. Subsequent operation of the mine confirmed the modeling predictions on the acceptability of groundwater impacts. Of greater significant was the requirement for mine operators to source water for their operations from the Great Artesian Basin some 200 km north of the mine. The borefields developed for Olympic Dam and the ongoing monitoring regime have lead to a far greater understanding of the artesian basin and improved management of the water resource. The mine operator has been able to reduce their water usage per ton of ore over the life of the mine and made a number of voluntary contributions to improve management of groundwater by pastoralists in the region.

The in situ leach mining projects at Beverly and Honeymoon raised serious concerns about their impact on groundwater systems. The injection of an acid solution into the orebody and eventual disposal of liquid waste into the aquifers were new technologies in Australia and generated considerable public interest and significant opposition. At Beverley, Heathgate Resources was required to establish to a high degree of certainty that the aquifer was essentially a fossil aquifer before the Environment Minister considered that the project was environmentally acceptable. The hydrogeology and geology of the area was subjected to independent expert reviews conducted for Environment Australia. The geological structure containing the aquifers at Honeymoon is significantly different than at Beverley and it remains to be seen whether or not disposal of liquid waste will be environmentally acceptable at that locality.

4. CONCLUSION

Issues around uranium and the nuclear fuel cycle attract a significant level of public interest and concern both within Australia and internationally. The radioactive nature of uranium necessitates that its mining, processing and use requires environmental protection measures that must have a high degree of reliability for unusually long periods of time. For these reasons the Commonwealth government has recently confirmed through new legislation that uranium mining and other nuclear related projects are nationally significant and require Commonwealth environmental approval. Environmental impact assessment conducted in co-operation with State and Territory governments will remain the primary key mechanism to provide the necessary information on which decisions regarding approval will be made. These assessments will also continue to inform other decisions relating to Australia meeting its international treaty obligations, including those under the Non-Proliferation Treaty and the Convention on the Physical Protection of Nuclear Material.

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US Environmental Protection Agency's assessment of environmental impacts of TENORM radiation sources: The example of uranium mining TENORM wastes

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Abstract. Over the last 30 years the US Environmental Protection Agency (EPA) has conducted field, laboratory, and scientific literature studies on a variety of technologically enhanced naturally occurring radioactive materials. In doing so, EPA has recognized that the physical and chemical characteristics of these wastes and products can vary significantly, and the Agency is conducting detailed evaluations of these radioactive materials on an industry-by-industry basis. An example of the Agency's current efforts to characterize and assess the risks of these materials from the uranium mining industry in a technical report is presented along with information on EPA's current field and laboratory studies.

1. INTRODUCTION

1.1. Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)

The US Environmental Protection Agency (EPA) and other federal as well as state government agencies, industries, and international organizations have identified an array of naturally occurring materials that, because of human activity, may present a radiation hazard to people and the environment. In general terms, technologically enhanced naturally occurring radioactive material (TENORM) is material containing radionuclides that are present naturally in rocks, soils, water, and minerals and whose radioactivity has become concentrated and/or exposed to the accessible environment as a result of human activities such as manufacturing, water treatment, or mining operations. The principal radioactive elements of concern in TENORM are the radionuclides of radium, uranium, thorium, radon, and potassium, and their progeny.

1.2. Legal oversight

EPA radiation protection standards are utilized by the US Nuclear Regulatory Commission (NRC) and the US Department of Energy for closure of uranium mill tailings sites. In addition, EPA has the federal government's responsibility for developing guidance and criteria for radiation protection and disposal of TENORM. If federal government agency regulations have not been written, the states may prepare their own. Uranium mining TENORM includes conventional mining overburden, interburden, and drill cuttings. Under US law, the NRC regulates both the production of uranium and thorium, and disposal of tailings from the extraction process rocks. EPA and the states can regulate the handling and disposal of residual mining wastes including such things as mining overburden, interburden, and drill cuttings from conventional mines.

In the United States, over a dozen major statutes or laws, plus Executive Orders by the US President form the legal basis for programmes of the Environmental Protection Agency, including its authority to develop radiation protection standards and to regulate radioactive materials such as TENORM. Some principal laws providing these authorities include the Atomic Energy Act, the National Environmental Policy Act, the Safe Drinking Water Act, the Clean Water Act, the Clean Air Act, the Comprehensive Environmental Response, Compensation and Liability Act, the Toxic Substances Control Act, and the Resource Conservation and Recovery Act. As a result, EPA set standards for limits of radionuclides in drinking water and industrial water discharges, guidelines for cleanup of radioactively contaminated soils, and limits for radon emissions from specific wastes including uranium mill tailings. However, regulations and radiation protection guidance for a variety of TENORM substances and wastes have not as yet been developed.

2. EPA's TENORM STRATEGY

The goal of EPA's programme for technologically enhanced naturally occurring radioactive materials (TENORM) is to evaluate the risks of exposure to this source of radiation and determine the appropriate next steps to be taken to reduce these risks. Although EPA has developed regulations to provide radiation protection and waste disposal guidelines for certain types of TENORM such as phosphogypsum and elemental phosphorous, there are others for which only limited protections exist. The agency has conducted field and laboratory studies for these radioactive materials since the earliest days of its history in the 1970s. However, over the last ten years, EPA undertook efforts to characterize and assess the risks from all TENORM industry wastes and products in a single draft "scoping document". The last draft report was studied and evaluated in 1994 by an internal review organization within EPA, its Science Advisory Board [1]. That review made a number of recommendations, which would require substantial efforts to update information on the characterization of each TENORM source, methods by which it was generated, and how risk assessments of the materials' hazards were carried out.

EPA took steps to respond to its Science Advisory Board recommendations in the ensuing years, further revising the draft scoping report on TENORM wastes while attempting to obtain voluntary industry and state data. These efforts were generally unsuccessful in obtaining the levels of information needed. Additionally, information came to light that other industries not originally characterized in the previous draft reports had TENORM problems. A study [2] on TENORM by the National Academy of Sciences in 1999, mandated by the US Congress, also made recommendations that affected EPA's approach to TENORM wastes and products. Among the recommendations was that EPA should look at each source of TENORM radiation separately as each material may have varying physical and chemical characteristics that could be modeled differently for risk assessments. The Academy also recommended that EPA should take into account background levels of radiation when evaluating the TENORM substances and wastes.

Based on the Science Advisory Board and National Academy of Sciences reviews, EPA re-evaluated its approach to TENORM and decided that covering all forms of TENORM in a single scoping report could not be accomplished with its available resources and time. Accordingly, a four pronged approach was decided upon. First, the agency would address only one commodity/TENORM industry waste at a time in a series of sequential technical reports. Similar to an effort undertaken previously on non-radioactive components of mining waste by another part the Agency [3], the sequential reports allow EPA to concentrate its activities and better characterize each source.

Secondly, while developing these reports, field studies of existing sites could be conducted. The field studies would help provide a nation-wide view by identifying problems with the waste or product, finding out where it was being produced or where it had been left unreclaimed by previous operators in years gone by. Also field and laboratory studies would be used to characterize the waste or product chemically and physically, and more realistically assess the risks of the TENORM source.

Thirdly, the Agency plans to develop and provide education and guidance. This would be for the purpose of preventing accumulation of TENORM wastes and products and unnecessary radiation exposure to workers and members of the public. It would also hopefully provide for a means for more safely and economically preventing, cleaning up and disposing of TENORM; this includes existing or "legacy" waste sites which may not have a current owner or industry operator planning on reclaiming the site.

Lastly, EPA will work to establish partnerships with other organizations and stakeholders to enhance data sharing, and avoid duplication of efforts. This includes states and localities, indigenous populations, other federal agencies, industry and environmental groups, and international entities, as well as the general public. By taking this step, EPA can gauge the need and type of solutions to risks/hazards of each TENORM substance.

3. URANIUM MINING TENORM REPORT

As an example of what EPA plans to do, the following describes what the Agency has underway for uranium mining TENORM. To assess the risks and impacts of uranium mining TENORM, EPA is developing a technical report that will provide a "state of the industry" overview, the risks presented by the resulting waste streams, remediation and reclamation efforts by stakeholders including costs and methods, and the results of case studies. The intended audience is anyone impacted by uranium mining and these wastes.

While it is being prepared as a technical document, some topics will be presented in a manner which will allow the general public to better understand the discussion. The draft report will be provided for stakeholder review and meetings with affected parties, plus peer review of the written material. After revision and issuance as a final report, it is expected that the study will be used as the basis for decisions on next steps for providing health standards or guidance for radiation exposure, economic and safe waste disposal practices, community and industry education, or regulations for this waste if needed.

Supporting the development of the report, and providing more data for input to the risk assessment, the Agency has commenced a number of field and laboratory projects. These projects expand knowledge of uranium mining TENORM's physical and chemical characteristics, as well as its uses and disposal. This research also fulfills certain recommendations regarding TENORM made to EPA by the National Academy of Sciences. In addition, the field projects establish additional contacts between EPA, the uranium industry, governmental and Tribal organizations, and individuals who manage or oversee the reclamation of uranium mining TENORM wastes.

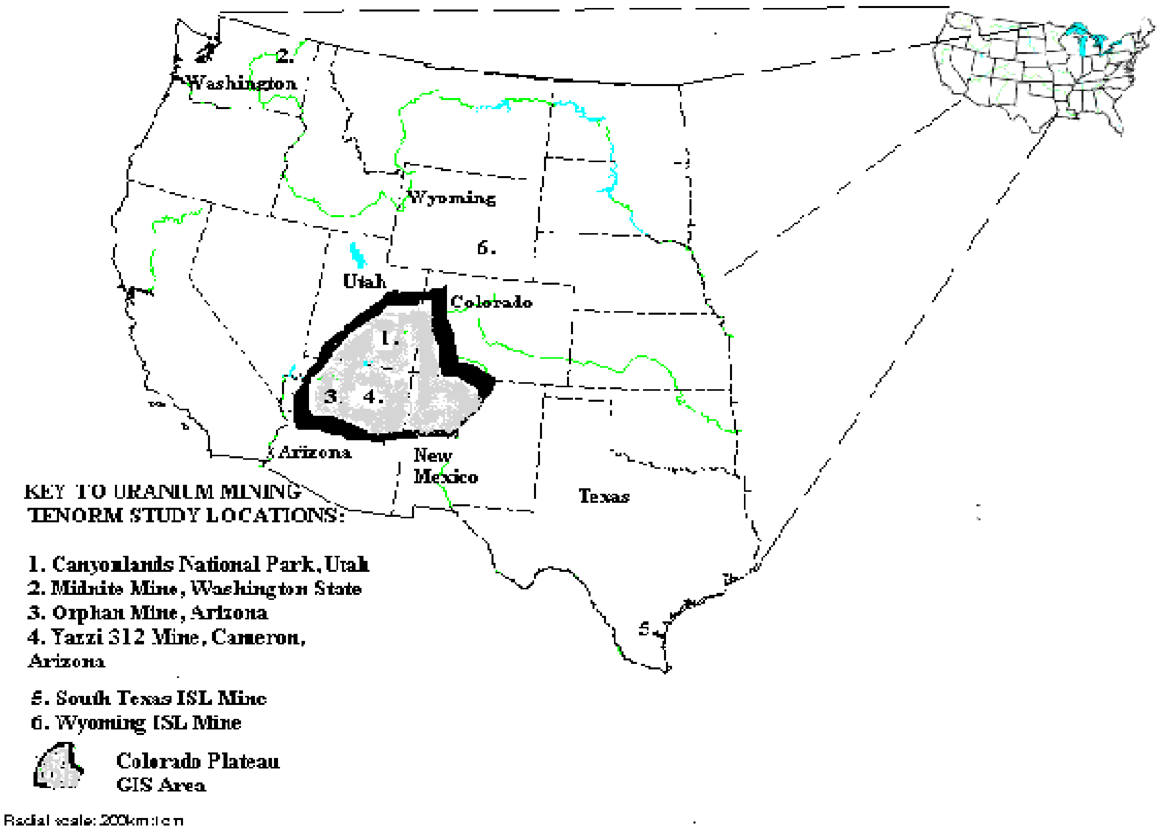
This is a significant challenge with approximately 4000 abandoned uranium mines nationally in more that 10 US States (both eastern and western). The variety of environments and physical/chemical conditions can vary significantly from site to site. EPA contract studies developed estimates that perhaps only 5 percent of these mines' wastes have been reclaimed nationally.

Based on EPA's previous and ongoing studies, radium content in the mining overburden tends to be low, averaging on the order of 20 pCi/g (0.7 Bq/g), but it may also include elevated uranium, thorium, and metals content. Radioactive dusts, radon, and migration of radionuclides and metals in water are the particular hazards of this waste material. Using the collected data, EPA will be modeling the risks of exposure to the uranium TENORM materials using realistic scenarios for maximally exposed individuals.

As well, EPA will examine the present methods and standards of remediation of these sites, the costs of remediation plus the existing regulatory regime. A significant amount of information has been generated recently in support of the joint Organization for Economic Cooperation and Development's Nuclear Energy Agency and International Atomic Energy Agency study of restoration of world uranium recovery facilities. The report of that international effort will be quite useful in assessing costs and methods worldwide.

4. URANIUM MINING TENORM FIELD STUDIES

To illustrate the range of some of the sites EPA is looking at in its current effort to categorize the physical and chemical aspects of uranium mining TENORM, as well as the risks posed by the mines, several of those field studies are described here. Locations of the sites are shown in Map 1 below.



MAP 1. Key to Uranium mining TENORM study locations mentioned in the text.

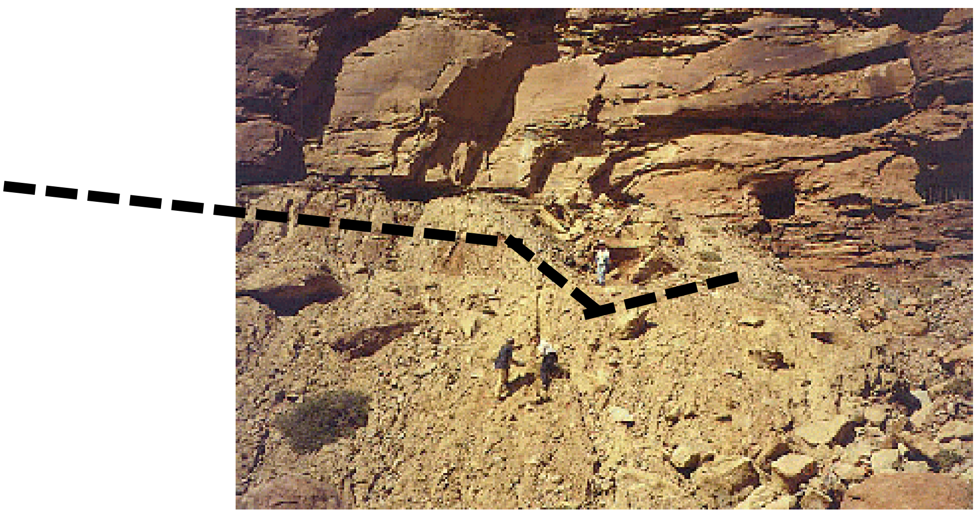


FIG. 1. One of 12 underground mines examined in Canyonlands National Park, Utah (Site 1 on Map). TENORM waste rock is located in bottom of picture underneath black dashed line. Mine entries are above the waste rock on the left of side the photo.

Many of the abandoned and unreclaimed mines we find in the southwest desert areas of the United States include small entry underground mines. A number of these can be found in isolated locations far from population centers. One site like that is found in the Canyonlands National Park in Utah (site number 1 on Map 1). While some of the spoil waste rock from the mine has been left in the rooms of this underground mine, other material has been dumped over the edge of the mine openings onto the slope and ground below. This spoil material has relatively low radioactivity, but yet could affect local wildlife, and the site poses a small but real radiation and safety hazard to occasional hikers. Fig.1 is a photograph of the mine openings and spoil material below. EPA staff collected water and sediment samples for radionuclide and heavy metals analysis from this location and 11 other mines in the vicinity [4]. Detailed physical analyses and measurements of spoil piles and sediments were made to characterize the TENORM from these mines.

The Midnite Uranium Mine in Washington State is on the Spokane Indian Reservation and its location is Site 2 on Map 1; an aerial photograph of this open pit mine is shown in Fig. 2. The mine was developed in 1955 and produced uranium until 1981. Currently, protore and waste rocks are located over the 320 acres (130 hectares) disturbed by mining. Two open pits collect seep water, pit water, and surface runoff. The other mined pits are back filled with waste rock. Water from the mine is contaminated with radionuclides and metals and is moving in plumes and seeps towards stream drainages. This site is now listed by EPA as a Superfund site and undergoing a detailed environmental site assessment [5]. Fifty-two monitoring wells have been drilled at the site, hundreds of sediment and water samples are being collected and analyzed for chemical composition including metals and radionuclides, and site radiological, ecological and cultural studies have been conducted as well. Challenges include how to reclaim the site, identifying who would be the maximally exposed individual in dosage pathway risk assessments, how to prevent drainage to the nearby streams, and what measures need to be taken to protect the local Tribal population.

FIG. 2. Midnite uranium mine, Washington State (Site 2 on Map).

Another study site is the underground Orphan Uranium Mine in the Grand Canyon National Park. The location of this mine is Site 3 on Map 1; a photograph of the mine's headframe and truck loadout area at the canyon rim is shown in Fig. 3. This mine site is 10 minutes walk from the visitor's center where 2 million people visit each year.

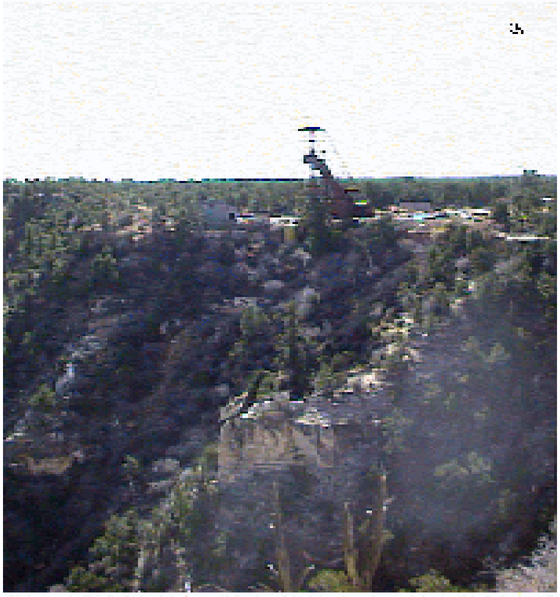


FIG. 3. Orphan uranium mine, Grand Canyon, Arizona (Site 3 on Map). Head-frame for the mine is shown on the canyon rim and the mine entry portal is near the bottom left of the photo.

Loosely fenced until 1998, the ground surface was contaminated with spilled ore and TENORM spoil materials. The mine and waste rock dumps, located down the Canyon wall over a hundred meters below, may leak water with radionuclides into springs at a site where park visitors hike a main trail in the Park. This site has presented a small but real hazard to a large number of incidental visitors. A number of radiological and geochemical site characterization studies were conducted by the US National Park Service, and consultations were held with EPA.

FIG. 4. Yazzi 312 water filled open pit uranium mine, Cameron, Arizona (Site 4 on Map).

Of all people affected by uranium mining TENORM, the Navajo and other Native American Tribes of the desert southwestern US may be the most heavily impacted. Located in Utah, Arizona, and New Mexico, Tribal members have unreclaimed mines on their property and in their communities. Some individuals have reportedly used the readily available spoil materials for home construction. The water filled open pits, like the Yazzi 312 Mine site of Fig. 4 (Site 4 on the Map), may be the only water for miles around in a very arid climate. This pit mine, which is currently being studied by EPA for ground water contamination and communication, has been used for swimming, livestock watering, and dust suppression. EPA's Regional Office has been analyzing pit and well water quality across the Reservation in Arizona, and mapping by air and ground the locations of mine sites. Laboratory and

field data on TENORM waste rock spoils and water contamination at these former uranium mine sites will be used in the EPA Technical report and risk analyses; information on ground water contamination will be used to assist the Navajo Abandoned Mine Land Reclamation Agency in deciding how to reclaim the Yazzi 312 and similar pits in the area.

In an effort to understand the radiological and other characteristics of the water, evaporates and drill cuttings from in-situ leaching (ISL) uranium mining operations, EPA has collected data at some of these ISL sites. It was determined recently that waste from these operations falls under the regulatory jurisdiction of another US federal agency (NRC), so EPA would not establish standards for ISL wastes. Data that EPA has collected will be used in EPA's technical report to present a more complete assessment of risks from uranium mines. Fig. 5 shows evaporation ponds from ISL operations in Texas (Site 5 on Map 1); other sites visited by EPA are in Wyoming (Site 6 on Map 1).

FIG. 5. Evaporation pond at ISL mine in South Texas (Site 5 on Map).

To assess the regional impacts of abandoned uranium mines, EPA is also developing a geographic information system for the Colorado Plateau in co-operation with the 4 states involved (Colorado, Utah, Arizona and New Mexico), plus the land owning government agencies and Tribes. This system which includes population data, abandoned uranium mine land locations, land ownership, wildlife and water data, will help EPA to assess the population and other impacts of the mines on a regional scale. The location of the Colorado Plateau is shown on Map 1.

5. RISK ASSESSMENT

In conducting EPA's new risk assessments, the Agency will be using both its own and commercially available risk assessment models. Data sets to model the uranium mining TENORM will include data from both previous research and the new studies. Monte Carlo approaches for calculating uncertainty and sensitivity of the models as well as TENORM data variability will be used. Radiation dose levels will be based on realistic scenarios and maximally exposed individuals in each case. Observations of human presence and interactions/use of these materials will provide information that can be used in formulating the dosage pathways and scenarios. Guidance obtained from EPA's Science Advisory Board will assist in model parameter setting and other aspects of the modeling effort including exposure scenarios to be used. Information on the non-radioactive chemical aspects of the uranium mining TENORM will be included in the characterization of the waste materials, and assessing their risks as appropriate.

6. STAKEHOLDERS

EPA's uranium TENORM stakeholders are the public, uranium and mining industries, government agencies at all levels, the indigenous populations and government for which EPA has a trust responsibility, environmental and other non-governmental organizations. These organizations EPA expects to turn to in sharing the data which is gathered, and to look towards in developing EPA's approaches to uranium mining TENORM.

The next steps for EPA will be based on what is learned from the technical report and stakeholders views. EPA expects to evaluate the needs for specific health standards and guidance to radiation exposure to this TENORM waste, evaluate what may be responsible economic and safe waste disposal practices, assist in community and industry education efforts if appropriate, and develop regulations if they are needed. While US sources of uranium mining TENORM are dominated by abandoned, not active mines, EPA is obtaining useful information from international co-operation with organizations such as the International Atomic Energy Agency and the Nuclear Energy Agency. Both of those organizations are co-operating with the EPA in studies of the environmental impact and methods for uranium mine reclamation.

7. CONCLUSION

The US EPA has changed its approach to TENORM wastes and products and is now developing a series of sequential, individual technical reports on each TENORM waste/product industry sector. The first technical report, which will be issued in draft for stakeholder and peer review, will be on the topic of uranium mining TENORM. This spoil material consists of overburden, interburden, as well as drill cuttings from conventional mines. EPA field studies at these sites around the country are providing new physical and chemical data on the TENORM wastes, and contributing to an understanding of the risks posed by the materials. This information will be used in conducting the risk assessment modeling of uranium mining TENORM. Meetings with stakeholders affected by these sites and peer reviews will be held to finalize the technical report. Based on these efforts and recommendations of the stakeholders, EPA will make decisions on its course of action: developing health standards or guidance for radiation exposure, new standards for economic and safe waste disposal practices, approaches for community and industry education on the wastes, or regulations for control of this waste if needed.

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PRODUCTION TECHNOLOGY

(Session 3)

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Technology and the uranium industry

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Abstract. Continuing economic and regulatory pressures on the uranium industry can be countered only through advances in technology. Low prices, the "ALARA" principle, and concerns about "sustainability" require the industry to continually improve upon its already impressive record of performance. Technological improvement in the uranium industry is necessary in order to: (a) Maintain our resource base through the discovery of ever-deeper deposits; (b) Improve the efficiency with which we may exploit (i) very high-grade deposits by remote underground mining methods (ii) very low-grade deposits with environmentally-benign, in situ leaching methods - and (iii) moderate-grade, near-surface deposits by open-pit mining methods (c) Meet increasingly stringent and, in many cases, arbitrary and unrealistic environmental and safety requirements; and (d) Cope with increasing competition from an expanding number of sources of secondary supply. Manifestations of the uranium industry's ability to improve its performance through technology can be seen in many ways including: a continuing reduction in production costs; large gains in productivity; and a truly superior record of employee safety. Maintenance of these trends requires both innovation and the open sharing of information.

1. INTRODUCTION

Few industries have been subjected to more stress than the uranium industry. Prices for our product have fallen by an order of magnitude in the last two decades (Fig. 1). This decline has rendered a large portion of known resources to be uneconomic. Production and production capacity have decreased by almost 50 percent. Increasingly stringent regulations require greater expenditures of time, effort and money to produce the same quantity of the same product. Non-governmental organizations are gaining a presence and a strength which threaten to dominate the licensing/permitting process. New uranium projects may now require ten years or more to complete this process. How can the industry cope with these pressures? Only through advances in technology.

Let us recognize, however, that technology cannot be considered in isolation within the uranium industry. Technology is driven by needs which may be economic, environmental, social or a combination thereof. Most uranium projects already operate under the "**ALARA**" principle: the environmental impact must be **A**s **L**ow **A**s **R**easonably **A**chievable. Now we must also address the issue of sustainability. Sustainability has been recently defined as: "A balanced integration of high quality economic, environmental and social performance". Definitions of "reasonable" and "sustainable" are likely to be quite different between regulators, stakeholders and operators. The difference is almost entirely in cost. It is only through technology that we can maintain an acceptable balance among the three cornerstones of sustainability: economics, environment and social responsibility.

Advances in technology are important to the uranium industry because they provide the means by which:

(a) Our resource base is sustainable through:
  (i) discovery of new orebodies;
  (ii) exploitation of both "difficult" orebodies and lower-grade resources; and
  (iii) application of new technology to known, undeveloped resources.
(b) Economic exploitation is sustainable through a continuing reduction in production costs;
(c) Our environment is sustainable through the decrease or elimination of adverse impacts;
(d) Our ability to meet social obligations is sustainable through increasing safety and well-being for both employees and stakeholders.

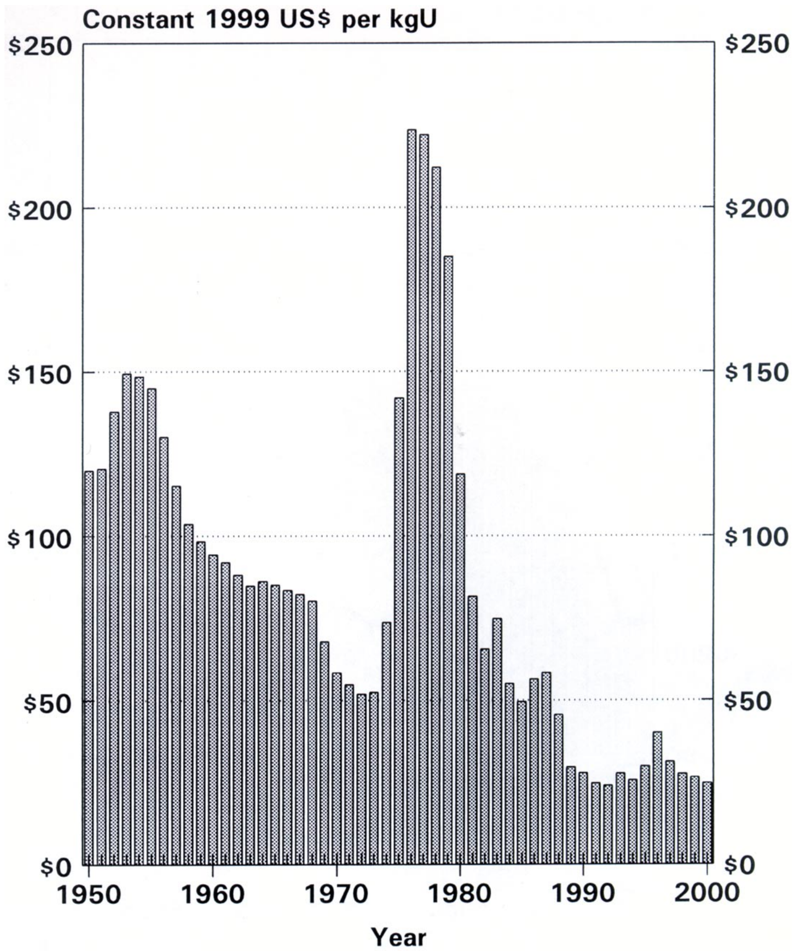

FIG. 1. Historical uranium prices.

This presentation sets forth a brief survey of current technology in the uranium industry, relates that technology to economic, environmental and social concerns, and attempts to provide a projection of current trends into the future.

2. EXPLORATION

Exploration is the means by which the industry maintains a viable resource base to provide for future production. It is also the first segment of the industry to react to changes in price (Fig. 2).

With today's low prices, less incentive to explore exists and only a few exploration projects are being pursued. Those few projects are located mainly in areas where a potential exists to discover large, high-grade deposits. Saskatchewan's Athabasca Basin is the focus of most of these activities, although Australia is seeing some exploration as a result of a change in government, which removed the restrictive "three mines" policy of the Australian Labor Party.

Most of the early discoveries in the Athabasca Basin were in relatively shallow areas of the basin where surface indications of mineralization, glacial boulder trains for example, provided clear evidence of nearby deposits. Extensive and intensive exploration of these shallow areas has now exhausted much of the near-surface potential and exploration is moving into deeper and deeper parts of the basin. This process is illustrated in the following table, which sets forth the year of discovery and depth for most of the major Athabascan orebodies.

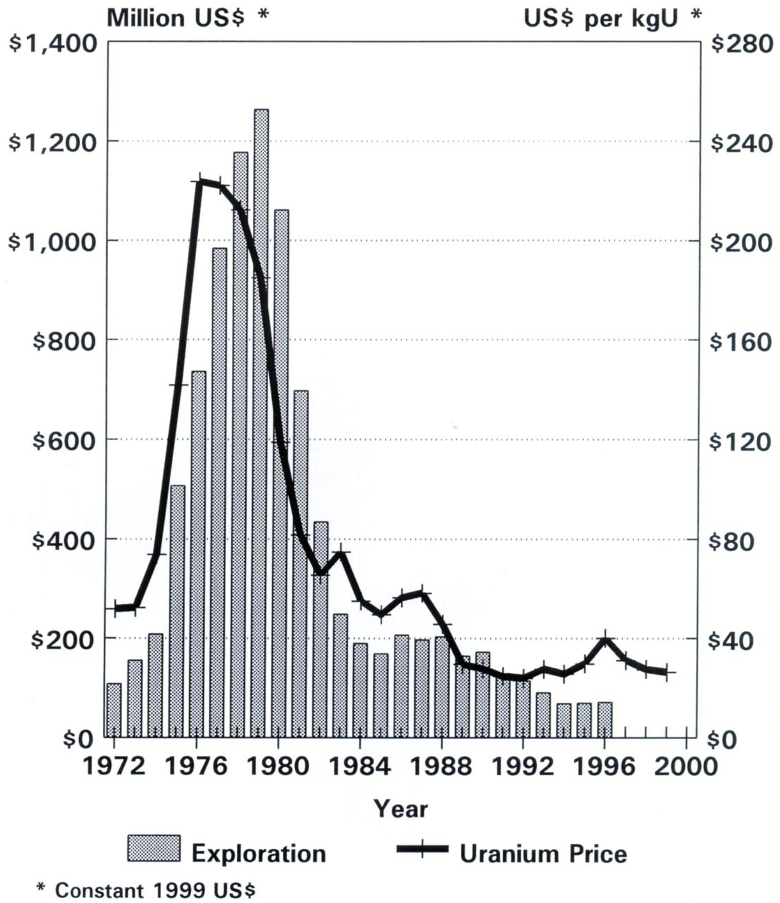

FIG. 2. Exploration expenditures and prices.

TABLE I: DEPTH-DATE OF DISCOVERY RELATIONSHIP ATHABASCA BASIN URANIUM DEPOSITS

Deposit	Year of Discovery	Depth (m)
Rabbit Lake	1968	150
Cluff Lake	1975	200
Key Lake	1975	200
Collins Bay	1976-1979	100
Dawn Lake	1978	200
Midwest	1978	200
Eagle Point	1980	400
McClean Lake	1980	200
Cigar Lake	1981	450
McArthur River	1988	550
La Roche Lake	1999	280

Discovery of progressively deeper orebodies with progressively less surface expression requires increasingly sophisticated methods and equipment. Much of the recent exploration work in Saskatchewan has utilized **large-loop ground electromagnetic surveys** to search for graphitic conductors at depth. To date, the deepest success for geophysics in the Athabasca Basin has been the discovery of a mineralized zone at a depth of 700 meters on Cogema's Shea Creek project. **Infrared spectroscopy** has been used in several instances to assess subtle variations in clay mineralogy which might be indicative of an alteration halo surrounding an unconformity uranium deposit.

While exploration is expected to continue in a few of the most prospective areas and higher prices will encourage a resumption of limited exploration in other areas, much of the future for our industry lies in applying new technology to known, but as yet undeveloped, deposits. This process applies especially to sandstone deposits, which may be amenable to in situ leaching (ISL) and to high-grade deposits, which may require some type of remote, bore-hole mining method.

3. MINING

Mining in the twenty-first century presents at least two major challenges: production of very high-grade ore under difficult ground and water conditions, and production of lower-grade ores under difficult economic conditions. Technological advances will be needed in both cases.

Current uranium production methods include conventional open pit and underground mining, in situ leaching and by-product recovery. Since 1982, the relative output of these four methods has changed substantially (Fig. 3). Output from underground mines has declined from almost 50 percent of the total to less than 30 percent. Open pit mining now accounts for just under one-half of total output, up from about one-third in 1982. By-product output has remained at somewhat over ten percent, but in situ leaching has shown a substantial increase up to 17.5 percent in 1999.

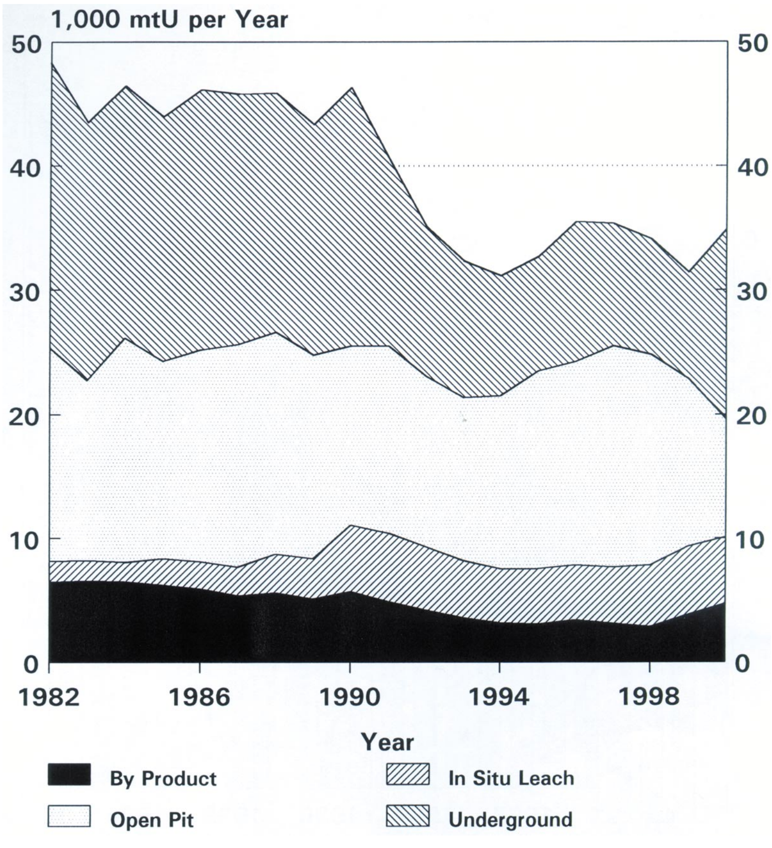

FIG. 3. Historical uranium production by method.

For the future, underground output is expected to regain its former share as McArthur River and Cigar Lake add almost 7000 mtU each to the total. No major changes are expected in open pit or by-product output. Modest price increases could stimulate a significant increase in ISL production since there are many projects on the drawing board which would likely be economic if prices rise to the $35 to $40 per kgU level.

3.1. Underground

It will be very interesting to follow the course of production at McArthur River, the first of a series new high-grade mines in the Athabasca Basin, to see if new production methods can achieve the cost and output levels desired. **Remote mining** of frozen ore, underground crushing and grinding, and pumping slurry to the surface are new to the uranium industry. Costs per metric ton of ore produced are projected to be quite high but, with a uranium content of 10 percent or more, costs per kgU of output should be very competitive.

This production technology is dictated by both ground conditions and regulations. Weak, water-saturated ground must be frozen in order to stabilize underground openings. Advanced drilling systems, which allow freeze holes to be cased as drilling progresses were developed to cope with high pressure water and squeezing ground. Concrete backfill is required to prevent subsidence. A special **cold-temperature concrete** has been developed for this application. Very high-grade ore, up to 20 percent U or more, presents a radiation hazard to miners and must be mined by remote means. McArthur River will utilize a high-pressure water, **bore-hole mining** method for much of its production.

Many underground mining operations are already using remote ore removal methods. Cameco, at its Eagle Point mine, has utilized **remote-controlled**, rubber-tired, diesel, load-haul-dump equipment for several years. Tests have been conducted using raise boring and bore-hole methods at Midwest and Cigar Lake, respectively, to produce high-grade ore. Blast-hole, box-hole and slot mining methods also limit miners exposure to radiation. Drilling from outside the ore zone is a primary characteristic of these methods.

It is expected that the development of the underground bore-hole mining method for high-grade deposits in Canada will lead, ultimately, to further development of the method for application to progressively lower-grade deposits. Bore-hole hydraulic mining from the surface was tested in the US in the 1970s for mining of uranium-bearing sandstone ores, but has yet to be applied commercially.

Underground uranium mining has also benefited from the development of **small equipment for use in narrow-vein mining** as at Cluff Lake.

3.2. Open pit

Despite its moderate ore grade, 0.25% U, the Ranger mine in Australia consistently ranks as one of the world's most productive uranium mines. In 1999, for example, the company employed a total of 272 people who mined 7.8 million metric tons of ore and waste, milled 1.8 million metric tons of ore, and produced 3710 metric tons of uranium. This productivity of 13.6 mtU per employee was the world's highest in 1999. Only the Key Lake and Rabbit Lake mines in Saskatchewan can compete with Ranger in terms of productivity and the ore grades at those mines have been much higher; about 1.7 and 1.2% U, respectively.

What makes the Ranger mine so productive? Part of the answer is **large equipment**: a 14 m^3 backhoe loading 125-metric ton haul trucks. Key Lake was using an 8 m^3 loader and 50-ton trucks.

Rössing is another success story in open pit mining. As the world's lowest grade, 0.025% U, conventional uranium mine, Rössing continues to increase its productivity and to evaluate new means

for further increases. Past implementations include: larger excavating equipment (34 m^3) and an **electric trolley assist** for haul trucks (180 metric ton capacity). Future improvements now under consideration include **in-pit crushing and conveyor haulage**. Rössing's productivity is now 2.3 mtU per employee-year, a very creditable output considering the grade of ore being mined, and double its production at full capacity in 1980.

3.3. In situ leaching

In situ leaching (ISL) has gained an increasing share of world uranium production. This increase can be attributed to a combination of economics, technology, and low environmental impact.

ISL production offers a more flexible cost structure, which has the capacity to react more readily to changes in market price than conventional methods. As a methodology of moving chemical solutions through a system of pumps, pipes and valves, ISL offers great opportunities for increased automation. ISL producers in the US, such as Smith Ranch, Crow Butte and Highland, rank quite high among uranium producers, in general, with productivity in the range of 6 to 8 mtU per employee-year. Much of this ranking can be attributed to **advanced instrumentation and computerization**. Fig. 4 illustrates the advances made in ISL productivity in the US ISL industry. Uranium production by ISL methods has a relatively low impact on the environment; the only major concern being degradation of the groundwater regime. This combination of attributes provides ISL with somewhat greater "staying power" than other methods.

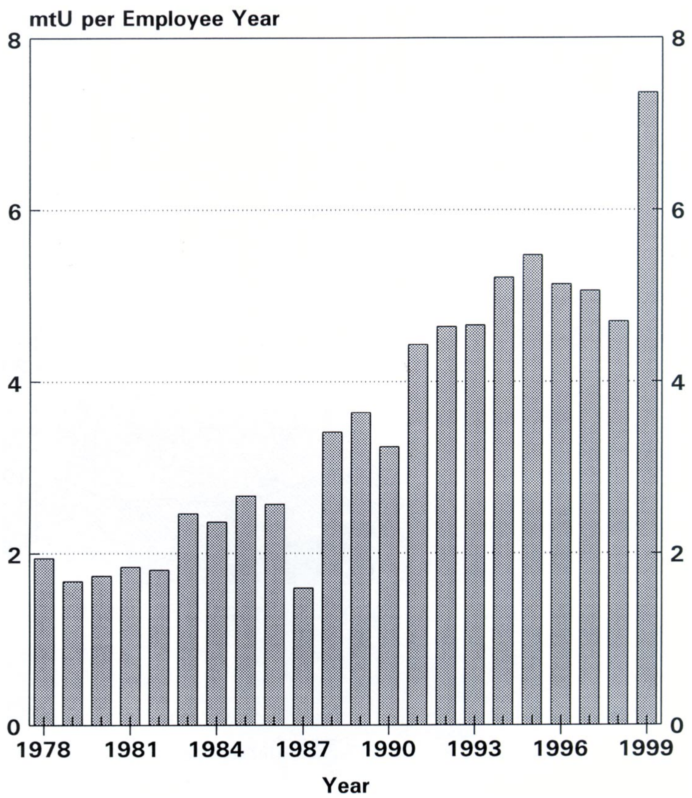

FIG. 4. US in situ leaching productivity.

Opportunities for technological improvements in the ISL method are many, but perhaps the most intriguing are those dealing with the wellfield, which is typically the most costly part of an ISL operation. Optimization of flow patterns and leaching chemistry holds the key to increased spacing between wells. **Directional drilling** offers the opportunity for multiple completions from a single drill site and may be employed in the future as an economic means of accessing deep orebodies. Horizontal wells are also possible through directional drilling.

3.4. Uranium as a by-product

Uranium has been produced as a by-product mainly from gold, copper, and phosphate. Uranium production from South Africa's gold mines has decreased as a result of both low prices and declining ore grades. In the past, some South African gold ores were sorted radiometrically to provide a higher-grade feed, in both gold and uranium, for the milling process. A "reverse" leaching process where sulfuric acid leaching of gold-uranium ore for uranium enhances subsequent gold recovery is used in the only two remaining uranium-from-gold by-product operations in South Africa. Substantial quantities of tailings were also reprocessed for the uranium and gold content. Low prices for uranium and depletion of the higher-grade tailings have caused such projects to be abandoned.

Olympic Dam, a copper producer in Australia, has recently increased its uranium output to almost 4000 mtU per year as the result of a major expansion project.

IMC has recently demolished its uranium-from-phosphoric-acid production facilities in the US due to low uranium prices. Uranium from phosphoric acid technology is old solvent extraction technology from the mid-1970s. Failure to improve that technology is probably responsible for its demise. Opportunities for potential improvements are seen to exist through both **ion exchange and membrane technologies**. It is interesting to consider that uranium removal from phosphoric acid may, some day, be a requirement for environmental reasons. That situation will then promote a new range of uranium recovery technology.

4. PROCESSING

Uranium ores have been processed, mainly, by: crushing and grinding, sulfuric acid leaching, and either ion exchange or solvent extraction concentration. Little change has occurred in these unit processes for decades. What is changing, however, is an increasing trend toward optimization of the recovery process.

Optimization is occurring in several ways.

Energy usage and chemical consumption are being balanced against recovery through increasing application of the **heap leach process**. Lagoa Real in Brazil is the world's newest uranium processing facility and treats all ore by heap leaching. Technology transfer from the gold industry where heap leaching accounts for a substantial percentage of production can be expected to contribute to the future of heap leaching for uranium. Several new heap leach projects in Australia, Portugal and the US have been proposed by Anaconda Uranium. China is shifting its production focus from conventional milling to heap and in situ leaching.

By-passing fines around the grinding circuit not only reduces energy consumption, but also reduces the generation of difficult-to-handle slimes. ENUSA's Quercus mill in Spain was designed and built on this principle. Rössing is considering implementation of a similar system.

For most of its history, the uranium industry of the Soviet Union/CIS has focused on maximum recovery of not only the identified primary resource, but also on recovery of minuscule amounts of by-products such as molybdenum, vanadium and scandium. Economics of the recovery process were not a major concern and, consequently, most of the Soviet/CIS producers consumed large amounts of energy and chemicals in comparison to their western counterparts. As market economy concerns become more widespread, we can expect to see increasing efficiencies in CIS processing facilities. This transition can be classified as the application of **economic technology**.

Radiometric sorting is an underused technology in the uranium industry even though it has proved its usefulness in Canada, South Africa and the US. A particular problem is the general softness of many uranium ores, which results in a wide range of particle sizes and consequent difficulties in sorting.

Nevertheless, the proposed Kintyre project in Australia has been designed to incorporate sorting and, as a result, the proposed plant milling rate will be less than one-fourth as large as would otherwise be the case. Kintyre is also notable for the proposed use of **heavy media** separation of fines in the crushing and sorting process.

5. TAILINGS DISPOSAL

Uranium tailings did not present a disposal problem during the first few decades of our industry; they were simply pumped to the nearest topographic low and discharged. Increasing concerns relative to groundwater contamination and windblown dispersion have now raised tailings disposal to one of the most important considerations for any uranium project. This elevation of concern has increased the cost of producing uranium, but several technologies have the potential to minimize that increase as well as to satisfy most of the concerns of NGOs and regulating authorities.

In-pit disposal of tailings is seen as a major advance in containment. Developed at Rabbit Lake as the "pervious surround" method, in-pit disposal has now been applied at Key Lake for tailings from McArthur River ore, at the McClean Lake project, and at Ranger. Several underground mines use the coarser portion of tailings for backfill.

It is clear that finely-ground tailings carried in a slurry pipeline to an above-grade disposal site present substantial opportunities for contamination of the surrounding area. **Paste disposal** is a technology, which addresses most of the concerns of such a system. Paste disposal, in essence, provides for elimination of most of the water from the tailings prior to disposal. Advantages are many, including: a reduction in volume, a reduction in geotechnical hazards associated with containment structures, a reduction in both short- and long-term environmental liability, an increase in siting and operational flexibility of storage facilities, and significant water conservation potential. Paste disposal technology will be used for Cigar Lake tailings disposal at the McClean Lake project where a portion of Cigar Lake ore will be milled.

Paste disposal is not new. It has been applied in at least one other instance: the Zirovski Vrh uranium project in Slovenia. At Zirovski Vrh, **belt filters** dewatered the tailings which were then loaded into trucks for transport to a nearby disposal area.

6. RECLAMATION

As more and more uranium facilities are forced to close because of low prices, a greater focus on reclamation activity is apparent throughout the industry. Within this activity, one key element emerges time after time: Reclamation is less expensive when designed into the initial project plan and when carried out **concurrently with production**. This principle is not always applied since reclamation is seen as non-productive and operators are inclined to defer non-productive expenses. This deferral can cause severe problems, particularly when an operator loses the financial ability to meet its reclamation obligations.

A lesson in the cost of deferral is evident in the "Title I" tailings remediation program conducted by the US Department of Energy (U.S. DOE) on a number of old US uranium processing sites for which no "responsible party" could be found to fund the cleanup. In this case, US DOE funded and managed the clean-up at a cost of approximately $53 per metric ton of tailings, or $30 per kgU produced. By contrast, company reclamation, albeit not necessarily contemporaneous with production, has cost about $2.50 per metric ton of tailings, or $2.00 per kgU produced.

New technologies are being developed and applied to uranium reclamation. Most deal with groundwater restoration since that is the most difficult problem facing the industry today. Because in situ leaching of uranium is a groundwater technology in and of itself, it can be expected that a substantial portion of groundwater restoration technology has its roots in the ISL process.

(a) Uranerz has demonstrated at its Ruth ISL pilot plant in Wyoming that the introduction of a **reductant such as hydrogen sulfide** into the depleted wellfield regime can precipitate and immobilize a variety of metal ions.
(b) **Reverse osmosis** technology is applied to most ISL restoration projects in the US Membrane and electrochemical water treatment methodologies are finding increasing application in a variety of clean-up situations.
(c) **Reactive chemical barriers** are now in use as a means of reducing groundwater contamination. Cotter Corporation recently installed a reactive barrier containing zero valant iron at its Cañon City, Colorado, US uranium mill to intercept molybdenum-contaminated groundwater.
(d) **Bioremediation** of uranium contaminated groundwater has been addressed by several researchers.
(e) A three-stage process of **ion exchange**, lime neutralization and filtration is being used to clean-up groundwater contamination from an underground acid-leach uranium mine in the former East Germany.

All of the above references relate to active means of combating groundwater contamination and are likely to find application to a large number of specific clean-up situations. Still, the most interesting approach to groundwater clean-up of which I am aware is that taken at ore body No.10 of the South Bukinai deposit in Kazakhstan: **natural attenuation**. Natural attenuation of contaminated groundwater has been studied in some detail at this location with a conclusion that background levels of contaminants were likely to have been reached within a period of 26 to 31 years. After an 11-year period of natural attenuation, however, this process was accelerated by pumping and reinjection of fresh groundwater from just outside of the mined area and was completed in just an additional 20 months. The significance of natural attenuation is that it may provide assistance in the restoration process and that it may place very real limits on the amount of restoration work required. A thorough understanding of the potential for natural attenuation prior to licensing or even commencement of restoration could provide substantial economic benefits. Even the US Environmental Protection Agency, one of the world's most conservative environmental regulators, has adopted this approach at a number of abandoned uranium mill sites in the US where contaminated groundwater is unlikely to pose an active threat to the environment.

Uranium is also being produced from so-called "**alternate feed**" materials, mainly uranium-contaminated soils from clean-up of nuclear weapons facilities. Existing tailings ponds at uranium processing facilities provide an economical means of disposing of this material even though the uranium content may be quite low. The current trend toward increasing protection of the public and the environment can be expected to generate additional opportunities for uranium recovery. These opportunities are likely to include an increasing variety of uranium-containing materials, which will be produced from both water and mineral treatment facilities.

7. HEALTH AND SAFETY

Social concerns in the uranium industry are centered upon the health and safety of 1) employees of uranium production facilities; and 2) people living in the vicinity of those facilities. Because the hazards of radiation are well known, most uranium production facilities are extremely safe from a radiological standpoint. This emphasis on radiological safety carries over into other areas of health and safety such that uranium production facilities are among the safest industrial facilities in the world.

In this regard, I want to specifically recognize the following operations: Rössing in Namibia, Ranger in Australia, and Highland in the US. Rössing receives continual recognition as one of the safest mines in southern Africa. Ranger ranks in the top five percent of industrial health and safety performance in Australia. Highland has produced over 10 million pounds U_3O_8 without a lost-time accident. These achievements occur at least partially because of the generally high level of technology within the uranium industry. I noted previously that Rössing, Ranger and Highland are among the most productive

mines in the world. I will ask again: Is it a coincidence that some of the most productive mines in the world are also the safest? Is it also a coincidence that these mines are technologically advanced?

8. CONCLUSION

A high level of technology is currently incorporated into most uranium production facilities. Continuing technological advancement is required in order to maintain a "sustainable" industry. These advances may be driven by a variety of concerns: economic, environmental or social. Let us continue to share these advances in forums such as this for the benefit of all.

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Mining the high grade McArthur River uranium deposit

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Abstract. The McArthur River deposit, discovered in 1988, is recognized as the world's largest, highest grade uranium deposit, with current mineable reserves containing 255 million lb U_30_8 at an average grade of 17.33% U_3O_8. In addition the project has resources of 228 million pounds U_30_8 averaging 12.02% U_30_8. Mining this high-grade ore body presents serious challenges in controlling radiation and in dealing with high water pressures. Experience from the underground exploration programme has provided the information needed to plan the safe mining of the massive Pelite ore zone, which represents the most significant source of ore discovered during the underground drilling programme, with 220 million pounds of U_3O_8 at an average grade in excess of 17%. Non-entry mining will be used in the high-grade ore zones. Raise boring will be the primary method to safely extract the ore, with all underground development in waste rock to provide radiation shielding. Water will be controlled by grouting and perimeter freezing. The ore cuttings from the raise boring will be ground underground and pumped to surface as slurry, at an average daily production of 150 tonnes. The slurry will be transported to the Key Lake mill and diluted to 4% before processing. The annual production is projected to be 18 million lb U_3O_8. The paper focuses on the activities undertaken since discovery, including the initiation of the raise bore mining method utilized to safely mine this high-grade ore body. Radiation protection, environmental protection and worker health and safety are discussed in terms of both design and practical implementation.

1. INTRODUCTION

1.1. Location

The McArthur River deposit is located in the eastern part of the Athabasca Basin in northern Saskatchewan, Canada (Fig. 1), and is located 80 kilometres northeast of Key Lake and 40 kilometres southwest of the Cigar Lake deposit. The site is approximately 620 kilometres north of Saskatoon, a city with a population of 220 000, and the location of Cameco's corporate office.

1.2. History

Cameco, through one of its predecessor companies, Saskatchewan Mining Development Corporation, began operating the McArthur River exploration joint venture in 1980. After several changes in joint venture partners, the project is now owned by Cameco Corporation (69.805%), and Cogema Resources Inc. (30.195%). In 1988 the ore body was discovered following eight years of systematic exploration in the area. Improvements to large-loop time-domain electromagnetic methods allowed the definition of graphite conductors in the basement fault structure which controls the location of the ore. Drilling confirmed this structure and discovered sub-economic mineralization five kilometres to the southwest of the McArthur River ore body. The recognition of favourable alteration patterns in drill holes helped guide the exploration drilling to the ore body.

Several years of core drilling from surface followed and resulted in the outlining of high-grade mineralization over 1.7 kilometres of strike length. By 1991, 60 holes were completed of which 37 holes intersected uranium mineralization at a depth of 500 to 600 metres. Based on this information a resource of 260 million pounds at an average grade of 5% U_3O_8 was estimated. Seventy per cent of the estimated resource was based on only seven drill holes, and 18% was based on a single hole which graded 43% U_3O_8 over 25 metres [1]. Following completion of the surface drilling it was decided to undertake an underground exploration programme which would provide the detailed information about the shape of the individual ore bodies.

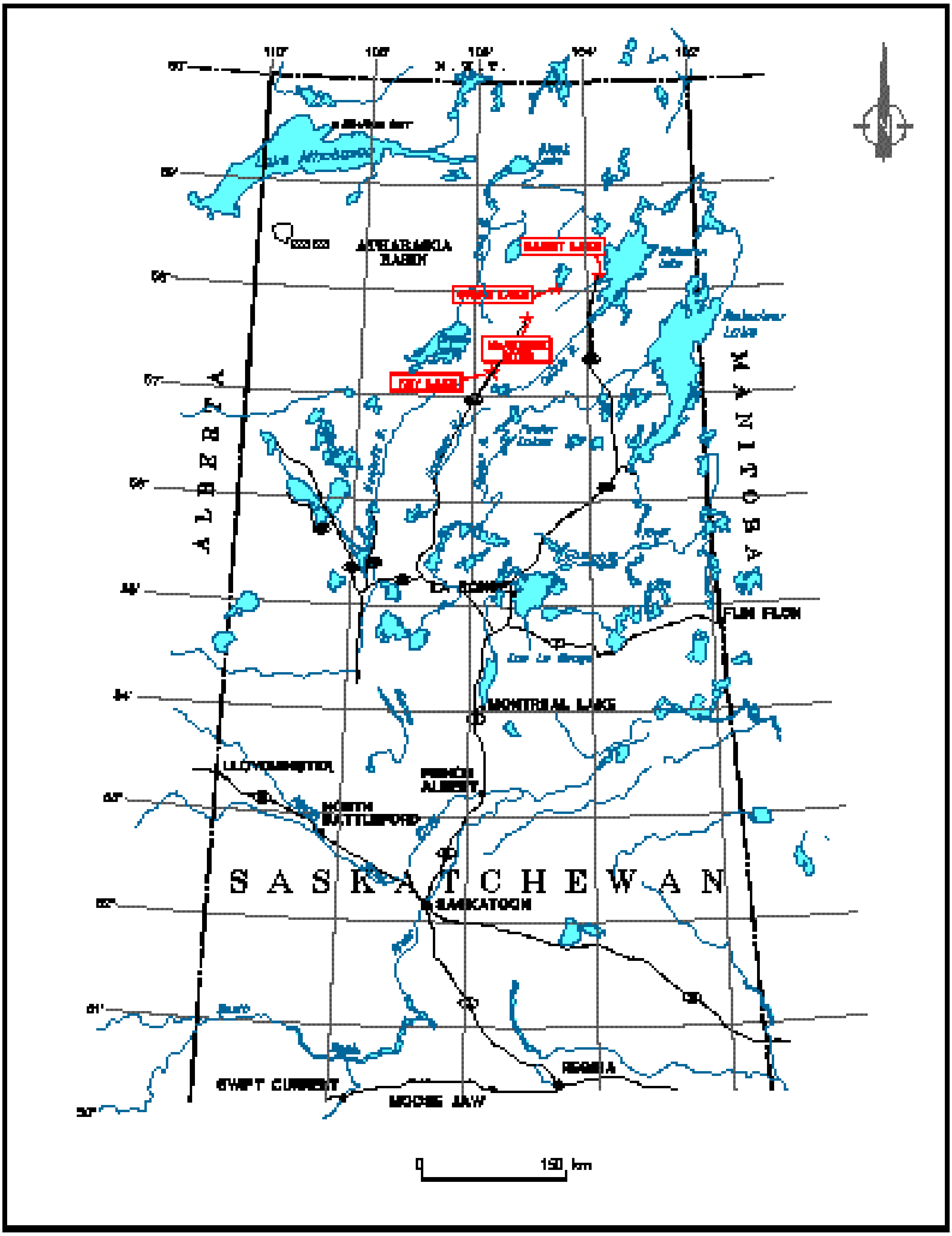

FIG. 1. Location of McArthur River and other uranium projects in northern Saskatchewan.

The project was referred to the Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan, in February, 1991. Scoping meetings were held in nine northern and three southern communities in early 1992 to get public input into the guidelines for the environmental impact statement (EIS). The guidelines were issued later that year, after a public review of the draft. Environmental studies had already been started to develop the information necessary for the EIS. An EIS for underground

development was developed and the Panel conducted hearings on this subject at five northern and two southern communities in December, 1992. After a favourable report from the Panel and licensing by both the federal Atomic Energy Control Board (AECB)[1] and the Province of Saskatchewan, shaft sinking commenced in the spring of 1993 [2].

Under that excavation license, horizontal development on the 530 metre level was undertaken to permit diamond drilling along a 300 metre strike length of the mineralized zone. This definition drilling increased the reserves and resources to 416 000 000 pounds U_3O_8 at an average grade of 15% [3]. A second EIS to proceed to underground production was submitted in late 1995, and the public hearings were conducted in the fall of 1996. A favourable Panel report was issued in February, 1997. Both provincial and federal government approvals were received in May, 1997.

In August 1997 all licenses and permits had been received by both federal and provincial agencies to allow the two years construction of the project to proceed. The main license issued being the 'License to Construct' by the AECB. Construction was completed within the feasibility cost estimate and on schedule.

Operating licenses were received in October, 1999 for McArthur River, and in November, 1999 for Key Lake to receive and process the high grade McArthur River ore. Production commenced, as scheduled, in early December, 1999 following the commissioning of process equipment with waste rock and low grade ore.

2. GEOLOGY

The large and high grade Saskatchewan uranium deposits occur at or close to the unconformity which separates the generally flat lying, unmetamorphosed middle Proterozoic sandstones of the Athabasca Group from folded and metamorphosed lower Proterozoic and Archean rocks beneath. At McArthur River this unconformity is at a depth of 500 to 600 metres. The mineralization at McArthur River is associated with a northeast trending, southeast dipping zone of reverse faulting along which the unconformity is displaced vertically 60 to 80 metres. This is referred to as the P2 fault. Locally the basement rocks include pelitic gneisses and significant quartzite units. Alteration is characterized by intense silicification of the sandstone with less intense clay alteration compared to other Athabasca deposits. The mineralization is largely pitchblende without the associated cobalt-nickel-arsenic minerals which are present at Key Lake and Cigar Lake [1].

Two distinctly different mineralized settings have been identified through both surface and underground diamond drilling. These mineralized zones are called Pod 1 and Pod 2 (Fig. 2).

In the first type, typified by Pod 1, mineralization occurs in sandstone and is structurally controlled by the P2 fault. It is associated with a strong (150 to 200 MPa) but fractured zone of silicified sandstone and conglomerate. This mineralization has been traced by surface drilling over a 1700 metre strike length. Significant intersections in Pod 1 grade typically 10 to 30% U_3O_8. Dip varies from 45 to 90 degrees and the ore zone width is typically 10 metres.

Shaft sinking and diamond drilling from underground revealed the presence of ground water associated with the sandstone and the conglomerate. The quantity of ground water depends locally on the nature of flow pathways, hydrostatic pressure and pathway impedance.

For Pod 1, ground water is associated with sandstone bedding planes, joints, and most significantly, faulting and brecciation related to the P2 fault (Fig. 3). These water bearing structures have generally responded well to pressure grouting techniques.

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[1] Atomic Energy Control Board (AECB) was renamed Canadian Nuclear Safety Commission (CNSC) on May 31, 2000.

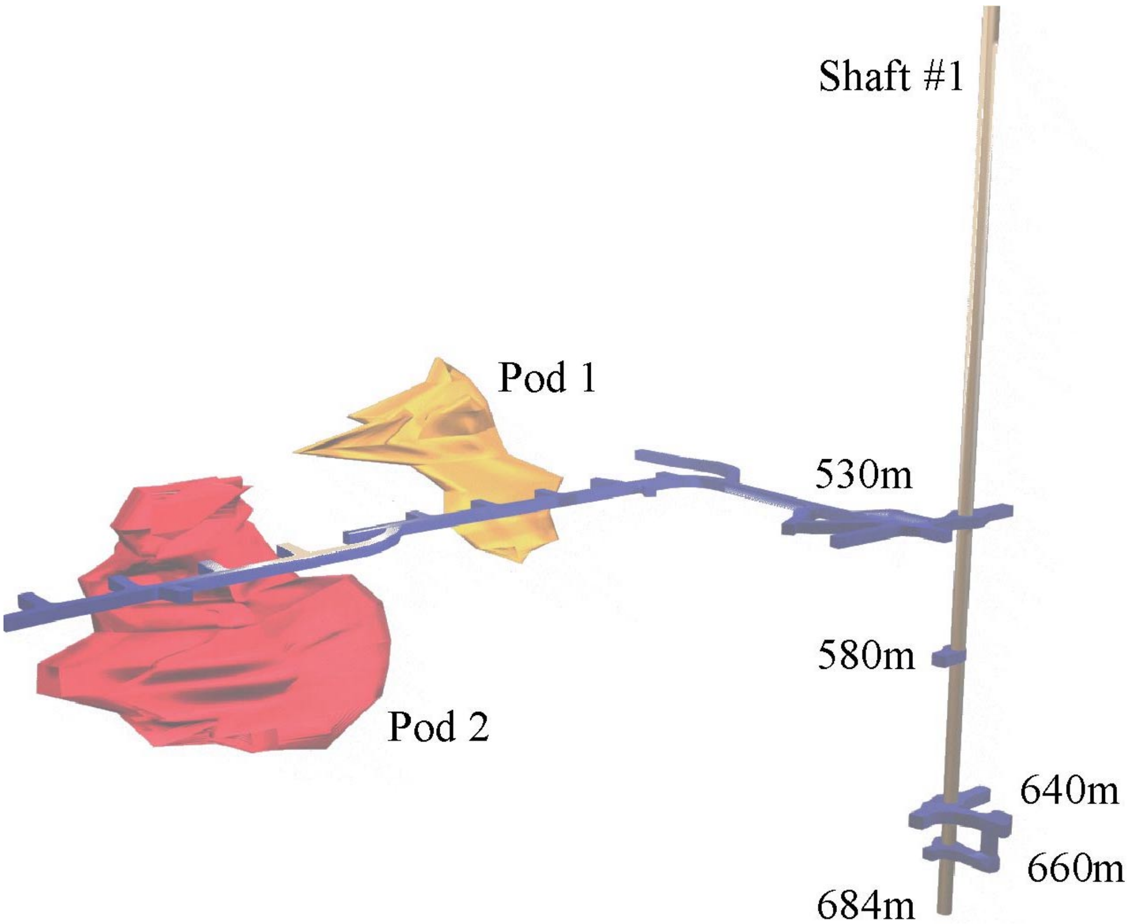

FIG. 2. Pod 1 and Pod 2.

Ground conditions are rated as good to very poor largely depending on the spatial relationship with the P2 fault. Few restrictions exist as to development placement from a stability perspective. However, mine development in sandstone and conglomerate requires extensive water control measures.

The second type of mineralized setting was identified primarily from underground diamond drilling. The large and high grade Pod 2, or Pelite ore zone is located in the basement rocks stratigraphically above a quartzite footwall unit (Fig. 4). The Pod 2 strike length is 100 metres, its height varies from 30 to 90 metres, and the width is typically 20 metres. Average *in situ* grade is greater than 20% U_3O_8. Occasional drill intercepts with grades higher than 40% U_3O_8 were encountered over significant widths. The host rock consists of sheared and altered pelite (30 to 40 MPa) containing zones of massive and stringer pitchblende [3].

Large ground water flows associated with unconsolidated sand, clay and brecciated rock have been intercepted along the footwall of the Pod 2 ore zone. These areas have not responded well to pressure grouting techniques due to the difficulty in penetrating the fine grained clays and sands in these areas. Ground freezing was deemed necessary to consolidate this zone prior to mining. Drilling has also revealed ground water and brecciated sandstone above the ore zone. Acceptable locations for mine development for Pod 2 are therefore limited to the hanging wall basement rock and the quartzite below the mineralization.

3. UNDERGROUND EXPLORATION PROGRAMME

In July of 1994 underground development commenced to allow the detailed diamond drilling of the ore zones identified by surface drilling. This program was aimed at determining the shape, grade and continuity of the central part of the ore body, on a strike length of 300 metres.

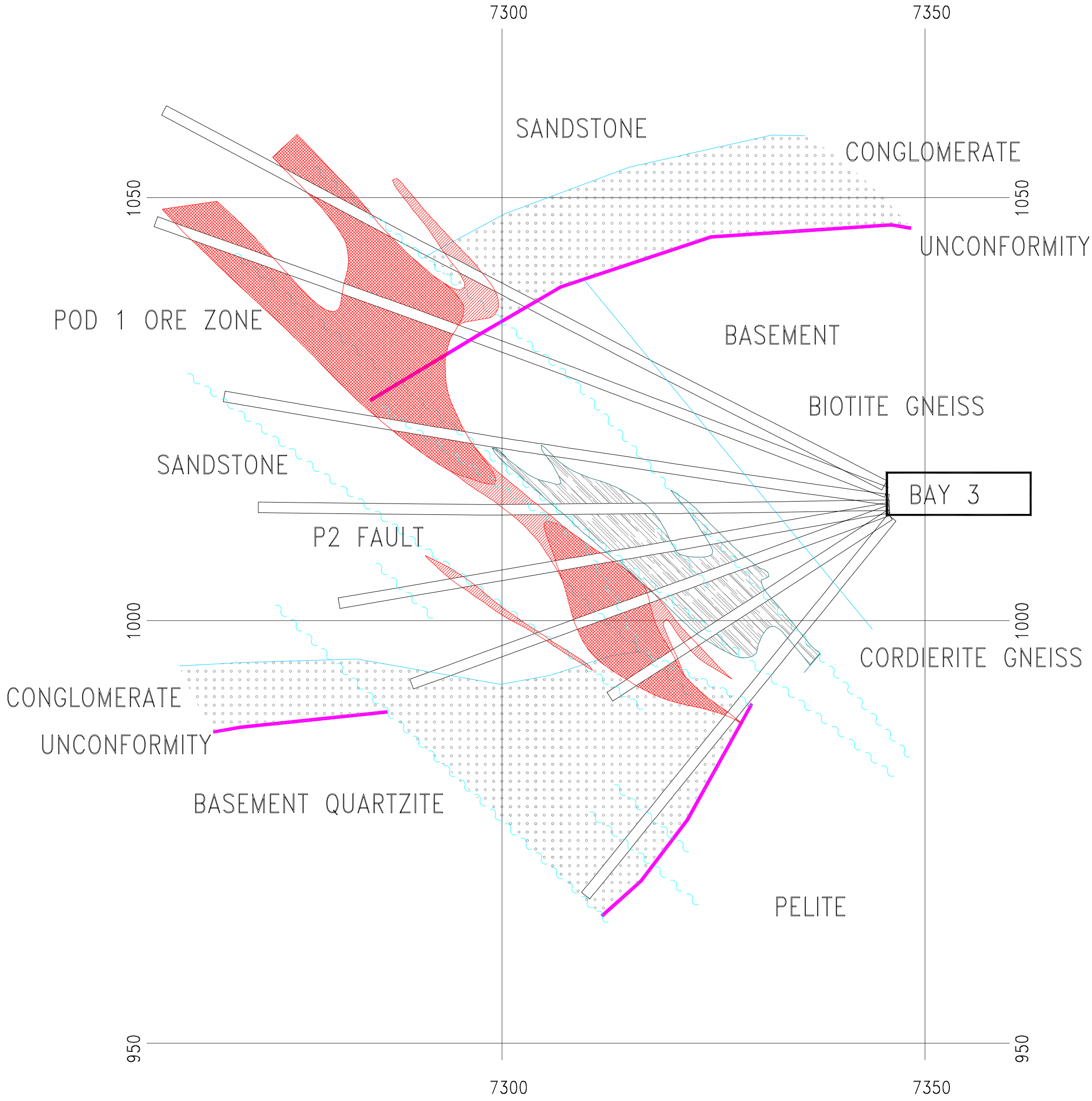

FIG. 3. Pod 1 ore at McArthur River — section looking north.

Once essential services were established for power, and the collection and pumping of mine water, development was extended to within 35 metres of the ore zone. Development then progressed southwards and parallel to the strike of the ore zone for approximately 300 metres. A total of 998 metres of development was completed by June 1996.

Diamond drill bays were created every 30 metres along strike. Diamond drilling commenced once development had adequately advanced, and holes were drilled on sections and fanned above and below the mineralized areas. Infill drilling was conducted, as encouraging results and time permitted, to define the ore zones every 10 metres along strike.

During the 1995/1996 underground drilling programme 115 holes were completed. The drilling of these holes provided both the ore geometry and grade as well as geotechnical and hydrogeological information necessary to select mining methods and design material handling systems [4]. As the high-grade ore was

encountered, extremely high levels of radon (up to 8.869 billion[2] Bq/m^3) were found associated with the ground water. The higher levels of radon were usually associated with low water flows, however the water pressures were normally hydrostatic at a pressure of 51 Bars.

Reserves of Pod 1 and Pod 2 as identified by the underground exploration program are presented in Table 1 along with the mineral resources identified by surface exploration.

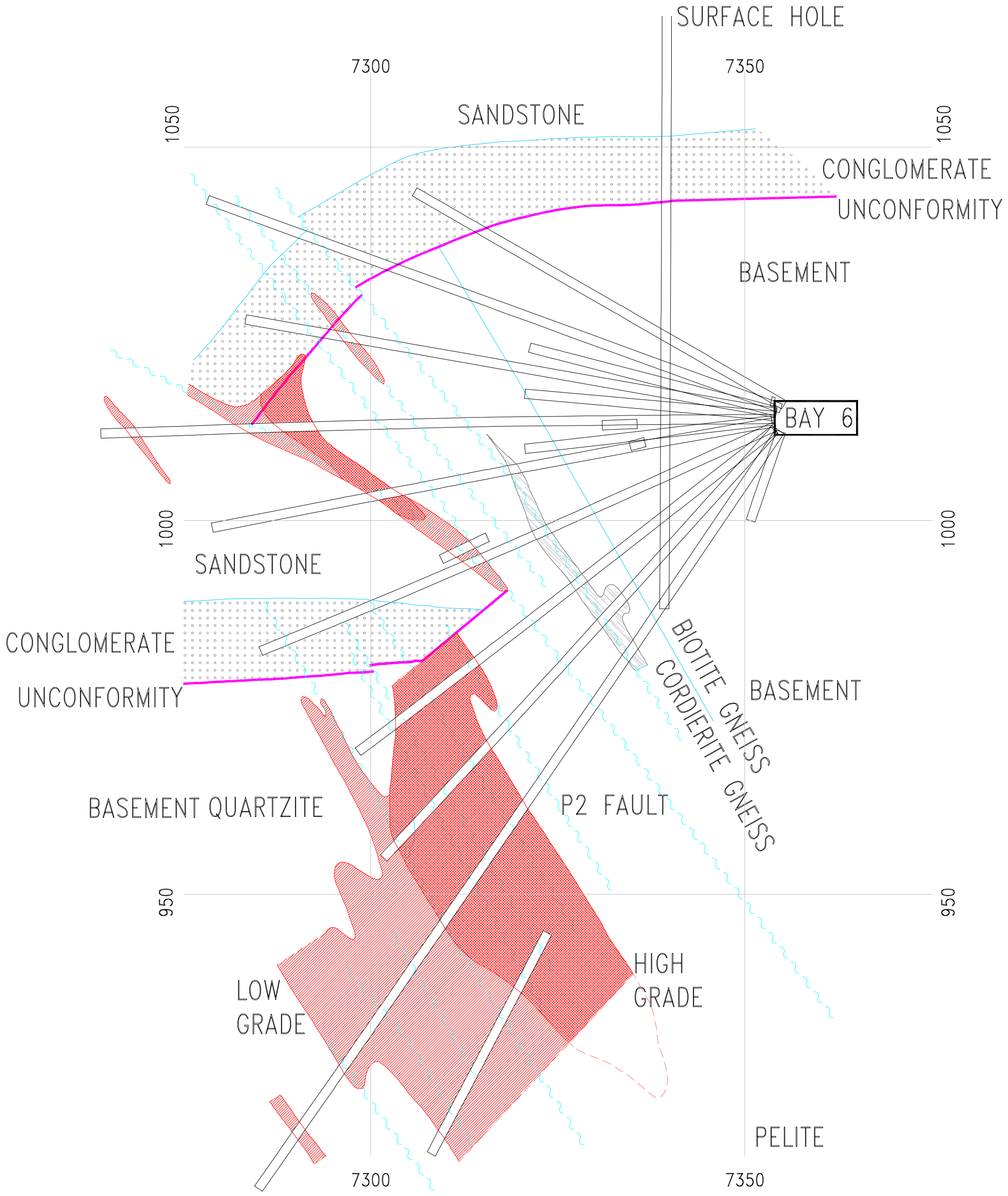

FIG. 4. Pod 2 at McArthur River — section looking north.

[2] One billion = 10.

TABLE I. MCARTHUR RIVER PROJECT - RESERVES AND RESOURCES

		TONNES	% U_3O_8	Million Lbs. U_3O_8
RESERVES	Pod 1	91 000	17.46%	35.05
(Undiluted)	Pod 2	577 000	17.3%	220.19
	TOTAL	668 000	17.33%	255.24
RESOURCES	Surface Drilled	859 000	12.0%	227.75

4. MINING METHODS

Seven potential mining methods were proposed in the EIS submitted for McArthur River, with final selection dependent upon ore grades and ground conditions. These methods are:

(1) Raise boring
(2) Boxhole boring
(3) Remote boxhole stoping
(4) Blasthole stoping, including vertical crater retreat
(5) Remote raise bore stoping
(6) Jet boring
(7) Remote boxhole stoping with "Viscaria" raise mining

The preferred options for the mining of the high-grade ore are raise boring, boxhole boring, and jet boring. Raise boring was selected as the initial mining method at McArthur River and offers the following advantages:

(a) Improved productivity when compared with boxhole boring.
(b) Capability to extract the high strength Pod 1 ore, in contrast to jet boring.
(c) Superior ability to limit the quantity of ore in process at any time, when compared to stoping methods.
(d) Ease of providing excellent ventilation control, in contrast to stoping methods.

All active mine planning to date has utilized this mining method. The high grade Pod 2 ore zone is the first zone being mined. Freezing has been introduced to control ground water and occasional unconsolidated ground conditions in this area, and was implemented approximately nine months prior to mining in order to provide a frozen barrier sufficient to permit the safe extraction of the ore.

A surface freeze plant of 800 tonne capacity provides a chilled brine (–40 degrees Celsius) which circulates through a heat exchanger located on the 530 metre level. A lower pressure brine at –30 degrees Celsius is then used to circulate through freeze pipes surrounding the ore zones. Freeze holes are at two metre centres and drilled to approximately 100 metres in depth. There are 78 holes in use for the freezing of the first two mining areas of Pod 2.

4.1. Raise boring

The raise bore mining method as applied at McArthur River requires the establishment of mine openings of adequate size in surrounding non-radioactive rock both above and below the ore zone. Conventional drill and blast tunnelling methods are used to develop these openings. Standard rock bolting, screening and a 75 millimetre application of shotcrete (a cement product sprayed onto the walls and roof of underground openings) are utilized to provide long term ground support. The raise boring mining method is a four-step process (Fig. 5) [5].

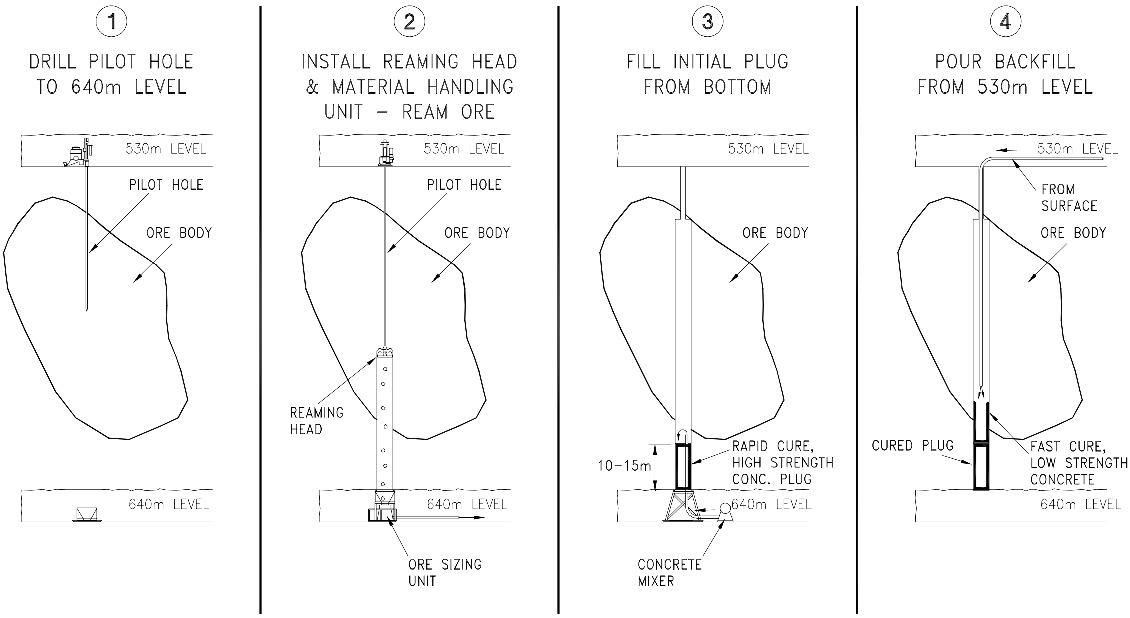

FIG. 5. Raise bore mining and backfilling sequence.

Firstly, the raise bore machine is set up in the production chamber above the ore zone. The raise bore machine then drills a 300 millimetre pilot hole from the upper chamber, through the waste rock, the ore zone and the waste rock below the ore zone and into the lower extraction chamber. These pilot holes are up to 125 metres in length.

Secondly, after breakthrough of the pilot hole into the extraction chamber, the pilot hole drill bit is removed and replaced with a reaming head.

The reaming head was initially 2.4 metres in diameter, but as geotechnical conditions have been positive in some areas, raises with a diameter of 3.0 metres are currently being utilized. Expandable reamer heads may also be developed to minimize waste dilution and to improve productivity. By applying upward thrust and rotation, the raise bore machine then reams the waste rock immediately above the extraction chamber to sink the reamer head into the rock. Reaming is then stopped, and an ore handling chute is placed beneath the raise opening. Once the installation of this ore collection chute is complete the reaming can then continue. Reamed cuttings are removed with a conventional remote control mobile mine vehicle and radiometrically scanned. Waste rock and low grade mineralized material is hoisted to surface for appropriate disposal. Higher grades of ore are processed through a screening unit. The underflow is pumped to ore surge bins located underground near the grinding circuit. All over-size ore product will be collected in a container and be transported directly to the grinding area. The raise bore reaming typically produces a fine material with few large pieces. Typically, 80% of the reamed product is less than 19 millimetres in size. Larger pieces are expected to arise from the structure and jointed nature of the ore zone, and are likely to originate within the raise during reaming of these areas, or as sloughage after the reamer head has passed.

Reaming continues upward until the top of the ore zone has been reached. At this point the reaming head is lowered to the extraction chamber and removed. The raise bore machine then raises the pilot drill rods and removes them within the upper chamber.

In the third step of the process, the bottom of the raise is then covered, and the empty raise is filled with a 5 metre rapid cure, high strength concrete plug introduced from below into the lower part of the raise. This concrete plug is designed to support the placement of the next, and much larger concrete pour.

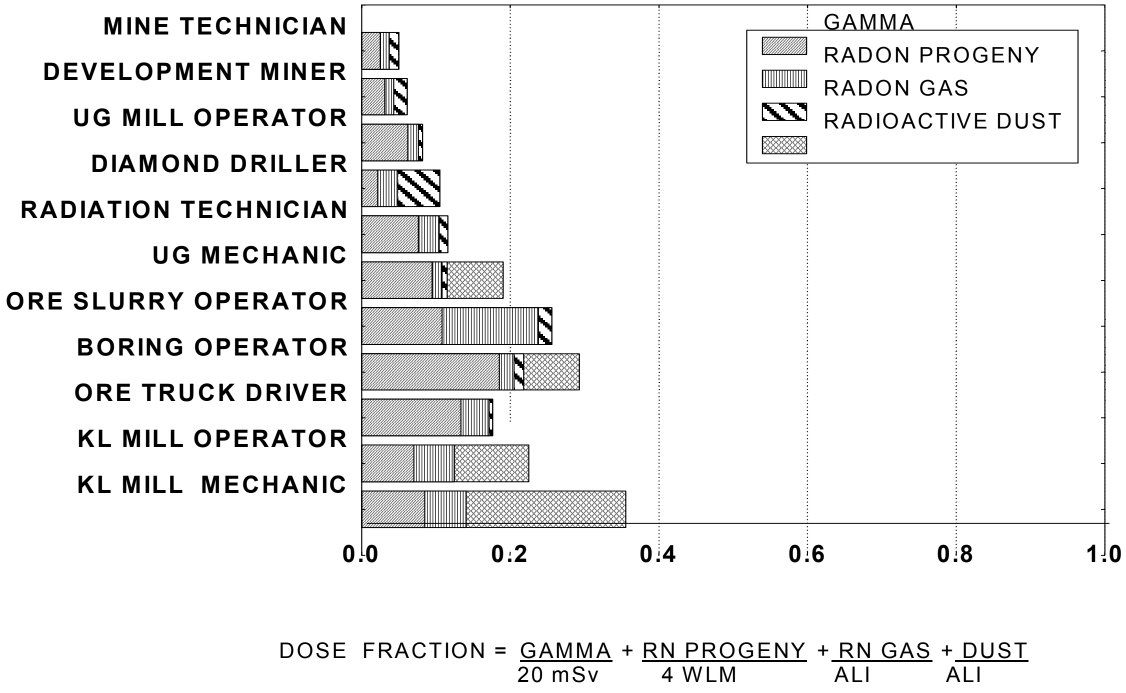

FIG. 6. Predicted annual radiation exposures.

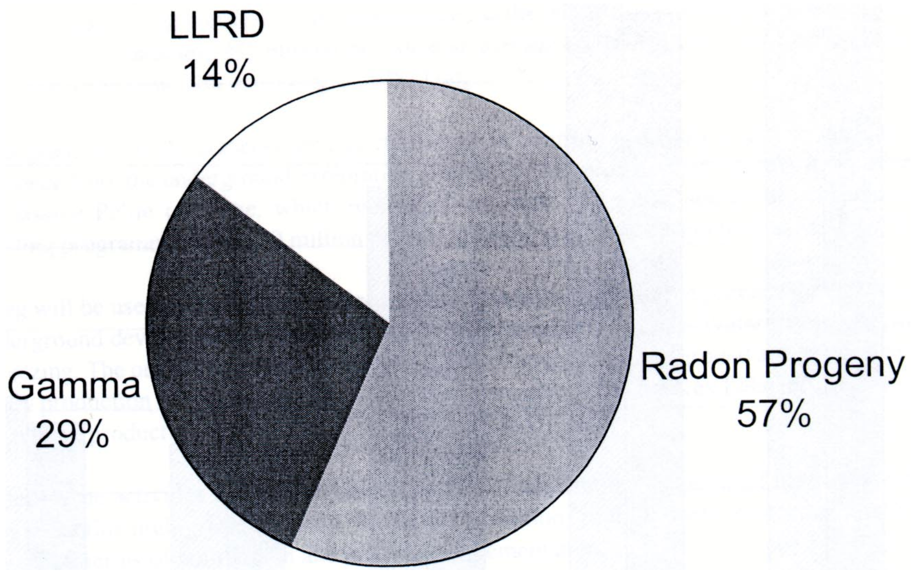

FIG. 7. Breakdown of effective dose for underground workers (first six months of 2000).

Finally, once this first concrete application has cured, the remainder of the raise is filled from the upper chamber with a lower strength, fast curing concrete.

After curing of the concrete fill, extraction of adjacent ore by repeating the sequence described above, possible. By overlapping the raises a high percentage extraction of the ore zone is achieved. After mining and filling a series of rows, the upper and lower chambers are widened to provide the ability to mine sequential rows of bored raises. The chambers above and below the completed raises are then filled with concrete to provide ground support as mining progresses with the completion of each row of bore holes.

On average, each raise will produce approximately 190 000 pounds of U_3O_8 from within initial mining areas of Pod 2, with this zone providing most of the production planned during the first years of mining. Due to the high grade of the ore, an average of only 150 tonnes is required to be mined each day [5]. A total of five raise bore machines are planned to be in operation during full production.

5. ORE PROCESSING

Once mined, the ore is transferred to a grinding circuit located underground. It was decided to process the ore to a slurry suitable to be pumped directly to surface. This eliminates the need to hoist the high-grade ore within the shaft used to move men and material and to supply fresh air.

The grinding circuit is fairly conventional and includes a semi-autogenous grinding (SAG) mill fed directly from the mining area, or from one of two ore surge tanks. The mill has been sized to grind ore that has a Bond work index of 17 kWh/t to 90% passing 300 microns. A classifying screen is operated in closed circuit with the ball mill. Classifying screen underflow, the final ground slurry, is pumped to the two underground ore thickeners. Overflows are recycled back to the SAG mill.

Thickener underflow slurry (controlled at 50% solids by weight) is pumped from the underground ore thickeners to a thickener underflow tank, which feeds the ore slurry to one of two positive displacement hoisting pumps, each of which is connected to a dedicated pipeline to convey the ore slurry directly to surface.

On surface the ore slurry is pumped through a U_3O_8 on-stream analyser. Depending on the indicated ore grade, the slurry can be placed into one of four ore storage tanks to allow for subsequent blending. When container loading begins, the ore is then re-slurried, blended, thickened to >50% solids by weight, and placed into purpose designed containers. Once all four containers are filled, washed and successfully scanned, the truck will depart for Key Lake. Each truck is designed to carry four containers and results in the transportation of 15 tonnes (21.2 m^3 of slurry) of ore per trip. Approximately ten trips per day will be required to transport ore to the Key Lake mill at average grades.

At the Key Lake operation the ore will be diluted to 4 % U_3O_8 by the blending of special waste material prior to milling. All tailings will be placed in the existing Deilmann pit tailings management facility at Key Lake.

6. WASTE ROCK MANAGEMENT

Waste rock is generated both by mine development and by mining activities. The production of waste rock is minimal due to the low tonnages of ore required to be mined each day. Potentially problematic material (waste rock >0.03 % U_3O_8 or net neutralizing with acid potential: neutralizing potential ratios of 1:>3) will be hoisted conventionally via the main service shaft and stored on lined pads at McArthur River. This material will either be used for backfill underground at the mine site, or transported to Key Lake for final placement in existing, and approved storage areas.

During the development phase, 140 000 tonnes of potentially mineralized (non ore) material, and 75 000 tonnes of potentially mineralized sandstone are expected. The extensive use of cement grout will likely mediate any residual pyrite content of the rock. A total of 900 000 tonnes of inert waste rock is expected from underground development including ventilation shaft sinking. Inert waste rock will be placed on surface at approved, un-lined sites.

7. RADIATION CONTROL

The control of radiation has been the primary factor in the designs for mine and plant layout, equipment selection and the processing of the ore at McArthur River. In order to minimize exposures the following criteria were applied:

(a) Radon gas is controlled by a dual ventilation system. A primary fresh airflow is always maintained in all active work areas, with a secondary exhaust system to remove contaminated air from particular sources.
(b) Radon is also controlled by the freezing and grouting techniques used to control ground water.
(c) During all mining and processing stages the ore is fully contained where practical.
(d) Gamma radiation is controlled by utilizing the principles of shielding, distance and time. The use of heavy wall steel pipes, thick vessel walls, concrete and sometimes lead sheeting is standard practice.
(e) Mining and ore handling and processing is accomplished remotely with computer control.
(f) Due to the low tonnages required to be mined there is a long period between scheduled maintenance work.

A total of three shafts will be utilized to provide 455 m^3/s of air a full production. Two shafts will supply fresh air (the main service shaft #1 called the Pollock shaft, and shaft #3, presently being fitted), while a third shaft exhausts mine workings (shaft #2).

Every job has been analysed for exposure time, and distance and shielding calculations have been done to ensure that radiation doses are acceptable. Design calculations have been confirmed by doing physical measurements of radiation fields around pipes filled with high-grade ore from the test mining at Cigar Lake, and at the existing Key Lake and Rabbit Lake mills. The radiation exposure calculations included estimates of exposures arising from equipment maintenance and spill cleanup.

As a result of these design criteria, the workers are well under the regulatory dose limit (Fig. 6) [3]. Actual experiences with radiation control, the treatment of radium-rich mine water, and waste rock management during the underground exploration phase has shown that the techniques used provided excellent results with very minimal exposures. This knowledge, and extensive public and regulatory review has resulted in a fairly broad based consensus that the project can be developed and meet current radiation protection and environmental objectives.

More recent experiences during production are supporting these expectations (Table 2 and Fig. 7) [6].

TABLE II. McARTHUR RIVER EXPOSURE SUMMARY FOR THE FIRST SIX MONTHS OF 2000

Job Group	Mean Effective Dose (mSv)	Maximum Effective Dose (mSv)
Surface workers	0.2	2.4
UG workers	0.6	4.2
Overall	0.4	4.2

8. MINE COMMISSIONING

The start of mining operations was dependent upon: 1) the receipt of operating licenses for both the McArthur River and the Key Lake operations; 2) the completion of construction and commissioning of all mining and process systems for the safe handling of the high grade ore; 3) the completion of necessary employee training and familiarization of these systems; and 4) the final closure of the freeze wall designed to protect the mine from water inflows.

All process facilities were first commissioned with water, and then waste rock. Only when systems operated as designed did commissioning with low grade ore commence. High grade ore commissioning (mine commissioning) was scheduled to start with the initiation of raise boring activities after closure of the perimeter freeze wall was confirmed. This confirmation was provided by temperature data recorded from 15 temperature monitoring holes placed strategically near the freeze wall. Final closure of the freeze wall was delayed due to an area of the ore zone with temperatures of 25ºC. This was about 15º above ambient rock temperature and was discovered during the drilling and installation of the temperature monitoring

holes subsequent to the completion of freeze hole commissioning. The cause of this thermal increase was determined to be heat generated from the natural decay of high-grade uranium ore in this area. The result was the delaying of final freeze wall closure until November 1999.

Mining commenced in December 1999 with the raise bore mining method. In order to provide the maximum time for freeze wall growth, and increased protection from potential water inflows, initial mining was purposely limited to the eastern part of the ore zone. This area offered more competent ground conditions and was furthest from the freeze wall. As an added precaution, the immediate area identified for mining was probed with diamond drill holes and any residual water encountered was eliminated by pressure grouting with cement. These early raise bore holes were all bored at 2.4 metres in diameter and, because they were located on or near the eastern extremity of the ore zone, were limited to 50 000 to 150 000 pounds of U_3O_8. The grade of the ore in these first raises was expected to be lower than average (8% to 10% U_3O_8) and, therefore, fitted well with the philosophy of commissioning with lower grades before progressing to higher grade material.

The actual mining of these first raise bore holes proved to be quite interesting. The design concept relied upon the raise bore machine providing control of the rate of mining. This was accomplished by limiting, if necessary, the rotation and pull force on the reamer to produce at approximately 25 tonnes per hour which matched the designed material flow of the Transportable Mining Unit (TMU) located immediately at the bottom of the raise. The design of the TMU permitted the containment of the mined material and the wet screening of the ore. Once screened, the undersize was immediately pumped to the ore surge bins which provided a buffer between mining and further underground ore processing. Oversize (+25mm) from screening was placed in a steel box for direct transfer to the grinding circuit. It was reasoned that this system design would limit exposures to employees from radon prodgeny, gamma and long lived radioactive dust (LLRD) due to its containment, shielding and exhaust ventilation characteristics.

Mining in the ore body had not been conducted prior to this time due to licensing constraints, therefore this was the first experience with raise bore mining in ore. What was experienced proved to be somewhat different than expected. Mining produced an excessive amount of oversize material that often would choke off the feed to the vibrating screen. As well, some unconsolidated clays encountered while mining occasionally blocked the raise itself. These conditions resulted in excessive employee intervention with the TMU in order to facilitate material flow. It was apparent that the system which was originally designed to protect employees from radiation was, in practice, exposing them to potentially higher radiation exposures and, as well, to unanticipated occupational safety hazards by working to clear obstructions.

On one occasion the material flow within the raise exceeded the processing capacity of the TMU, and the raise gradually filled with clay and rock. A minor water flow into the raise (from residual water trapped within the perimeter freeze wall) was contained by the material in the raise creating the potential for an uncontrolled run of material. This danger was recognized and precautions were taken to remove all employees from the area. A run of material did occur shortly thereafter with damaging consequences to the TMU. A subsequent review of the handling of mined material followed resulting in a new safer, and simpler design. The new design is referred to as the Ore Collection Chute (OCC) and is basically a conical chute covering the borehole with a 1.5 metre bottom opening supported on four steel legs. This design eliminated the need for employee interaction altogether as remote controlled vehicles were utilized to receive the ore cuttings and transport them to the grinding circuit.

Approvals were received from the regulatory agencies, and a test trial concluded over the following ten raises. The radiation exposure results were closely monitored and reported after each of the first three raises with satisfactory conclusions. A summary report was issued following the tenth raise indicating that the use of the OCC met expected radiation exposures to employees.

Having improved this key part of the mining cycle, work then progressed to re-establish a stationary screening facility to permit the use of the two ore surge bins which were located underground and designed to add a buffer between mining and ore processing operations.

Other mine commissioning challenges were related to the grinding and transportation of the ore. The grinding circuit initially created a product that was too coarse and resulted in the sanding of pipelines and extreme difficulty in the slurry unloading operation at the Key Lake operation. These problems led to increased maintenance activities and the potential for increased radiation exposures. After careful review the grinding circuit was modified resulting in improved grinding performance.

9. MANAGING RADIATION EXPOSURES IN AN ADAPTIVE ENVIRONMENT

All new mining operations enter the mine commissioning phase with the expectation of surprise. Sometimes these surprises are positive, and occasionally they offer new challenges. This adaptive environment is always present in a mining operation as the operators gain experience with the mining method and its effect on ground conditions, rock mechanics, the general impact on the health and safety of employees, material handling systems, and overall production expectations.

This is fundamentally different to the design of a nuclear facility where production systems can be carefully engineered to achieve the desired output. Mining operations, especially underground operations, are subject to changing conditions as dictated by the geology of the ore body and the stresses placed upon it as mining progresses. Nowhere is this more evident than in the mining of high-grade uranium at McArthur River.

The change from the TMU to the OCC as discussed above is an excellent example. The unexpected change in ground conditions ultimately forced a modified approach towards material handling. In this case the change to the OCC was carefully evaluated utilizing an established change control process and then approved by the regulatory agencies prior to implementation. The established safety systems such as dual ventilation, code of practice, and remote operation of equipment allowed the change to be made with due consideration of impacts to worker (radiation and health and safety) and the environment.

The radiation monitoring programme has two overall goals, which are dosimetry and engineering monitoring. While both types of monitoring provide important feedback of the workplace conditions, the engineering monitoring is particularly important in managing day-to-day exposures. Because of the possibility of high radiation levels at McArthur River, there has been considerable attention placed on engineering monitoring that can provide prompt feedback of the workplace conditions to the employees.

Dosimetry for radon progeny and long lived radioactive dust is done with personal alpha dosimeters (PADs), which provide an integrated exposure over the period of a month. For gamma radiation dosimetry is done with thermoluminsicent dosimeters (TLDs), which are also changed on a monthly basis. At uranium mines in Canada TLDs are usually changed on a quarterly basis. However, given the potential for very high gamma fields, a tighter monitoring schedule was chosen until it could be demonstrated that other control mechanisms were working.

These other control mechanisms include engineering monitoring and administrative controls. Engineering monitoring for radon progeny is done by daily grab samples and continuous radon progeny monitors that are located in throughout the mine. The continuous radon progeny monitors take a measurement every ten minutes and are connected to a light panel system that alerts the workers of any upset conditions. There are approximately 35 of these units in use at McArthur River.

With regard to gamma radiation engineering monitoring includes routine surveys by technicians, the use of pocket gamma meters by supervisors so they can assess changing conditions, and arguably most important, workers in process areas are issued electronic direct reading dosimeters.

The direct reading dosimeters and the continuous radon progeny monitors are very important tools in controlling radiation exposures because of their ability to inform the worker directly about his or her working environment. Most workers are very receptive to these tools and have come to expect them and rely upon them.

Backing up the monitoring program is a system of administrative controls. One of these systems is what is called in the uranium mining industry in Canada a "Code of Practice". This is a system of predefined responses to changing radiation levels. The Code of Practice helps to ensure consistent and appropriate actions are taken before a serious exposure situation develops. At McArthur River there is also a formal Radiation Work Permit system to deal with situations with the potential for high exposures. In addition, daily and weekly investigation levels have been established for gamma exposures as assessed by the electronic direct reading dosimeter results. These various administrative tools have been very important in helping the workers understand the significance of radiation monitoring results and meet dose objectives in a dynamic environment.

10. CONCLUSION

The McArthur River deposit has proven to be a major uranium discovery during the past few years. As a world class ore body, this deposit will help secure Cameco's position as a competitive uranium producer for decades to come.

The McArthur River Joint Venture has spent approximately C$ 450 million during the 11 years from discovery to production. While this may seem a long project lead time, it is in reality representative of the normal time investment required to bring a uranium mine into production within Canada.

The underground exploration program has proven mineable high-grade ore zones. Through well-focused engineered design and extensive project review, it has been shown that this deposit can be mined by non-entry methods, such as raise boring, to achieve the goal of high-grade ore extraction in a safe and well-engineered manner.

Radiation exposures can be effectively managed while mining high-grade uranium ores. During the first six months of production, radiation doses have remained relatively constant while production has increased considerably. As a result, the collective dose per unit production is now between 0.1 and 0.2 mSv per tonne of uranium (Fig. 8) [6].

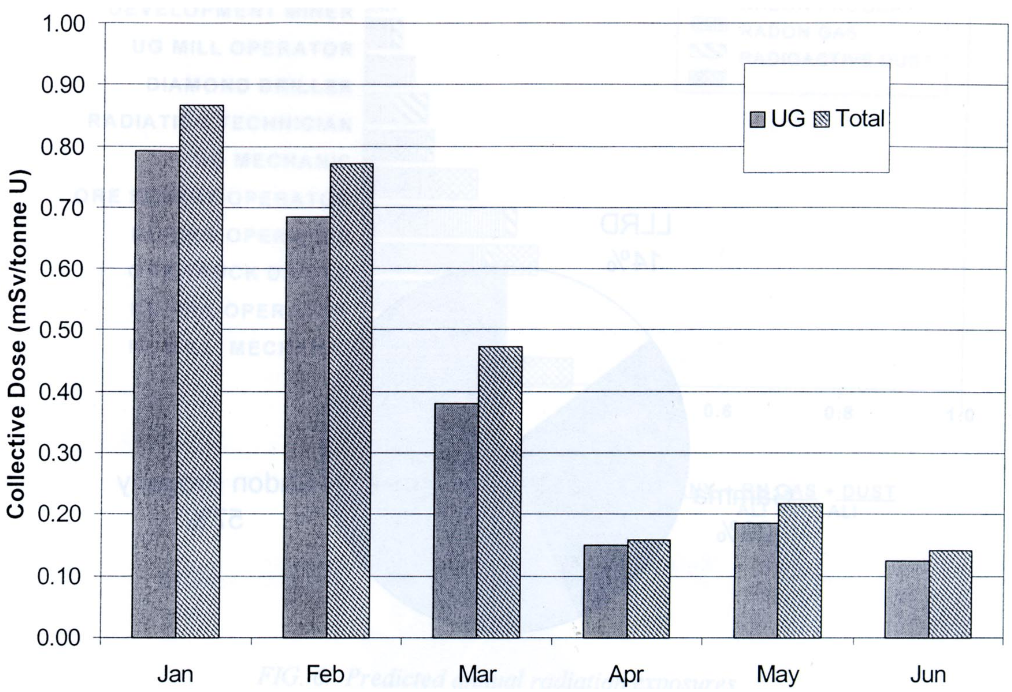

FIG. 8. McArthur River: Collective monthly dose per tonne U mined for the first six months of 2000.

Mine commissioning in high grade ore is continuing with the raise bore mining method using both 2.4 metre and 3.0 metre diameter reamers. Mining rates are increasing as productivity improvements are being made with the three raise bore machines presently in operation. The production rate of 11 million pounds of U_3O_8 per annum planned for this first mining area has been achieved. Two additional mining areas are planned to be brought into production during the next two years in order to achieve the designed annual production rate of 18 million pounds of U_3O_8 in 2002.

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Exploration for in situ leach amenable sandstone uranium deposits and their impact on the environment in China

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Abstract. Taking the No. 512 uranium deposit in YiLi Basin, Xinjiang as an example, this paper describes the ore-forming geological settings of inter-layer oxidizing zone roll-front type of ISL amenable uranium deposits. It also summarizes the different exploration methods used during various stages of exploration. The paper also introduces the Dabu uranium deposit in Taoshan, Jiangxi, which is amenable to the in-place-leach mining method. It probes into the possibilities for transforming non-economic and sub-economic uranium deposits into economical and minable ones. In addition, the paper emphasizes that ISL uranium mining, when compared with conventional mining, plays an active role in reducing environmental contamination and restoring ecological balance.

1. INTRODUCTION

At present, two main directions are guiding uranium exploration throughout the world. One is looking for unconformity type U deposits such as those occurring in the Athabasca Basin, which have large high-grade reserves. The other is ISL sandstone U deposits like those found in Kazakhstan and Uzbekistan. Although low grade, the reserves are relatively large. In recent years, in accordance with the geological setting and practical conditions in China, the main prospecting programme has targeted ISL sandstone U deposits; significant success has been achieved.

2. GEOLOGICAL BRIEFING AND THE CASES OF ISL SANDSTONE U DEPOSITS

The test mining of ISL was initialed in the 1970's in China. Success was achieved in1987 at the No. 381 Deposit in Tengchong, Yunnan. Later a test was operated at the No. 512 Deposit in Yili Basin, Xinjiang. Satisfactory results were achieved. As early as 1963, heap-leaching testing began, and industrial production has operated since the 1980s. A successful inplace leaching test after crushing was conducted in Lantian, Shanxi. At present, there are five U deposits where either the ISL method or heap leaching is being used.

Mesozoic and Cenozoic sandstone Basins are widely scattered in north China, northwest, northeast and south China as well. According to available data, there are 377 basins, both large and small, in northwest China, among which, seven are more than 50 000 km^2 in size. They are the Talimu, Zhunger, Chaidamu, Erlian, Tulupan-Hami, Shan-Gan-Ning and Badanjilin basins. The area of 14 basins ranges from 10 000 to 50 000 km^2. North China is situated within the same geotectonic unit as the central Asian countries of Kazakhstan, Uzbekistan and Mongolia and the geological setting and metallogenic environment is similar. These relationships indicate a great potential for U prospecting in north China.

The No. 512 Deposit in Yili, Xinjiang, is situated at the margin of Mesozoic and Cenozoic continental intermountain basins. The basement of the basin occurs as medium acid and medium basic volcanic detrital rock in the Paleozoic era and granite in the Variscan. The basin filling rocks are detrital in the Jurassic, Cretaceous and Tertiary systems and loose sediments in the Quaternary system. U deposits occur in detrital rock formations containing coal in the Jurassic Shuixigou Group. These occurrences can be classified as typical sandstone U deposits of interlayer oxidizing zone type (roll front).

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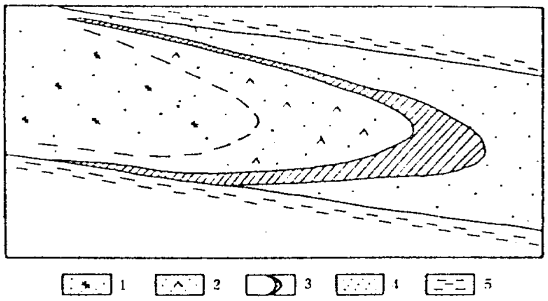
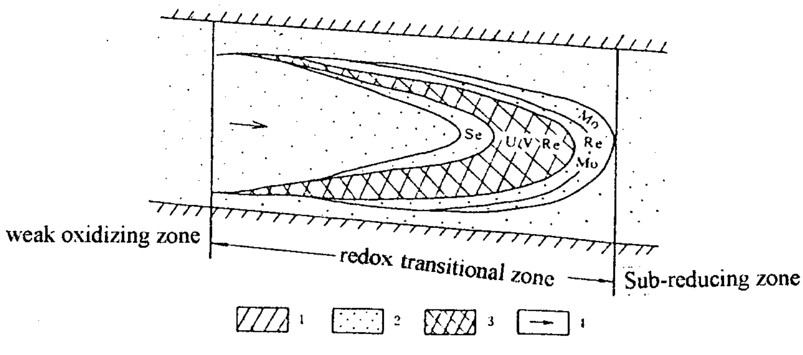
U mineralization is strictly controlled by the redox transitional zone. The age of main mineralization is 14–25 million year. The ore bearing host rock consists primarily of medium-coarse lithic sandstone. Ore bodies occur as rolls, plate rolling, and plate state. Ore bearing beds are all monoclinal dipping stratum with a dip angle of 5–8°. U minerals are mainly ultra fine grain pitchblende, with minor quantities of coffinite and U organic complexes. The average ore grade is 0.06% U. An associated elements include Mo, Se, Re and V which can be recovered and used. The depth of the ore body is 150–270 m. The No. 512 ore body is relatively ideal for ISL recovery with a typical clay-sand-clay structure and a 15–25 m thickness of ore bearing sand. It has significant size, a suitable permeability coefficient and a uranium mineralization amenable to acid leaching [1].

The No. 512 U deposit is typically controlled by a stratabound oxidizing zone deposition (see Fig. 1). The width of zone is about 1000 m. The profile occurs as linguoid lensing or obtuse lensing. The interlayer oxidization is distinctively zoned, with clearly defined distribution from strong oxidization, weak oxidization to redox transitional zone and then to reducing zone. The color of rocks changes gradually from brown red, to brown yellow to light yellow to light brown, to gray white, to gray and to dark gray as the transition progresses from the oxidizing zone to reducing zone. This variation shows that the content of oxidized iron gradually changes from high to low. The redox potential (ΔEh) changes from low to high whereas the ratio of U^{+6}/U^{+4} goes from high to low. The U/R equilibrium ratio changes regularly; it inclines towards Ra in oxidizing zone and to U in the redox transitional zone. The U/Ra ratio is basically equal in the reducing zone. Spatial zoning of Se, Mo, Re can also be observed (see Fig. 2) [2] [3].



1. sandstone in strong oxidized zone; 2. sandstone in weak oxidized zone; 3. sandstone U ore body in redox transitional zone; 4. sandstone in Proterozoic era; 5. argillaceous rock

FIG. 1. Sketch map of interlayer oxidizing zone in ore bearing bed at southern margin of Yili. Basin.



1. mudstone water proof strotum; 2. sandstone ; 3. U ore zone;
4. flowing direction of interlayer water containing oxygen

FIG. 2. Sketch map of associated elements such as Re, in No.512 U deposit.

Generally speaking, an economical and minable ISL uranium deposit is always relatively large, the ore-bearing sand has considerable thickness and lies at a shallow depth. The stratigraphic structure is a mud-sand-mud sequence with a gentle dip angle. The uranium grade is good, and the uranium minerals are easy to leach. The associated mineralization is minor, the underground water dynamics are suitable and the permeability is high.

2. METHODS APPLIED TO PROSPECTING FOR ISL U DEPOSIT AT VARIOUS STAGES OF DISCOVERY

Prospecting for ISL U deposits is difficult because most have no near-surface manifestations. Even more, the identifying criteria for this type of deposit are indefinite. Various methods are suitable for different stages of exploration. These methods must determine if the sandstone U deposit is in situ leachable and if it is economically competitive.

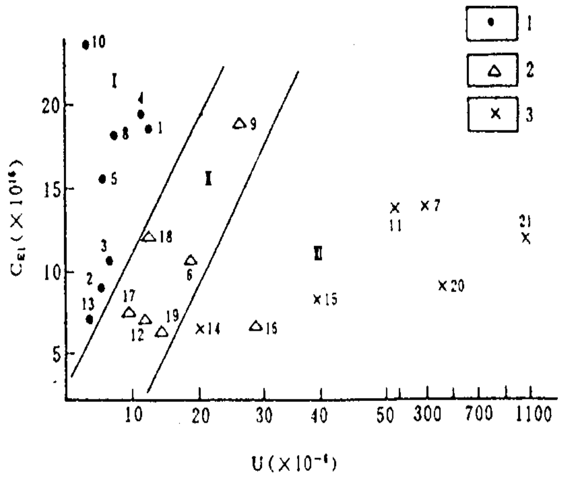
Presently four stages have been practiced for mineral prospecting in China. They are reconnaissance, prospecting, general exploration and detailed exploration (see Table 1).

During above mentioned four stages, in addition to geological mapping at different scales and drilling in different grids, geophysical exploration includes methods such as airborne radioactive survey, airborne gamma ray spectrum survey, airborne magnetic survey, remote sensing.

TABLE I. EXPLORATION METHODS APPLIED TO PROSPECTING ISL SANDSTONE U DEPOSIT AT DIFFERENT STAGES

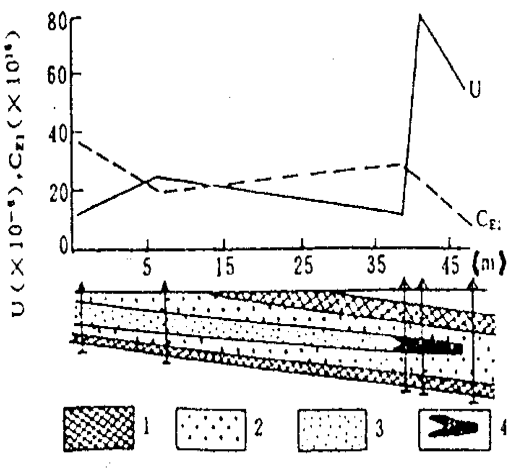
No	Exploration stage	Exploration method	Aims
1	Reconnaissance	Regional geological survey, geophysical and geochemical methods, a small amount of drilling.	Selecte prospective metallogenic basin. Delineate favorable metallogenic target area for prospecting. Assess prospective U resource. Estimate predicted U reserve.
2	Prospecting	Outcrops checking, geological mapping, wide space drilling, geophysical and geochemical methods.	Determine spatial distribution of interlayer oxidizing-redox transitional zone. Generally determine the ore body mining conditions. Delineate the scope of general exploration.
3	General exploration	large scale geological mapping, certain amount of drilling, comprehensive geophysical & geochemical methods, in-house column leaching and field ISL test.	basically identify geological features of the deposit and quality of the ore. determine continuity of ore body. understand technical conditions for ISL, delineate scope of detailed exploration.
4	Detailed exploration	Fill-in drilling, comprehensive logging.	Identify geological features Identify hydrogeological condition of mining area.

Also, geochemical methods such as humic acid determination, geoelectric surveys, gas survey and hydrological methods such as bottom sediment are also used during the first stage. Geophysical and geochemical exploration methods are also applied at the second and third stages. These methods include seismic measurements, electrical sounding, magnetic survey, gravity, logging, stream sediments sampling and gas chemistry. The combined well logging during the fourth stage appears to be very important. During all stages of the geological work, in-house analysis of and test samples and geological age, identification of ore minerals should be conducted. In practice, the combination of field and laboratory work has achieved success. Radiation damage measurements have been applied when prospecting for sandstone U deposits of the interlayer oxidizing zone type. This method determines the proportional relationship between the central concentration of paramagnetic quartz and radiation absorption dose. The method was applied at the No. 512 deposit with excellent results (see Figs. 3, 4 and 5) [4].



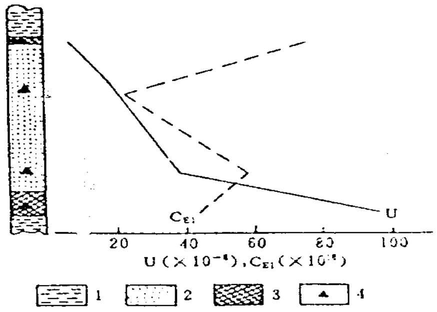
1. rocks in oxidizing zone; 2. rocks in reducing zone; 3. rocks in transitional zone; I oxidizing zone; II reducing zone; III redox transitional zone

FIG. 3. Ce1-U relationship among rocks at different location in interlayer oxidizing zone.



1. siltstone; 2. sandstone; 3. oxidized sandstone; 4. ore body.

FIG. 4. U-ce1 changing curve of rocks at No.4 exploration line.



1. argillaceous rock; 2. sandstone; 3. mineralized rock; 4. sampling site.

FIG. 5. Vertically changing curve of ce1-U in No. 3006 hole at No. 30 exploration line.

Generally speaking, when prospecting for ISL sandstone U deposit in China, the first stage is to select a favorable basin, delineate the metallogenic geological setting and the prospective blocks, and estimate possible reserves. The second stage includes locating a favorable target, defining he spatial arrangement of interlayer oxidizing zones, and estimating the inferred reserve. During the third stage, a preliminary deposit size can be determined and a controlled reserve of ISL is calculated. During the fourth stage the ore body is delineated, and the ore body grade and overall ISL conditions are determined. An assured reserve of ISL U is then calculated.

3. ECONOMIC EFFICIENCY OF ISL U DEPOSIT

The exploration results and evaluation of the economic and technical qualities of the No. 512 ISL deposit show that it has the best economic efficiency in China.

During industrial operations, the average U concentration in the No. 512 production liquid is 61.22 mg/l when the ratio of liquid to solid is 2. The U extraction is 75% and the acid consumption per unit of U is 45:1. The production cost for one ton of U_3O_8, as determined by raw material consumption per ton of U, is US$ 8893 (using an exchange rate of $1=8.3 RMB). After adding other expenses, the total cost for one ton of U_3O_8 is $18 530 (see Tables 2 and 3) [5].

TABLE II. MAJOR PRODUCTION INDEX DURING JANUARY–JULY 1995

Item	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
H_2SO_4(t)	65.25	72.95	262	192	81.37	128	106.7
H_2O_2(t)	3.05	1.89	5.16	5.94	3.92	2.83	3.23
NaCl(t)	9.14	16.99	18.48	9.57	4.22	9.25	10.36
NaOH(t)	1.65	2.86	5.39	1.86	1.54	2.51	1.41
U_3O_8(t)	1.751	1.33	1.298	2.476	4.000	4.659	4.343
Content in production liquid (g/L)	68.01	62.75	50.06	57.1	66.13	60.18	60.3
Grade of product (%)	47.58	47.58	48.96	52.16	52.68	52.68	52.56

TABLE III. RAW MATERIAL CONSUMPTION IN PRODUCTION OF ONE TONNE METAL U

Series	Material	Unit	Unit price ($)	Unit consumption (t)	Cost of consumption/T ($)
1	H_2SO_4	t	81.9	45.7	3746.6
2	H_2O_2	t	404.8	1.31	530.2
3	NaOH	t	321.8	0.867	279
4	NaCl	t	48.2	3.928	189.3
5	Na_2SO_4	t	108.4	5.594	606.4
6	Lime (40%)	t	30.1	7.503	225.8
7	Resin	t	3614.4	0.118	426.5
8	Filter cloth	m	0.12	3 000	360
9	Drilling	m	24.1	104.88	2527.6

The economic value of the No. 512 deposit is increased by considering the content of associated elements, which can be recovered. In ore containing grade >0.1% U, the content of Se reaches $790 \cdot 10^{-6}$%; Mo $140 \cdot 10^{-6}$%; Re $6 \cdot 10^{-6}$%; V $250 \cdot 10^{-6}$%, all of which reaches or exceeds the original estimates. Taking Re as an example; it exists as absorbed ReO_2 and can be effectively utilized so long as the Re content is $>0.1 \cdot 10^{-6}$% in the ISL sand stone. The content of Re is three times the comprehensive utilization index in the transitional zones of No. 512 deposit (see Table 4).

TABLE IV. DISTRIBUTION OF ASSOCIATED ELEMENTS IN No.512$\times 10^{-6}$ DEPOSIT

Element	Strong oxidizing zone	Weak oxidizing zone	Transitional zone	Sub-reducing zone	Reducing zone
Se	1.98	17.52	136.61		2.45
Mo	4.60	3.17	4.39		6.28
V	108.6	82.9	104.5		101.4
Re (in deposit)	0.0 133	0.0 130	0.3 178	0.0 390	0.0 200
Re (1-4 cyclic)	0.011	0.014	0.275	0.039	0.020
Re (5 cyclic)	0.013	0.013	0.348	0.023	

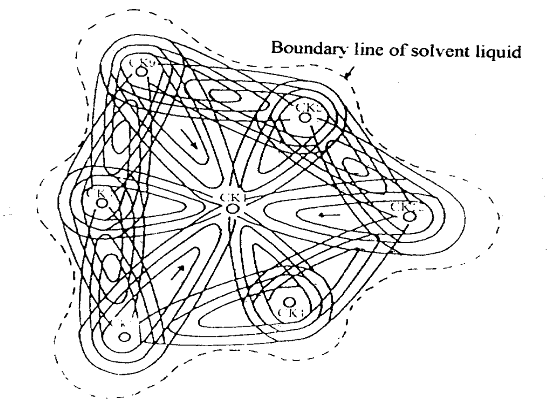
The laboratory experiment using the in place leaching technique was conducted at the Dabu U deposit in Taoshan, Jiangxi. The Dabu ore shows better U leaching properties with low acid consumption, high recoveries and faster extraction. In place mining on broken rock is considered the best approach. The parameter and results used for designing the extraction technology are: ore: 200 tons; grade: 0.08%; grain size: <200mm, among which <100 mm accounts for 80%; section height: 10 M; period of extraction: 200d; 5–50 g/L of H_2SO_4 as extraction agent; acid consumption: 3%; taking 0.3% of natural chemical material as oxidizing agent; intensity of ejection and leaching as 6–12 $l/m^2 \cdot h$ and interval ejection and leaching adopted; rate of leaching: 80%; rate of recovery of ion exchange: 98%; rate of precipitation of ammonium diuranate: 98%; difference of retrieving: 3%. It can be seen that non-economical and sub-economical U deposits can be converted into economical ones by improved mining technology [6].

4. MINING OF ISL SAND STONE U DEPOSIT AND ITS IMPACT ON ENVIRONMENT

Compared to conventional mining, ISL mining of U deposit has clear advantages when considering resource utilizations economic efficiency and environment protection [7].

The question as to how much ISL leaching will contaminate and influence the underground water when using acid reagents is unavoidable and important. Available information shows that the scope of underground contamination after ISL by acid is limited and depends on the concentration of sulfate ion, area of halo and the seepage velocity of underground water when ISL ends. Typically, the diffusion of ISL liquid extends 50–70 m along the brachy-axis of the mining section and 100–150 m along macro-axis direction. In recent years test patterns using (1) two injection wells and one recovery well and (2), four injection wells and one recovery well have been conducted in No. 512 deposit. The

ratio of pumping and injection is 1:2, at the block of 120 m depth of the hole, original water level around 7 m, pressure of pumping liquid 5 kg/cm^2, maximum value of water drawdown 20 m, pumping 5% more than injection. After three years of pumping and injection, the scope of solvent liquid extends out 30 m along the dip of ore beds (see Fig. 6). As the negative pressure area of underground water is formed during ISL, sampling and test are conducted at the point of 30 m, 50 m, 80 m along the seepage direction of underground water away from the margin of mining block. The point of 30 m is an exception where the acid concentration is higher than normal. The 50 m point is exactly same as normal. Of course, besides the sulfate ion, nitrate ion causes serious contamination to the environment [8].



CK1 as pumping hole, other holes exchange

FIG. 6. Superimposed profile of solvent liquid distribution.

After the underground water is contaminated by sulfate ion and nitrate ion, the environment can be restored by purification through natural demineralization. But, generally speaking, it will take tens of years to restore the environment. Sequential operation can be used to restore the environment more rapidly. This procedure involves pumping ISL residual liquid in the first mining block to second and third blocks. This approach not only reduces acid consumption but also protects the environment. In addition, for effective environment restoration and keep a balanced ecology, a microorganism method can be adopted [9] [10].

Based on the preceding information, China embarked on a programme for prospecting and developing ISL sandstone U deposits. Satisfactory results have been achieved. ISL mining has shown economic efficiency and has limited adverse influence on the environment. Overall programme results support China's decision to focus attention on prospecting for and subsequently developing ISL sandstone uranium deposits.

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Environmental aspects of sulphuric acid in situ leach uranium mining in the permafrost zone (Vitim District, Russian Federation)

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Abstract. Currently in situ leaching pilot tests are in progress at the Khiagda deposit, Vitim District, Russian Federation. The deposit is of the sandstone basal channel type, or paleovalley type in the Russian classification. It contains about 15 000 mt U at an ore grade averaging 0.05% U. Mineralization occurs in permeable unconsolidated Neogene fluvial sediments located below the permafrost which extends to 100 m deep. The basement rock is Paleozoic granite. Neogene-Quaternary basalts overlap the ore hosting sediments. The thickness of the ore host horizon varies from a few meters to 120 m. The depth of mineralization averages 170 m. Ore bodies are of lens and strataform shape. The following types of underground waters have been identified: groundwaters of the near surface or active layer, the aquifer in the Neogene volcanics, the ore host aquifer of the Neogene permeable sediments and fault related waters. The permeability in the ore bearing horizon varies from 0.1 to 20 m/day (averages 2 to 3 m/day). The waters of the productive aquifer are not suitable for industrial nor potable water supply due to their initial chemical composition. The ore host horizons occur between two impermeable horizons, which confine leaching solutions. Using sulphuric acid solutions as leaching reagent decreases the pH and increases Total Dissolved Solids (TDS) of the groundwaters within the leaching area due to concentration of sulphate-ion and other dissolved components. Principal components contaminating the underground waters are sulphates of aluminium, manganese, nickel and chrome. Their content during leaching significantly exceeds initial values. The available information on residual acid migration with the ground water shows that the concentration of contaminants significantly decreases away from the leaching contour. This occurs due to precipitation of contaminants during migration of the underground water from ISL sites. The external contour of the contamination aureole is defined by sulphate-ions. Recent theoretical and experimental research show the host rock resistance to chemical influence and also the tendency for environmental self-rehabilitation after ISL. The estimated properties of natural geochernical media should be accounted for in environmental monitoring and aquifer rehabilitation.

1. GENERAL

The development of the uranium industry in the Russian Federation is focussing on in situ leaching uranium mining at three new production centers. One of them will be based on the uranium deposits of the Vitim uranium-bearing district. It is situated in the northern part of Central Transbaikalia (Buryatia Republic of Russia), about 160 km from Chita City, in the remote unpopulated and economically undeveloped area of the southwestern part of Vitim Plateau. In situ leach sulphuric acid pilot mining is in progress at the Khiagda deposit.

2. GEOLOGY

The Khiagda deposit is a part of Khiagda uranium district, which includes eight neighouring deposits with similar geological settings (Fig. 1). They are of the sandstone basal channel type (or paleovalley type in the Russian classification). The distance between deposits is 1.5 to 6.0 km. However, there are no exact boundaries between deposits. Each of them includes several contiguous ore bodies.

The Khiagda deposit is the largest deposit in the district, containing about 15 000 t U at an ore grade averaging 0.05% U. The host rocks are permeable unconsolidated Neogene grey fluvial sand-clay pebbly sediments, filling relatively narrow paleovalleys. Paleovalleys are basal channels eroded into the granite basement. The thickness of the ore host horizon varies from some metres to 120 m. The basement is Paleozoic granite. Thick (45 to 100 m) Neogene-Quaternary basalt sheets overlays the ore hosting sediments. Mineralization occurs below the permafrost zone at depths from 100 to 180 m as lenses and lenticular (ribbon-like) ore bodies. Single ore bodies are 850 to 4100 m long, 15 to 400 m wide and 1 to 20 m thick. Uranium minerals occur as disperse pitchblende, coffinite and sooty pitchblende.

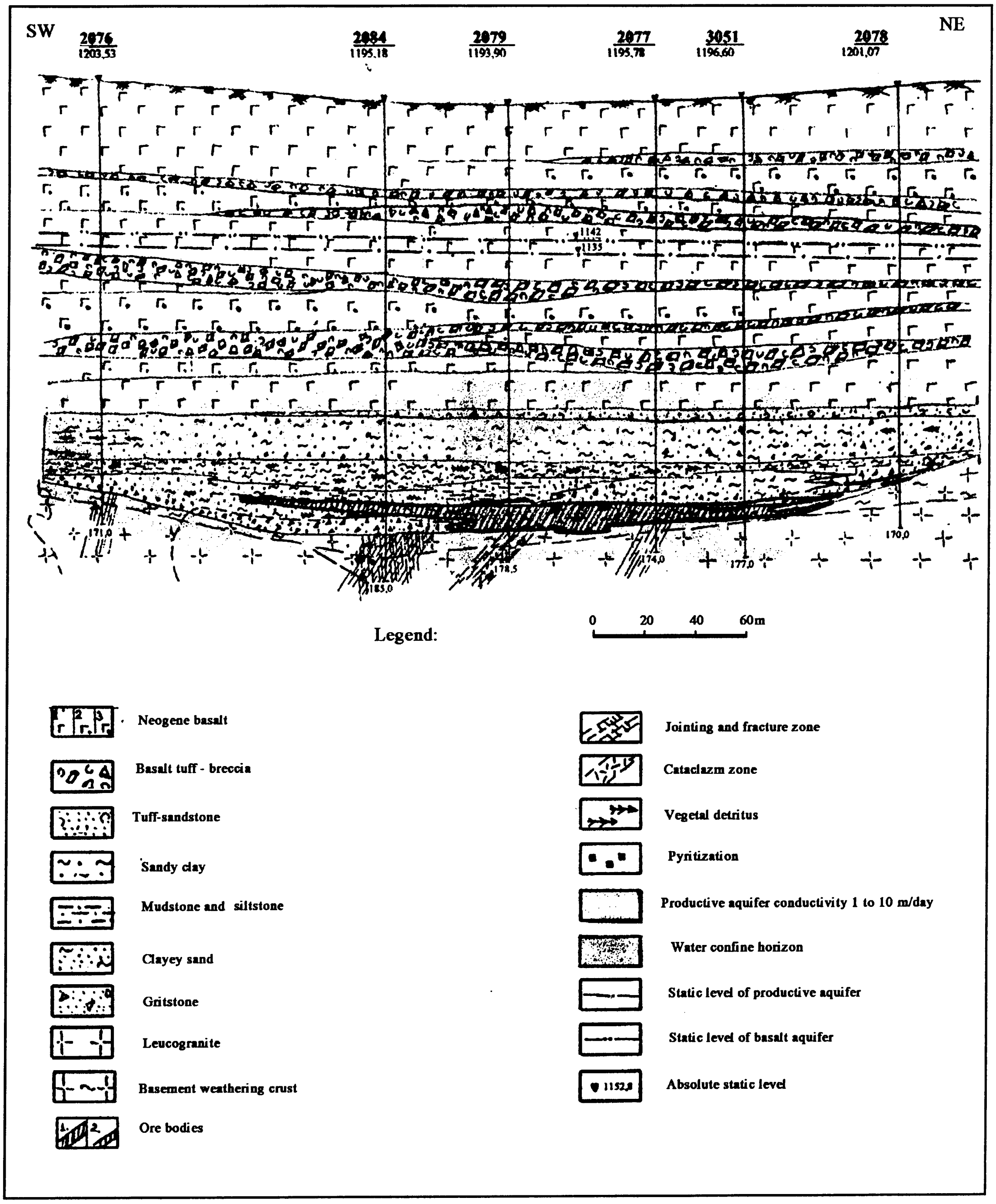

FIG. 1. Geological section of the Khiagda deposit.

3. SURFACE CHARACTERIZATION

Elluvial-delluvial lumps, boulders and gravel with loam and generally basalt fragments occur at the slopes and drainage boundary of the hills. Mixed sand-gravel and sand sediments dominate within the channel. A 100 m thick permafrost zone is present. The depth of seasonal melting is from 0.5 to 1.5 m. Cryogenic structures such as subsidence cones, sinkholes, minor depressions and freezing zones are widely distributed in the area.

The vulnerable environment within the permafrost zone is very susceptible to industrial impact and requires careful environmental management.

4. CLIMATE

Long and frosty winters (from October to April) characterize the weather in the region. The average temperature in December and February is –30ºC, reaching at some periods –56ºC. Annual precipitation totals 250–400 mm, 75% of which falls in the summer period.

5. HYDROGEOLOGY

The following types of ground water are present within the Khiagda ore district:

- Ground water of the near surface active layer (perched and meteoric water);
- Aquifer in Neogene volcanics;
- Ore bearing aquifer of the Neogene unconsolidated sediments;
- Water in fault zones.

Waters of near surrfce active layer have seasonal supply and discharge regimes. The layer is 2 to 3 m thick. Waters are ultra fresh with 0.1 g/l mineralization (rarely to 0.5 g/1), hydro-carbonate with various cation composition and oxygen-nitrogen gas composition.

Aquifer of Neogene volcanics occcur in water saturated basalts. The depth of its top depends on the lower border of the permafrost rocks. Ground water is concentrated in intraformational weathering crusts, in fracture zones and faults. The horizon is of the artesian type and the pressure level is from some meters to 300 meters above the top of the formation. Water conductivity is from 50 to 500 m^2/day and averages 200 m^2 /day. Specific wells yield 0.5-1.5 l/sec, springs yield 0.5-1.0 l/sec. Waters have a hydrocarbonatic, calcium-magnesium composition with 0.12 to 0.3 g/l total mineralization (TDS), total hardness 2–3 mg-ekv/1, pH 7–8. The gas composition is usually oxygen, rarely oxygen-nitrogen. The radon content is 5–10 eman, uranium $n\cdot 10^{-7}$g/l (*Note: In this and following equation n=1 to 9*), Ra-$n\cdot 10^{-13}$ g/l. The horizon water supply comes from atmospheric and fault waters.

The ore bearing aquifer occurs between two water confining horizons: the overlying basalt and underlying granitic crystalline basement. It consists of up to 80 m thick of unconsolidated alternating sands, gritstones, siltstone and rare clays occurring at the depth 100 to 280 m in the main paleovalleys of the first order and 80 to 300 m wide in tributaries. The aquifer usually has a strata-band shape. Aquifer isolation by the channel edge is indicated by the difference between their static water levels. The hydraulic gradient averages $n\cdot 10^{-3}$.

Water saturated layers are hydraulically connected. The gradual transition from unsaturated sediments to a water table aquifer and then to a confined aquifer can be observed frequently. The water pressure head is 0 to 300 m over the horizon. Intrinsic permeability is from 0.1 to 20 m/day, and averages 2 to 3 m/day and changes roughly in the vertical direction due to variation in the sediment.

The aquifer water supply comes from infiltration basement fractures and is probably due to partial flow from the basalts. There is no ground water discharge to the surface and no direct connection with the basalt aquifer, whose level is usually 2 to 60 m higher. This was demonstrated during pump tests.

Water in the ore bearing aquifer contains hydrocarbonatic calcium — (or rarely sodium) magnesium and a TDS from 0.5 to 0.8 g/l, rarely to 0.4 g/l. Total hardness is 9–14 mg-eqv/1, reaching 60 mg-eqv/1. The uranium content is $n\cdot 10^{-6}$ - $n\cdot 10^{-4}$ g/l.

It is not possible to use underground waters for water supply due to their pre-leach composition. The seasonal stability of static levels in productive horizons was determined during systematic observations. It does not depend on the depth or on the amount of precipitation.

Fault zone water: Cold carbonate waters penetrate from the surface through regional faults. They are distributed in the sediments of various paleovalleys within the ore district. Total mineralization (TDS) reaches 800 mg/l and the carbon dioxide 500 to 4000 mg/l. When summarizing the hydrogeological characteristics of the Khiagda deposit we can denote that the productive aquifer occurs between two water confining horizons, which prevent leaching solution seepage from spreading through the geological section.

6. ENVIRONMENTAL ASPECTS

ISL involves extracting the ore mineral from the deposit with minimal disturbance of the existing natural conditions. In contrast to underground and open pit mining, there are no rock dumps nor tailings storage, and much smaller volumes of mining and hydrometallurgical effluents that could contaminate the surface, air and water supply sources. Therefore the impact of ISL on the environment is much less than for other mining methods, as long as projects are properly planned and operated.

The principal environmental impacts during Khiagda deposit ISL mining are:

- Contamination and disturbance of the geological environment, soil-vegetal cover and surface waters;
- Potential radiation risk for working personnel;
- Ground water contamination.

Spills and leaks of leaching solutions on the surface during operation will remain near the surface due to the permafrost zone screen effect, and will migrate with atmospheric precipitation in the surface water system and contaminate it. This should be considered by constructing protective dams on the drainages of stream that could become contaminated.

Systematic environmental-geochemical monitoring should be performed to control the contamination of the soil-vegetal layer and water sources. It includes the study of:

- Soil;
- Bottom sediment;
- Water sources;
- Flora and fauna.

The radiation risk is monitored within sanitary-protective zone by systematic gamma-measurements. Results of environmental-geochemical studies within the pilot ISL site of the deposit show that environmental contamination can be successfully controlled and managed when monitoring is performed in a proper way. During ISL mining of the Khiagda deposit, primary attention should be paid to groundwater contamination.

Sulphuric acid is used as the leaching reactant in ISL mining. Leaching solutions usually have an acid concentration of 5–25 g/l. This reduces the pH in the aquifer and increases the amount of total dissolved solids (TDS) due to accomodation of sulphate ion and other components in the leaching solutions. The main components which determine ground waters contamination during sulphuric acid ISL are ions of sulphate, Al, Mn, Ni, Cr, etc. Their concentration in the leaching solution is significantly higher than the initial value. The pH of productive solutions decreases to 1–2, and TDS reaches 10 g/l. A comparison of the chemical composition of the ISL production solution and natural ground water is illustrated in Table 1.

TABLE I. CHEMICAL CHARACTERISTICS OF NATURAL GROUND WATER AND ISL LEACH SOLUTIONS AT THE KHIAGDA DEPOSIT

	pH	Total hardness, mg-	TDS mg/l	ELEMENTS CONCENTRATION																				
				Cl^-	SO_4^{2-}	Ca	Mg	Fe	Al	Sr	Ba	F	Mn	Cu	Zn	Pb	As	Be	Mo	Ni	Co	Cd	Cr	U	Sc
				Mg/l										mkg/l										mg/l	
Ground water	6.5-7.7	10-15	400-1000	7-14	0	100-120	140-180	20-250	<0.05	0.01-0.1	0.002	0.8-1.2	0.001-0.01	1-10	2-20	<1-3	no	no	<1	1-5		H/O	1.5-15	0.0001-0.01	H/O
Productive solution*	1-2	101-18	1200-10000	20-40	800-8000	140-300	210-300	20-250	75	27-37	0.19	0-1.2	9-12	145-181	1285-1377	0-3	no	140	85	13500-14975	140-200	H/O	34992-38925	75-90	0.45

* - data from pilot ISL site (productive solution identifies the leach solution in ore bearing acquifer)

The available information on migration of residual acid solutions away from active ISL sites show that the concentration of all contaminants decreases significantly depending on the distance from the leaching site. Schematic distribution of the plumes for various components can be presented as the following zonation (in the direction of plume migration):

$$U \rightarrow Fe^{3+} \rightarrow Al^{3+} \rightarrow Ca^{2+} \rightarrow NO_3^{-} \rightarrow SO_4^{2-}$$

Complete neutralization of solutions to pH=6–8 occurs as a rule at the distance of 10 to 15 m from the ISL operating site limit, depending on the thickness of host aquifer, its physical properties and the permeability of the host rock. In most cases precipitation of components and the decrease in their concentration to the background value takes place in association with increasing pH and decreasing Eh. For uranium and selenium it depends on the reducing properties of the host media; for strontium and radium it occurs at pH = 2.0–2.5; for iron (III) – pH~3; for thoriurn and chrome pH=3.5; aluminium pH=5.5–6; iron (II) pH=6.5 (Eh=+50 mV); Pb, Cd, Mn – pH>7.0. This also depends on the presence of sulphate producing microflora in the media. Cations of alkaline metals are intensively adsorbed by the clay fraction of the host rocks in neutral media.

Generally, the complexes of contaminants in low concentration precipitate during ground water migration away from depleted ISL sites. This outcome has been confirmed by lithological-geochernical considerations, thermodynamic calculations and on site observations at ISL deposits in Kazakhstan and Uzbekistan (i.e. the Uvanas, Kanzhugan, South Bukinai, Ketmenchi, Northern Karamurun ISL mines).

The analysis of the residual leaching solution shows that the external contour of contaminated zone is defined by sulphate ion, which has the highest migration capability. According to theoretical and experimental studies the mineralization of the hosting media is relatively inert to the chemical impact; even to such an aggressive chemcial activity as sulphuric acid ISL mining. It relates to environmental resistance to the contaminants, which were formed during ISL operation, and to the tendency for natural attenuation and self-restoration. It has been concluded that after an ISL operation is stopped a slow but irreversible neutralization and dernineralization of contaminated waters takes place in all aquifers containing plumes of residual leaching solutions. In this aspect, the ground water composition returns to the state which existed before the operation started.

The characteristics of natural geochemical media should be determined during special environmental investigations, and the monitoring and rehabilitation of aquifers affected by ISL mining.

Calculations were made to predict the migration of residual leaching solution in the ore host aquifer of the Khiagda deposit. It is anticipated that the plume of contaminated waters will migrate 260 m in 10 years under the influence of natural flow, dispersion and gravitational settling of the more dense acid bearing solution. However, these analytical calculations for migration do not account for all physical and chemical interactions between host rocks and residual solutions, because information on rock properties regarding the sorption capacity and conductivity is not now available.

Based on the experience from ISL mining in Kazakhstan and Uzbekistan, and accounting for the displacement length of natural flow, we can confidently predict that the complete neutralization of residual leaching solutions will occur, and that the groundwaters of the productive aquifer will return to their initial composition.

The following procedures for ISL mining of the Khiagda deposit will provide environmental safety for the ore host aquifer:

- Temporary mining lease registration for the period accounting for ISL pilot site mining and 10 year monitoring;

- The sorption and water conducting properties of the rock in conditions of natural demineralization, (attenuation) as well as a study of the kinetics of the demineralization process;
- The final method for aquifer and ground waters rehabilitation will be selected after pilot ISL mining is completed taking into account the results of monitoring the residual leach solution.

Summarizing the above information the schedule for environmental monitoring at the Khiagda deposit is recommended as shown in Fig. 2.

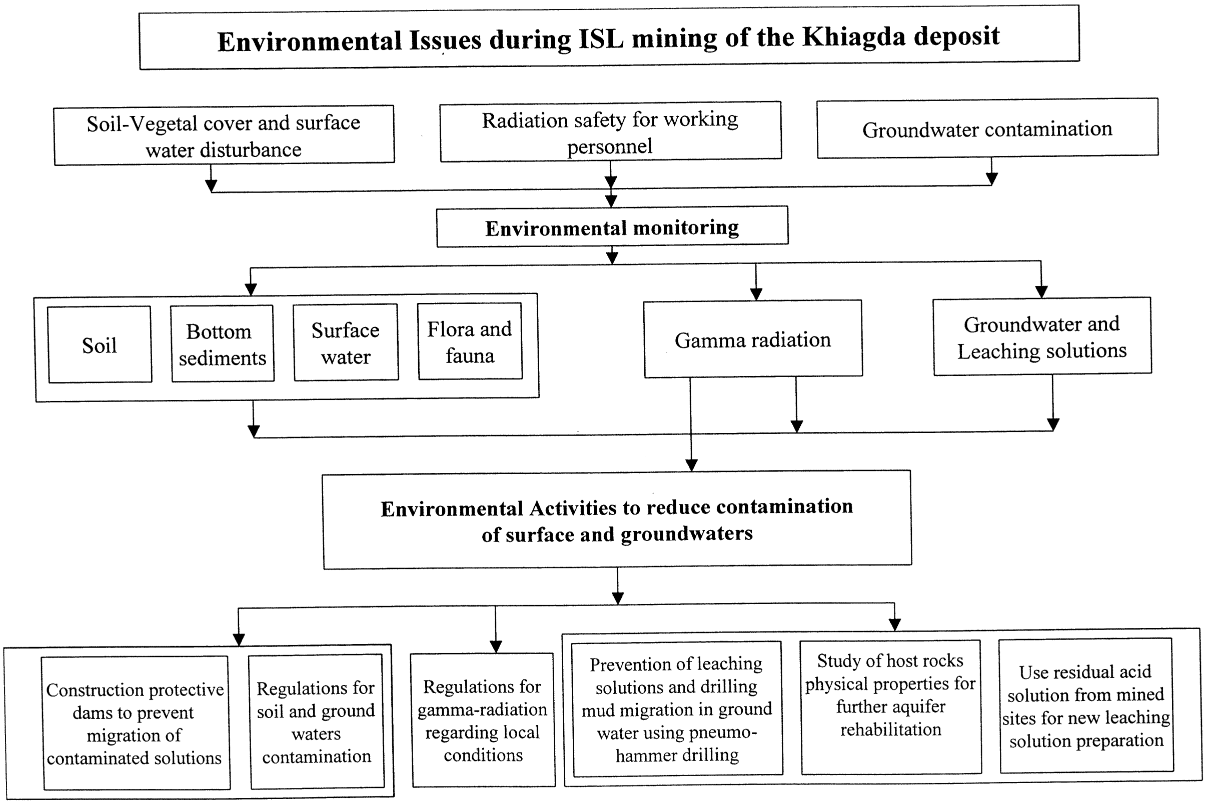

FIG. 2. Figure showing environmental issues during ISL mining of the Khiagda deposit.

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Environmental design of a uranium mill[1]

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Abstract. In the frame work of the Cleaner Technology Project for Uranium Mining and Milling, Australian Nuclear and Technology Organization (ANSTO), Environment Division of ANSTO has carried out a programme of research which seeks to identify, investigate and develop cleaner technologies that have the potential to minimize the environmental impact of uranium mining and milling. This paper describes three design options of a new uranium mill that can meet environmental, technical and economical objectives. The feasibility of such an approach was examined in the laboratory and in a pilot plant study.

1. INTRODUCTION

ANSTO has undertaken many collaborative projects with industry. These projects were concerned with environmental management for uranium mining and milling in Australia. Through this work, a number of technologies have been identified that, if incorporated into a single mill design, could represent Best Practice Technology (BPT), with regards to environmental performance. The feasibility of such an approach was examined and is described in this paper.

The objectives of the study were to design and evaluate a proposed uranium milling circuit for an Australian deposit that would satisfy at least three environmental aims:

- Minimize plant footprint;
- Disposal of tailings underground;
- Maximize water recycle and re-use.

These constraints were focussed on minimizing the impact of an operating uranium mill on the local environment. This approach is a clear example of the changing attitudes in the uranium industry, which has accepted more responsibility for greater environmental awareness during the design stage. The early uranium processing operations were typical of conventional practice, and environmental problems were generally given low priority. There was little or no recycling of process water, acid waste streams were not neutralized and tailing storage and management was not always considered in the broader long term context. Nowadays mill design is no longer a case of putting together known technology in the most economic configuration, but rather the total performance of the mill – environmental, economic and social factors must be addressed and considered at the design stage.

2. CONVENTIONAL URANIUM FLOW SHEET

Uranium is mined by both underground or open pit operations. The ore is subjected to a size reduction process to liberate the mineral particles. A typical grind size is 50 wt% less than 75 µm. In the most common flow sheet, uranium ores are treated by sulfuric acid leaching under oxidizing conditions. Ferric ion and a secondary oxidant are required to achieve rapid and complete oxidation of most uranium minerals (typically uraninite). The selection of suitable leaching conditions requires a balance between uranium recovery and processing costs, which is usually determined by the consumption of reagents and energy. Following leaching, solid-liquid separation step and washing are usually

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achieved in a counter current decantation (CCD) circuit. From this step, the tailing slurry is pumped to a retention facility, and the 'pregnant liquor', after clarification, undergoes solvent extraction (SX) for uranium recovery. The strip liquor from the SX process is the feed liquor for a precipitation step in which the uranium is recovered typically as ammonium diuranate. The raffinate is recycled to the washing circuit. The diuranate is washed, dewatered and calcined to produce a high purity product. A simplified mill flow sheet is shown in Fig. 1.

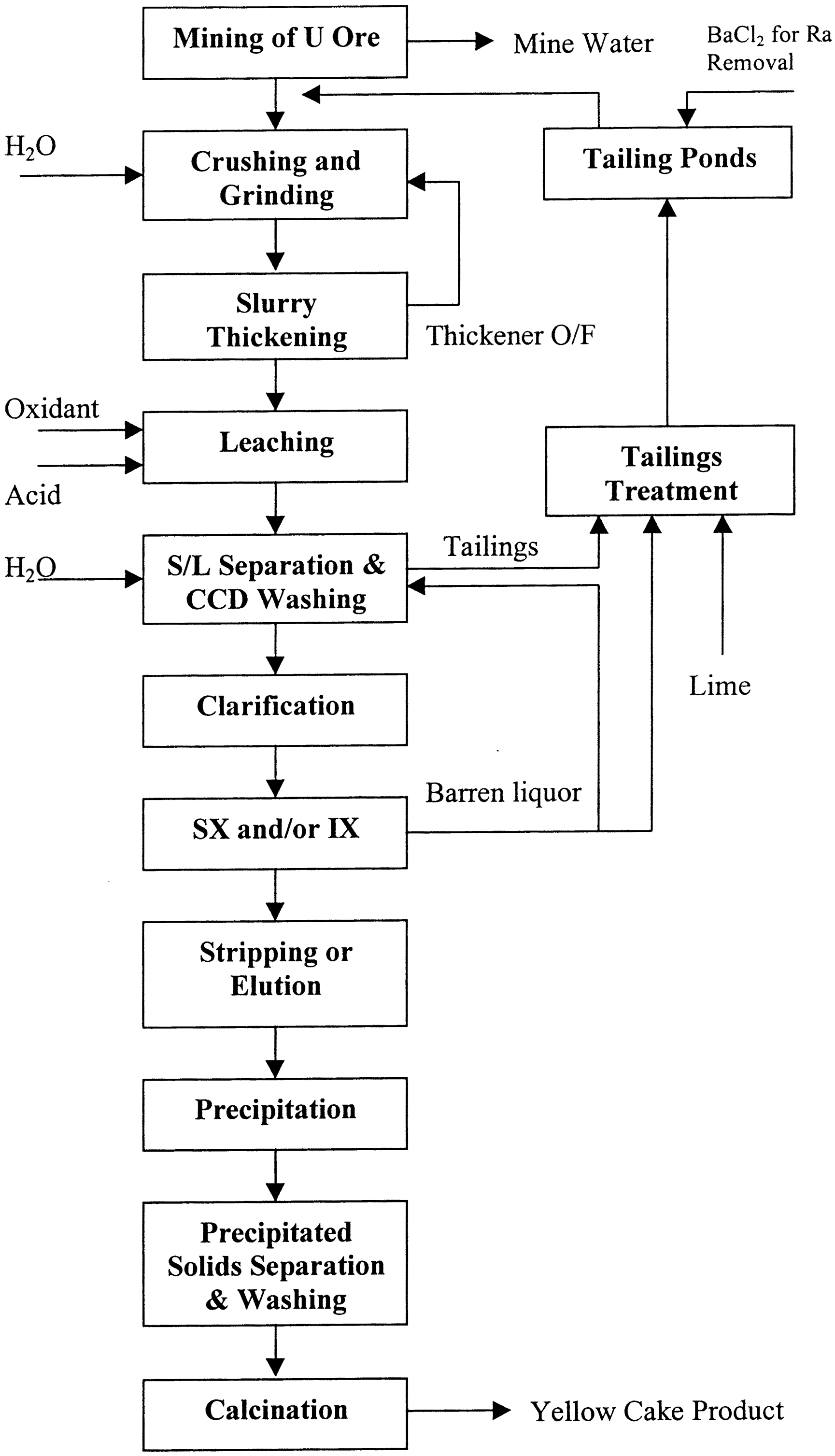

FIG. 1. A conventional acid leaching uranium mill flow sheet.

3. PROPOSED FLOW SHEET OPTIONS

The first design criteria, viz., minimize plant footprint makes a CCD washing circuit unattractive. An alternative to CCD washing is belt filtration and washing. The study criteria to dispose of all waste solids underground also strongly favours an approach whereby the tailings are prepared as a paste. The advantages of disposal of mine tailings as paste are now realized [1]. The paste is total tails thickened to a density where it can still be pumped, but will not segregate into fractions. It may or may not contain additives and has good settling characteristics.

For this design exercise, the option of paste technology has an impact on many aspects of process plant design. The filtration option after leaching has the potential of producing a highly dewatered filter cake that can be used directly to produce paste. Therefore, the simplest approach (option-1) is to replace the CCD circuit with belt filtration and washing and then recover the uranium using SX followed by precipitation. Filtration has usually taken second place to a CCD circuit on the grounds of ease of operation and reliability, even though filtration has the advantages of reducing water usage and increasing the uranium tenor of the pregnant liquor.

Two other less conventional options were also considered:

— The direct precipitation flow sheet (option-2). This flow sheet has a similar 'front end', which includes grinding, leaching and filtration, as the option-1 flow sheet. The 'back end' includes a partial neutralization step in place of the solvent extraction circuit, followed by direct precipitation of the uranium.

— The resin-in-pulp (RIP) or resin-in-leach (RIL) flow sheet (option-3). Instead of separating the leached solids from the pregnant solution, as in both options 1 and 2, a uranium-selective ion exchange resin is added to the leach slurry to recover uranium directly in a RIP process. Alternatively, leaching and RIP are integrated into a single unit operation as a RIL flow sheet.

A block diagram of the three proposed flowsheet options is shown in Fig. 2.

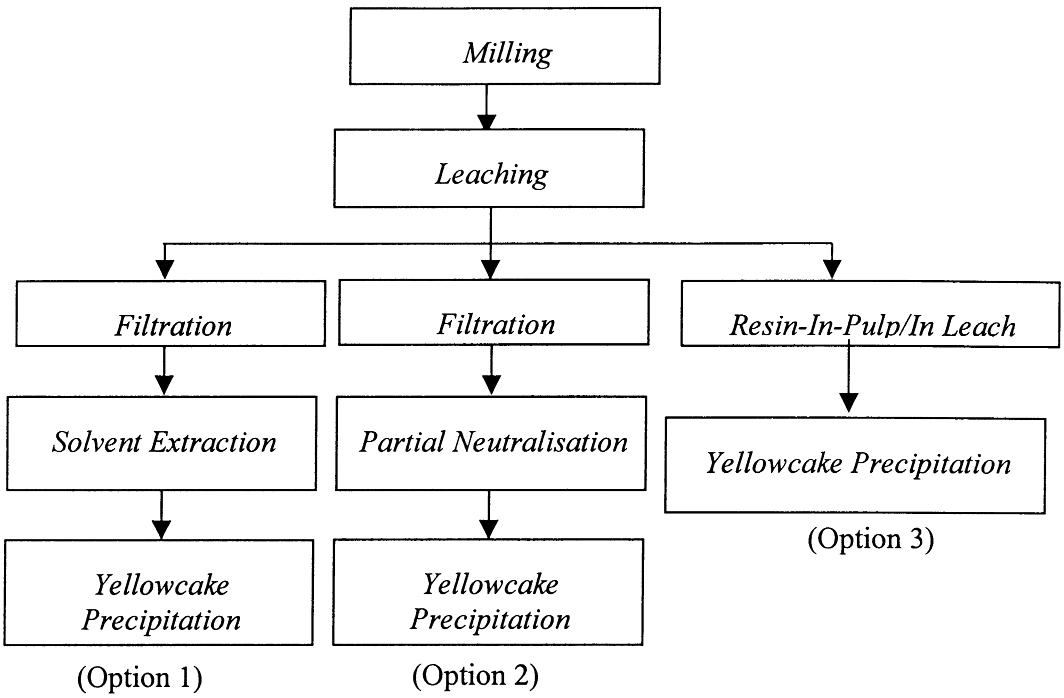

FIG. 2. Three flow sheet options under consideration.

3.1. Option 1 – The conventional approach

The horizontal belt filter is chosen to replace the multistage CCD circuit in the solid liquid separation step. In a typical design, this filter works by separating (under vacuum) the solids and liquor contained in the uranium slurry. The filtrate drains through a filter cloth transported by a carrier belt. The carrier belt is supported by an air cushion generated by a series of air boxes on either side of a central vacuum box assembly. The air cushion helps to reduce the friction generated by the weight of the materials on the cloth and the belt, and the applied vacuum. The belt filter has the ability to filter large volumes of solids with quite efficient washing. The wash volumes used are comparatively low and produce only minimal dilution of the uranium leach solution. During the late 1960s belt filtration received increasing acceptance in Europe. During the mid 1970s horizontal belt filters were installed in South African and North American uranium mills [2]. The horizontal belt filter was also proposed for the Kintyre mill in the recent feasibility study.

The belt filter also produces much drier tailings, containing 20–25 wt% water, which may be suitable for paste disposal. However, not all tailings can be effectively dewatered on a belt filter, especially the clay-rich ores, because the filtration rate may be too low to be practical. The CCD circuit for this type of ore also produces sludge underflow of very low density. Consequently, this flow sheet option will have application for some ores, but will be limited for clayey ores.

3.2. Option 2 – The direct precipitation flow sheet

In the so-called direct precipitation flow sheet, a partial neutralization step is introduced to effectively replace the SX circuit in the option-1 flow sheet. After filtering the leach slurry, the acid leach liquor is neutralized to a pH condition where iron and other impurities, but not uranium, are selectively removed. The technical feasilbility of the flow sheet is dependent on the circuit configuration and the impurities that are leached with the ore. Although the use of SX is economical for the production of high-grade yellowcake when using a very selective extractant [3], there have been frequent reports of losses of organic to the environment and crud problems associated with the SX operation. One review stated that there was a hidden cost in the solid-liquid separation involved with SX recovery due to the imperfect washing, resulting in soluble uranium losses [4]. Also, the operating cost of treating low-grade ores is proportional to the volumetric feed rate in an SX plant. An attractive feature of the option-2 flow sheet is the elimination of the SX circuit. The performance of the proposed direct precipitation flow sheet was evaluated in bench-scale laboratory experiments, and in a pilot scale study, for two uranium ores. These feasibility studies will be discussed and summarized later in this paper.

3.3. Option 3 – Resin-In-Pulp/Resin-In-Leach flow sheet

The first resin-in-pulp (RIP) process for the recovery of uranium from leach slurry was developed in 1953 in the former USSR [5] with a relatively high losses of the resin. Since then other researchers [2;4;6] have reported various success in developing the RIP/RIL process for uranium hydrometallurgy. Although the ability of ion exchange resin to adsorb uranium from solution has been known for a long time, there were engineering problems associated with the separation, transportation and mixing of the RIP/RIL mixture. These engineering aspects have an impact on resin losses and preventing the commercial implementation of the RIP/RIL process to recover uranium from ‘thick’ pulps. Major innovations in processing equipment are still taking place.

This flow sheet option appears to be the simplest of all because it eliminates the unit operations of solid-liquid separation and solvent extraction by adding the resin beads directly to the leach pulp, without clarification, to adsorb the uranyl sulfate ions. The uranium-bearing resin beads are then recovered by screening such that the finely ground ore particles will pass through the screen, but the coarse resin will not. In fact, when large throughput of low grade uranium ores are processed, the capital and operating costs of the solid/liquid separation circuit can become significant in relation to the total cost. South African Mintek has undertaken an extensive R&D program to develop RIP

technology for the recovery of gold and uranium [9, 10]. They considered that the significant developments in screening systems for the carbon-in-pulp process could be used for RIP. Different types of screen have been tried for this application, with some types being much more successful.

The application of RIP is attractive to uranium processing. However, it has been demonstrated that ion exchange resins have the potential to minimize the effects of preg-robbing during the leaching of uranium from carbonaceous and other ores. This is the RIL application. The resin beads are added in the leach tank for the adsorption of uranium almost as soon as it is extracted by the acid. A preliminary design concept of RIL was tested in the laboratory using a four stage counter-current circuit to contact an available commercial resin and the leach pulp followed by continuous counter current resin stripping. Based on this flow sheet a simple mass balance revealed an inherent difficulty with the flow sheet. The head grade of the ore was 0.5–0.1% U_3O_8 and given a 20 hour resin cycle time the resin inventory would have to be excessive. An additional concern was the rate at which the resin would have to be recycled through the plant and probable loss of resin due to abrasion. An annual loss of only 5% of the resin would have been prohibitively expensive given the size of the resin inventory.

An alternative to a conventional ion exchange resin is a magnetic ion exchange resin. This type of resin incorporates a magnetized component in the resin structure which allows the resin particles to act as an individual weak magnet. These resins can be tailor-made for specific application and have smaller particle sizes than conventional resins. A simple wet magnetic drum separator can then be used to effectively separate the small resin particles from the leach pulp. The magnetic separation method is generally considered to be a less vigorous or abrasive method (mechanically) when compared to the screening method used for the conventional non-magnetic resin. Therefore, physical degradation of the magnetic resin will be lower than that of sreening on the conventional resin.

ANSTO is currently undertaking a research and development collaborative project with a leading Australian chemicals company to develop a novel magnetic ion exchange resin (MIEX®) and process for the recovery of uranium (and gold) from hydrometallurgical operations. Following dissolution of the uranium in the leaching circuit, the slurry is contacted with the MIEX® resin in the adsorption circuit. The resin is separated from the slurry and advanced counter-currently along the circuit until it is loaded with uranium. The resin is advanced by passing the slurry through a magnetic separator on which the resin is retained and moved on to the next adsorption vessel. The slurry passes through the magnetic separator and back to the process, eventually discharging from the last vessel to the tailings impoundment.

The MIEX® resin has very small particle size of around 200–400 µm. It provides a high surface area allowing rapid adsorption kinetics. Equilibrium loadings of up to 20 g of U per litre of wet settled resin can be obtained. Recent tests have shown that the time required to achieve 50% of the equilibrium loading, t_{50}, for the MIEX® resin is only a few minutes.

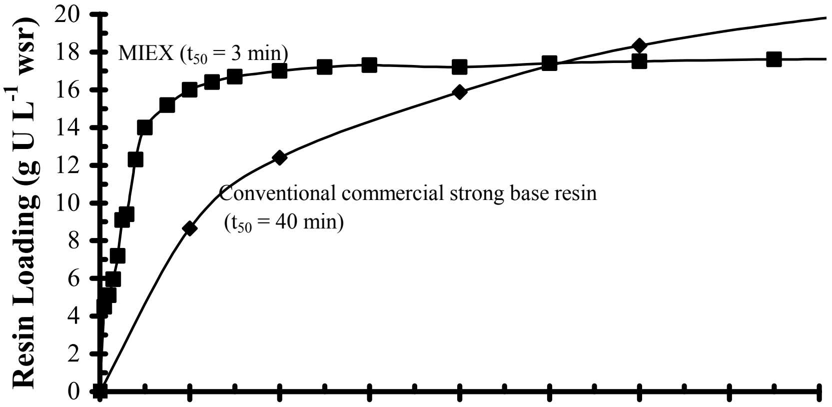

FIG. 3. Comparison of resins for uranium loading kinetics.

Figure 3 shows a loading time comparison between the MIEX® resin and a conventional strong base commercial resin. The required t_{50} loading time is about one tenth of that required for the conventional non-magnetic commercial resin.

The application of MIEX® and magnetic separating equipment is attractive to uranium processing using RIP. This because (i) the resin inventory would be less than that required by the RIL process; (ii) the elimination of expensive conventional solid-liquid separation and (iii) the fast loading kinetics of the resin which can be translated to fewer adsorption stages. All these benefits will result in smaller plant footprint and minimize water usage in the process. The design of resin-pulp mixture agitation and separation, and the pilot scale study of the MIEX® RIP process are currently taking place at ANSTO.

The development of a RIP uranium process in the Western World was initially driven by the poor filterability of some ores in the USA [8]. Various RIP systems were used in three Wyoming uranium mills to produce uranium from sandstones ores, and the operating personnel in these mills concluded that the continuous RIP process offered substantial benefits in their situation [11]. However, a major impetus to the further development of the RIP technology resulted from its adorption for gold processing applications. For a variety reasons, the use of ion exchange technology for gold processing was overtaken by the development of CIP/CIL technology. The role of ion exchange was also superseded by the development of SX technology to process high concentration uranium pregnant liquor.

4. FEASIBILITY STUDY

We have identified that the two proposed flow sheets (options 2 and 3) warrant consideration. The application of RIP in the option-3 flow sheet has been undertaken to further assess the MIEX® resin approach. The more readily applicable in the feasibility study is the direct precipitation (option-2) flow sheet. The flow sheet was studied for two Australian uranium ores separately in the laboratory and in the pilot scale experiments. A brief discussion of the performance of the flow sheet from a hydrometallurgical perspective is presented below.

4.1. Laboratory study

Two ores were tested in the laboratory using the direct precipitation flow sheet. The influence of pH and reagent selection on the performance of the iron precipitation, the iron cake releach and the uranium precipitation stages of the proposed flow sheet has been examined. Emphasis was placed on selectivity towards uranium and the ease of handling of the solid phases produced in the work. The sulfuric acid leaching conditions were similar for both ground ores at 40°C, pH 1.8, 55 wt% solids and under oxidizing condition (controlled ORP with oxidant addition) for 24 h. Uranium extraction of 98–99% was readily achieved.

The leach residue was filtered and washed on a Buchner funnel using an industrial belt cloth type. The filtrate was treated with an oxidant to oxidize the ferrous ion before adding limestone to pH 4.0. This partial neutralization step adequately removed iron, thorium and some of the aluminium and silica. In this step, some of the uranium also reported to the solids. Subsequently the neutralized solids (iron cakes) were releached in sulfuric acid to recover uranium, and the residue was combined with the primary leach filter cake to make into a paste product for tails disposal. In practice, the releach liquor could also be recycled to combine with the feed solution to the iron removal circuit.

After iron removal, the final liquor containing a few mg L^{-1} of Fe was achieved. This liquor, after clarification, was precipitated with hydrogen peroxide and sodium hydroxide (to pH 3.8) to produce a uranium peroxide product. The remaining uranium in the supernatant liquor represented a loss of ~0.1%. The precipitate was readily filtered, washed and dried to give a uranium concentrate product containing about 22 wt% moisture. Further calcination of the oven-dried precipitate to 600°C produced a final uranium product, which satisfied available converter specifications. The main issue

with this circuit concerns the impact of recycling the process water and the consequent build up of cations, which have the potential to contaminate the yellowcake product. A process model was used to evaluate steady state concentrations of all species in process water and a synthetic solution was then prepared to assess the impact on circuit performance. However, the impact of these cations on the properties of the paste tailings remains unknown.

4.2. Pilot plant study

An upgraded uranium ore product (from a medium grade using gravity concentration and radiometric sorting) was used as the feed material in the pilot plant. The process flow sheet used in the pilot plant was divided into three main circuits – leaching, iron precipitation and uranium precipitation. The pilot plant was successfully operated continuously over seven campaigns for a total of 42 days. During this period a range of plant operating conditions were tested. The objectives were to verify the technical feasibility of the proposed direct precipitation flow sheet under continuous operating conditions and provide data necessary for a commercial plant design.

The ore was first wet ground in a closed circuit ball mill with a 500 µm vibratory screen. The ball mill was only operated to grind enough ore to last for six days duration of each pilot plant campaign. The screen undersize was stored as slurry at 56 wt% solids in a 4500 L stirred tank from which the feed to the leach circuit was drawn. The leach circuit consisted of a cascade of stirred tanks to give a leach residence time of 14–25 h. The slurry in the tank was heated to the required leaching temperature of 45°C by means of steam and/or electric heaters. Sulfuric acid and an oxidant were added to the tanks to maintain the target leaching conditions. Uranium dissolution after 24 h generally exceeded 98% at 45°C and pH 2.0.

After leaching, the primary leach liquor was oxidized with hydrogen peroxide to oxidize all the ferrous ion before entering the iron circuit. Lime was added to the tanks to control the pH for iron precipitation. Iron concentration in the supernatant liquor was reduced to 2 mg L^{-1} at pH ~4.0. However, the iron sludge still contained up to 2% U_3O_8. This uranium was recovered by releaching the iron precipitate. There was no dissolution of ferric iron during the releach and therefore the releach filtrate was returned to the iron circuit feed. The washed releach filter cake was blended with the primary leach filter cake to be disposed of as tailings. This represented ~2% of the solid tailings produced in the whole process.

The iron circuit filtrate was passed through a clarifying filter to remove any suspended solids before entering the uranium precipitation circuit. Uranium peroxide was precipitated with the addition of hydrogen peroxide and the pH was controlled to the set point using sodium hydroxide. Stage recovery of more than 99.9% was achieved for the uranium. The uranium peroxide precipitate settled very easily in a thickener underflow with densities of ~65 wt% solids. The underflow solids were filtered and calcined at 250°C for 1 h to produce a product that contained 94% U_3O_8 and met the converter specification.

This bench scale investigation and the successful pilot plant operation have proved the technical feasibility of the direct precipitation flow sheet for processing two Australian uranium ores. Further optimization of the operating conditions such as the distribution of reagents and water management within each circuit as well as adopting the paste technology for tailing disposal will make this process option commercially and environmentally attractive.

5. CONCLUSION

New approaches to minimize environmental impacts for uranium mill design will, in future, receive wider attention by the industry. The environmental and technical constraints of minimizing plant footprint, water usage and disposal of tailings as paste were identified as important criteria in the design of a new uranium mill. Options for meeting these criteria are available and the feasibility of these approaches were assessed in a mill design case study.

On the grounds of minimizing water usage, the belt filtration system can replace the CCD circuit or be incorporated into a smaller CCD circuit. The highly dewatered filter cake tailings can be converted to paste for underground disposal. This option can be easily implemented into the conventional uranium hydrometallurgical plant.

The direct precipitation of uranium from the pregnant liquor makes the unit operation of solvent extraction redundant. The direct precipitation flow sheet was successfully tested at bench scale and pilot plant operation. The proposed uranium mill has a smaller footprint than the conventional design, utilizes almost complete water recycle, and allows for disposal of all waste as paste tailings.

The application of resin beads directly to the leach pulp in the RIP/RIL flow sheet has been considered to have several advantages over both the conventional and the direct precipitation flow sheets. The major advantages are the elimination of the solid liquid separation for the leached ore and the fast kinetics of the resin beads for uranium loading. The RIL process also has the potential to minimize the effects of preg-robbing during the leaching of uranium from carbonaceous ores. However, the major problems that prevented the implementation of RIP or RIL to uranium hydrometallurgical plant in the Western world are attributed to the difficulty in the effective separation of the resin from the leach pulp and the physical degradation of the resin beads at an acceptable rate. These are the driving forces for the development of the MIEX® resin. The magnetic resin-in-pulp process will meet all the environmental design criteria for a new uranium mill and as such, it warrants further development. ANSTO will continue to research and monitor developments of cleaner technologies in uranium processing and waste management.

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WASTE MANAGEMENT AND DECOMMISSIONING

(Session 4)

S.E. FROST
Canada

Decommissioning: A critical component of the design for uranium tailings management facilities

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Abstract. Uranium was discovered in the Beaverlodge area of northern Saskatchewan in 1934 with the first major mill beginning operation in 1953. Little attention was paid to tailings quality or tailings management practices. With the onset of the modern uranium operations beginning in the late 1970's, it was repeatedly evident, that the public had significant concerns, particularly with respect to tailings management, that must be addressed if the developments were to be allowed to proceed. Primary considerations related to environmental protection, public safety and an assurance of the ongoing sustainable development of the region. Integrating the decommissioning of a mine/mill site into development planning from the very outset has proven to be a critical component that has contributed to the ongoing success of the Saskatchewan uranium operations. This paper will provide a case study of the evolution of the uranium tailings management technology utilized in Saskatchewan. It documents the evolution of tailings management processes and the characteristics of tailings produced by successive mines in northern Saskatchewan. It also discusses the evolution of technologies applied to management of uranium mill tailings and demonstrates how progressively increasing levels of environmental protection have been achieved during the last 47 years of uranium mill operation. The paper also shows that the planned and progressive decommissioning of an operational site is the key to: Minimizing environmental impacts; Satisfying public and regulatory concerns; Minimizing operational and decommissioning costs; Minimizing corporate liability; and Shifting public resistance to public support.

1. INTRODUCTION

The Athabasca basin located in Saskatchewan, Canada has become one of the most important uranium producing regions of the world. Currently, five mines produce approximately one-third of international uranium output, exploiting some of the world's richest ore bodies.

Development of the regional uranium industry in northern Saskatchewan has required technical innovation, careful operations, and long term management strategies to meet public concerns with respect to environmental protection and worker health and safety. There was sufficient public concern about developing the higher grade ore bodies, that extensive public consultation and definition of a new regulatory framework was required to educate the public that the risks associated with uranium mining and milling were manageable and could be mitigated. The principal issue was management of mill tailings, both during operations and in the long term, after mill closure and decommissioning. Given the persistent nature of associated metals and radionuclides, consideration of very long term (10 000 years) effects have become commonplace. Operators routinely develop a decommissioning plan and predict long term effects during the environmental impact assessment and licensing phases. Decommissioning has evolved from being ignored to being the central component of a long term management scheme. This paper tracks the evolution of tailings management and decommissioning practices over the past 50 years in northern Saskatchewan.

1.1. Saskatchewan uranium belt

Saskatchewan lies between 49° and 60° N, and 102° to 110° W, with about one million people occupying approximately 650 0000 square kilometres of land in western Canada, as shown in Fig. 1. Most of the population is located in the southerly one-third of the province, the primary agricultural region.

FIG. 1. Location of Saskatchewan.

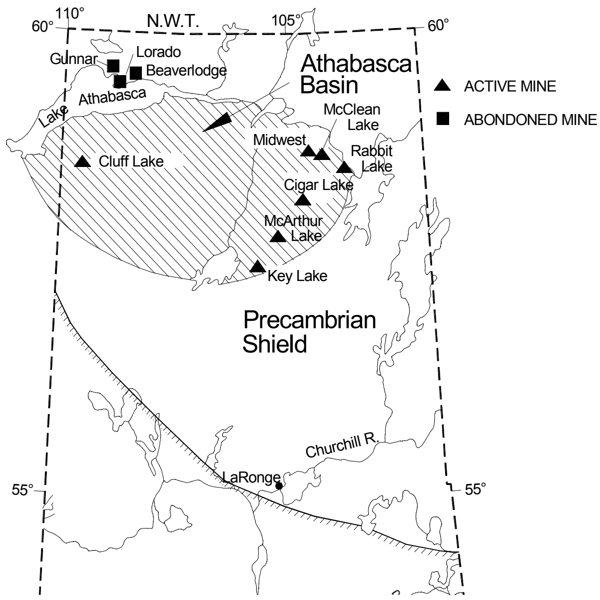

FIG. 2. Location of uranium mines in northern Saskatchewan.

Approximately the northern half of the province is within the Canadian Shield, an area of metamorphosed Precambrian rock with thin topsoil and overburden, having been scoured by multiple glaciations during the past million years. It is generally a pristine area of boreal forest with pure fresh water lakes and rivers that make up slightly more than 10 percent of the land area. It has wildlife and fishery resources that are important to both local communities and other residents of the province. The region also provides important summer habitat for a number of North American migratory bird species.

The high grade uranium mines are located in the Athabasca basin, an area of Precambrian age sandstone and conglomerate that generally lies between 57° and 59° N, and 104° to 110° E, as illustrated in Fig. 2. Mining in the basin has become the primary economic activity and source of employment for the 37 000 residents (mostly aboriginal) that occupy the northern 300 000 square kilometres of Saskatchewan. They live in the subarctic continental climate that has an average annual temperature between –4°C and –5°C, with extreme temperatures rising to above +30°C in summer and falling to below –40°C in winter. The region has a frost free growing season of less than 100 days and receives about 550 mm of total annual precipitation, about one-third of which is snow. The lakes are generally ice free from late May to the end of October.

Drainage in the area is poorly integrated with numerous peak bogs (muskegs) and swamps. Sporadic permafrost is common, particularly in low-lying swampy or shaded areas. The uranium-producing belt generally lies near the northerly limits of the boreal forest. Few of the trees reach sufficient size to be commercially valuable, but are nonetheless a valued ecological component.

1.2. Regulatory framework

From a statutory perspective, regulation of the uranium industry is shared between two senior levels of government, but in practice it has become a tripartite system between Canada, Saskatchewan and the local communities affected by mining (Parsons and Barsi, 2000). The federal government has statutory authority over mining, milling and disposition of radioactive materials, fisheries, migratory birds, some aspects of the environment and welfare of aboriginal people. The province has responsibility for management of the mineral and forest resources, wildlife, land use and the environment.

The involvement of local communities has progressively increased, by agreement between senior governments and mine operators, to provide public oversight of environmental management practices, particularly those with a social and economic impact on communities in the region. Thus, a Saskatchewan uranium mine operator must meet the statutory and regulatory requirements of the provincial and federal governments while at the same time maintaining social approval within the effected communities.

Specific permits are required for mineral exploration; lease of the surface land; to operate the mine, mill and waste management facilities; discharge effluents; and, to decommission facilities. A condition of many of the permits is to seek involvement of the community Environmental Quality Committees (EQC's).

1.3. History of uranium mining in Saskatchewan

Uranium was discovered at the Goldfields Mine on Lake Athabasca, Saskatchewan in 1934. At that time, radium was the mineral of interest, since uranium had no commercial value until after 1940, when it became central to defense research and development efforts. The Atomic Energy Control Board (now the Canadian Nuclear Safety Commission) was established in 1946 to administer the Atomic Energy Control Act governing mining and milling of uranium. The first mining began at Beaverlodge on Lake Athabasca in 1949. Uranium City was established in 1952 and the first mine, Beaverlodge Mine, went into production in 1953. The Gunnar Mine came into production in 1955 and closed in 1964. The Lorado Mine opened in 1957 and closed in 1960.

Richer and more valuable ore bodies were discovered at Rabbit Lake, Cluff Lake and Key Lake in 1968, 1969 and 1975, respectively, with Midwest in 1978 and McClean Lake in 1979. These were followed by Cigar Lake in 1983 and the McArthur River discovery in 1987. The discovery of these higher grade, higher value ore bodies with differing tailings characteristics lead to progressive changes in tailings management strategies and technology.

The first generation of Saskatchewan uranium mines on Lake Athabasca were supported by ore bodies grading as low as 0.05 percent U_3O_8. By comparison, the Rabbit Lake deposit, discovered in 1968, had

an average grade of 0.32 percent U_3O_8. Deposits currently being exploited contain very high grades of uranium (1 to 20 percent by weight) and are often associated with significant values of other minerals including nickel, arsenic, molybdenum and other heavy metals.

The ore, which is typically acid generating, is processed by grinding to 40 to 50 percent passing the 75 µm sieve; acid leaching to solubilize the uranium; decanting, precipitating and recovering uranium; neutralizing the barren solutions with lime; and, discharging the neutralized solution and leaching residue as a hydraulic slurry. Various depositional techniques and management systems have been utilized as are described later in this paper.

1.4. Evolution of tailings management systems

Four distinct stages of evolution of tailings management practices can be identified in Saskatchewan operations. The early operations focused on resource recovery, used uncontrolled hydraulic discharge of tailings to lakes or topographic depressions. The sites were subsequently abandoned without decommissioning. The Eldorado Nuclear Ltd. Beaverlodge site, which began operation in the early 1950's, broke this trend and was the first site to be formerly decommissioned following a closure decision in 1980. This was a "hind-sight" decommissioning process, in that site decommissioning had not been provided for during mine planning, engineering or operations.

The second generation of tailings facilities came with development of the Rabbit Lake mine, starting in 1976, and with the Cluff Lake operation soon thereafter. These were the first facilities that received tailings from the richer ores, and were subjected to progressively more stringent regulatory scrutiny. Regulations required disposal of the tailings in engineered facilities above the groundwater table. Tailings management facilities for the Rabbit Lake mine, Cluff Lake and Key Lake, were of the traditional “valley dam” or surface dyke impoundment type. While decommissioning received some consideration, adequate tools did not exist at that time to predict long term, post decommissioning environmental performance.

The third generation of waste management facilities commenced with the Collins Bay expansion of the Rabbit Lake mine. The environmental impact assessment process rejected conventional surface tailings management systems in 1980, resulting in an innovative proposal to dispose of tailings below the groundwater table in a pit specially prepared with a pervious envelope surrounding the pit perimeter. This so-called "pervious surround" pit disposal system, with subsequent application of thickened tailings technology, was utilized for the Rabbit Lake expansion and later expansion of the Key Lake facility. Its key attributes were use of the pervious surround to divert regional groundwater flow around the tailings mass, while depositing the tailings in a low gradient regional groundwater system. Migration of solutes from the tailings was controlled by "hydraulic containment" during operations, and was governed primarily by diffusion rather than advective flow in the long term, following decommissioning. Alternative decommissioning schemes utilizing either water cover or soil and rock cover, were considered. Associated issues included consideration of tailings consolidation and control of frozen zones within the tailings mass.

The fourth generation of tailings management systems evolved in the design and licensing of the JEB Pit tailings management facility for the McCLean Lake project. The “pervious surround” system was evaluated but the degree of containment provided by natural geologic barriers was found to be superior. Optimal pit containment options were found to be a function of tailings properties and the properties of the natural system. Again, depression of the groundwater table around the pit provided “hydraulic containment” during operations, allowing all solutes to be collected and treated before discharge to the environment. Numerical modeling indicated that migration of radionuclides from the tailings management facility was not a concern in the long term, due to the adsorptive capacity of the surrounding natural materials. The levels of dissolved arsenic were, however, an issue. It was determined that the most effective means of controlling the mass of arsenic that may migrate from the facility was to control the quality of porewater in the tailings, thus controlling the “source term”. In this manner, the fourth generation of uranium tailings disposal technology was developed. The

approach maximized the use of natural barriers in a renovated open pit, incorporates hydrodynamic containment while engineering the tailings to achieve specific physical, geotechnical and geochemical properties. These technological advances are supported by comprehensive operational monitoring to verify that the tailings management facility will achieve the long term performance anticipated during design.

Uranium mining and milling has been ongoing in northern Saskatchewan for 47 years. During this time, more than 31 million tonnes of tailings have been placed (Barsi and Ashbrook 1992), including more than 12.3 million tonnes in above ground facilities at Key Lake, Cluff Lake and Rabbit Lake mines. One of the first generation facilities (Beaverlodge) has been successfully decommissioned, while two others (Gunnar and Lorado) have been abandoned without decommissioning and are now considered orphan sites. All of the second, third and fourth generation facilities now have approved decommissioning plans with the fourth generation decommissioning scheme consisting of thick soil and rock covers with sufficient post closure care to allow full consolidation and recovery of the leachate generated during that time. Decommissioning plans and monitoring results are regularly reviewed with the EQC's and a general acceptance of these schemes has been achieved.

In summary, the current approach for tailings management facilities includes:

- Utilization of a fully engineered system;
- Maximum control of releases during the operational phase;
- Comprehensive evaluation of long term performance to 10 000 years following decommissioning;
- Progressive decommissioning of the facility as operations allow; and,
- Offsetting potential public liabilities with funded financial sureties to ensure long term care and maintenance.

2. CASE HISTORIES

The location of abandoned and active uranium mines in Saskatchewan is shown in Fig. 2. A brief description of each of these is given in the following paragraphs.

2.1. Beaverlodge

The location of the Beaverlodge facility is shown in Fig. 3 which also identifies locations of other tailings sites in the Uranium City area. Milling started at Beaverlodge in 1953, exploiting an ore body with head grades generally less than 0.25 percent U_3O_8. Slurried tailings were discharged at 21% solids with the sand fraction removed for backfill. The remainder was discharged directly to the lake.

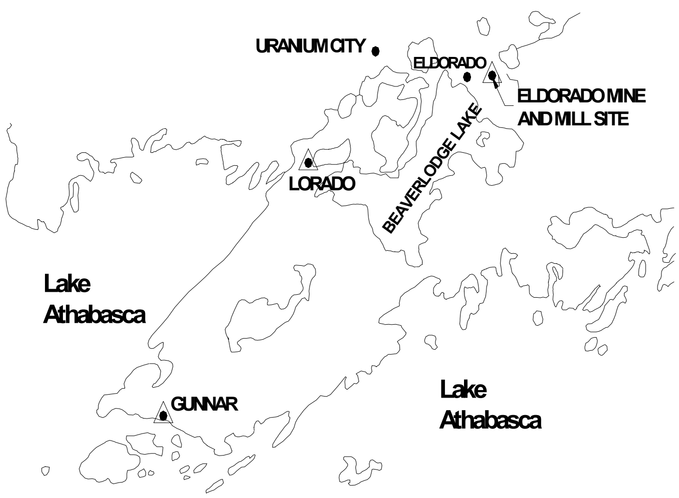

FIG. 3. Location of uranium facilities in uranium city area.

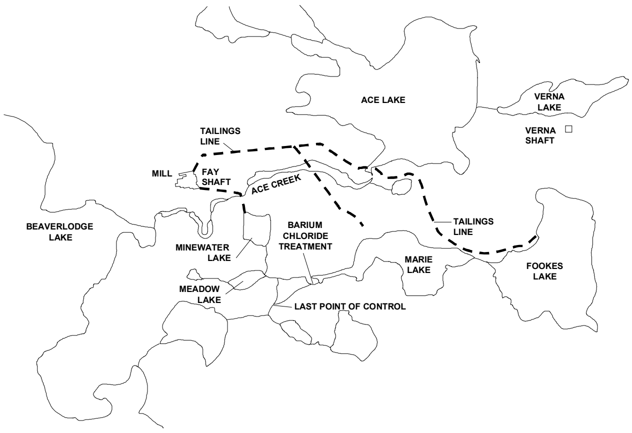

FIG .4. Map of the Beaverlodge tailings system.

In total, 10 100 000 tonnes of tailings were produced, of which 4 300 000 tonnes were used as backfill. The tailings were initially discharged to Marie Lake and later to Fookes Lake with no preconditioning and no effluent control. Control and treatment works for discharged water were first established in 1977. An overview of the Beaverlodge tailings system is given in Fig. 4.

A closure decision was made in 1980 and a comprehensive closure plan was prepared. Decommissioning consisted of collecting and consolidating the tailings in as few areas as possible, covering those on land with a vegetative cover in the case of low grade tailings, waste rock or water. Monitoring of performance is on going in preparation for transferring the site to government institutional control sometime in the future.

2.2. Gunnar

The Gunnar Mine opened in 1955 as the first open pit uranium mine in Saskatchewan. The later stages also included an underground mine. It is estimated that 5 494 000 tonnes of ore were milled before production ceased in 1964. The site location is illustrated in Fig. 5.

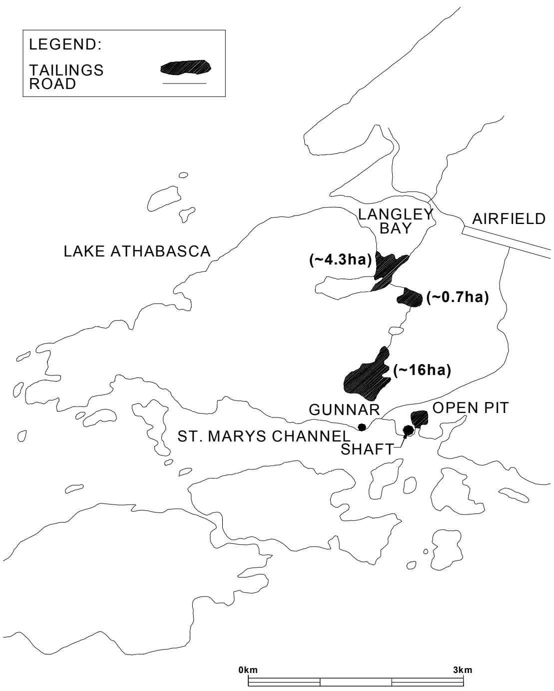

FIG. 5. Map of the Gunnar mine site.

The tailings were discharged into a small lake as a slurry, which overflowed into Langley Bay on Lake Athabasca. After closure, the site was abandoned and the tailings remain unreclaimed.

2.3. Lorado

The Lorado Mine opened in 1954 with the mill opening in 1957 to process Lorado ore and to custom mill ore from several other mines. It is anticipated that 554 000 tonnes of ore were processed before the mill ceased operations in 1961. Details of the Lorado tailings area are given in Fig. 6, which indicates the tailings were deposited as a slurry to Nero Lake, which overflowed into Beaverlodge Lake. The tailings were acid generating resulting in local areas of strongly acid conditions.

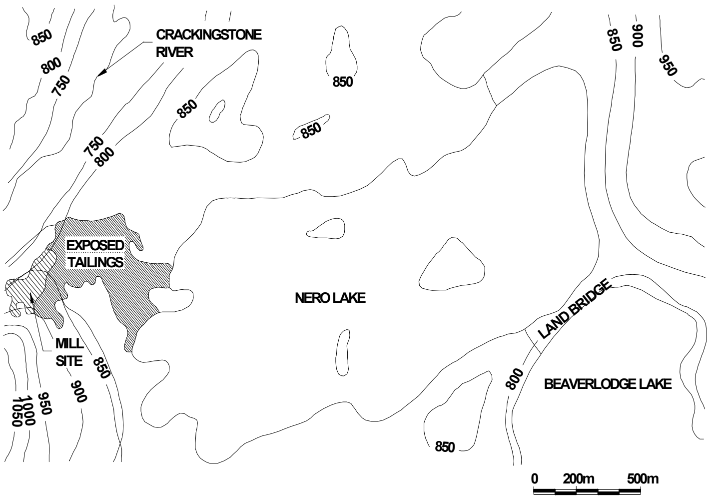

FIG. 6. Map of Lorado tailings area.

The site was abandoned after shutdown and the mill site has since been reclaimed. No reclamation or decommissioning activities were undertaken for the tailings areas and they remain unreclaimed.

2.4. Rabbit Lake

The Rabbit Lake tailings, illustrated in Fig. 7 were the first fully engineered tailings structure for uranium tailings in Saskatchewan. It was a conventional valley dam constructed of cycloned tailings and till. It had adequate capacity for the Rabbit Lake tailings only, but expansion of the system was rejected in 1981, leading to development of the Rabbit Lake pit.

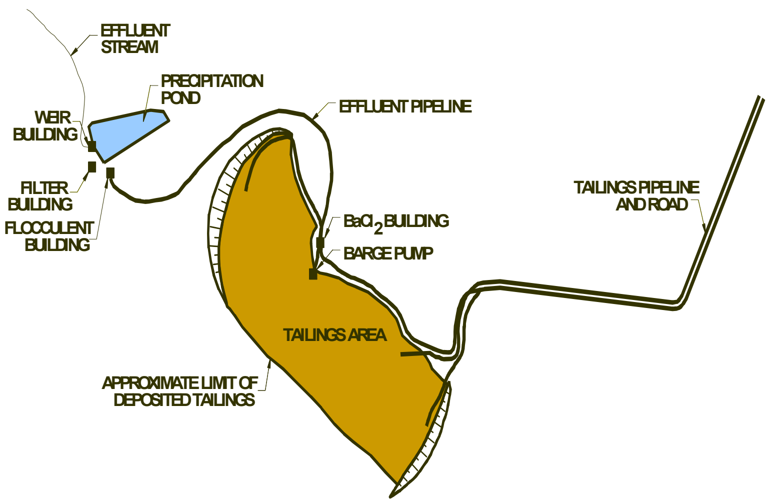

FIG. 7. Map of Rabbit Lake tailings facility.

The Rabbit Lake tailings area is currently being renovated in preparation for decommissioning (Holl, 2000). This involves placement of a waste rock and till cover, stabilization of containment structures and control of drainage and seepage. The cover has been designed not only to provide generic environmental and radiation protection, but also to promote consolidation of the tailings mass. Waste rock is being used in the cover to provide geometric shaping and pre-loading to accelerate normal consolidation processes and minimize future settling.

2.5. Cluff Lake

The Cluff Lake waste management system was the first joint federal-provincial regulated tailings facility in Saskatchewan. It was a surface valley dam scheme that accommodated subaerial discharge of slurried tailings. The scheme as it looked at its inception in 1982 is illustrated in Fig. 8.

Segregation of the tailings was experienced, this was controlled by cross dykes and controlling discharge density. It is currently anticipated that milling at the site will cease in 2001 and the TMF will be at capacity with approximately 2.7 million tonnes of tailings. The 1999 configuration of the TMF is demonstrated in Fig. 9. Current decommissioning plans call for stabilizing the surface with a simple cover, stabilizing the containment structures and transferring the system to institutional care after monitoring demonstrates adequate long term performance.

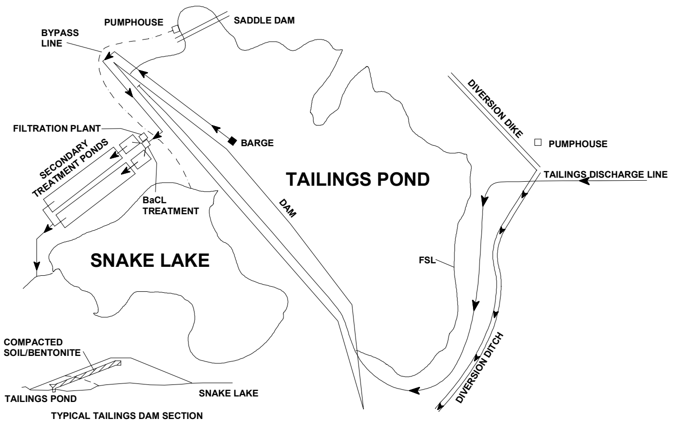

FIG. 8. Map of Cluff Lake tailings facility.

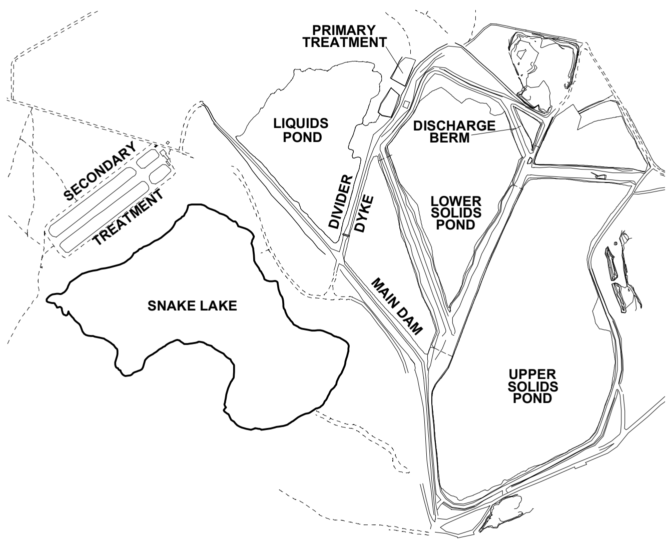

FIG. 9. Map of the Cluff Lake tailings management facility for 1999.

2.6. Key Lake Subaerial tailings

This system was designed on the "subaerial" principal with atmospheric discharge of tailings as a thickened slurry. Segregation and permanent freezing of the tailings were issues that were addressed. Cross dykes were installed to control segregation and reduce entrapped ice. Mechanical thawing of incorporated ice was undertaken. The section through the layered tailings scheme as proposed in 1983 is given in Fig. 10.

At present this TMF is in a care and maintenance mode. There is approximately one-half million cubic meteres of storage capacity remaining in this facility. Studies are underway to determine the preferred decommissioning strategy. Preferred options are for the relocation of the tailings mass to the Deilmann TMF, with or without nickel recovery, or closure in-place utilizing a fully engineered cover (Holl, 2000).

2.7. Rabbit Lake Pit

The Rabbit Lake pit was the first of the third generation tailings system and was the first licensed storage of uranium mill tailings below the water table. It was an innovative approach that incorporated a pervious filter surrounding the pit with a full water recovery system that allowed complete containment during operations. In the long term, diffusion rather than advective flow would control solute migration from the pit. More than 3.6 million tonnes of tailings have been deposited (Donohue, 2000) as thickened slurry. Typical pervious surround details are shown in Fig. 11, which illustrates tailings placement and water control systems. At the time of decommissioning, a soil cover will be placed over the tailings mass and the pit flooded.

A comprehensive evaluation of the Rabbit Lake pit has been completed (Nixon and Holl, 1998). Evidence of segregation and frozen tailings was detected. The impact of the frozen zones on decommissioning is yet to determined, but alternative schemes of water cover and soil cover have been considered.

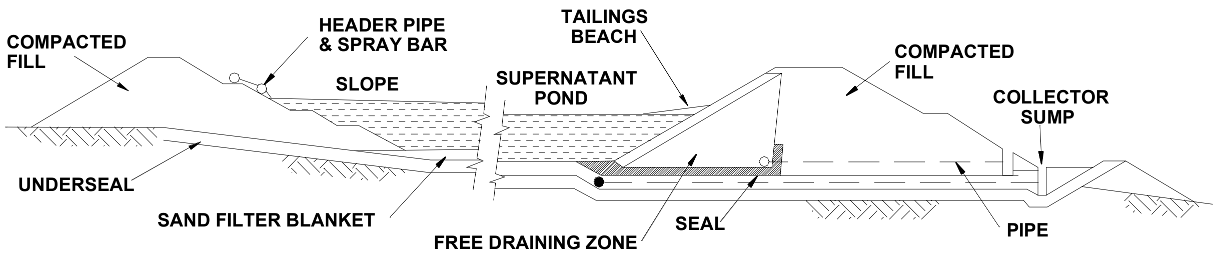

FIG. 10. Cross Section of Key Lake tailings management facility.

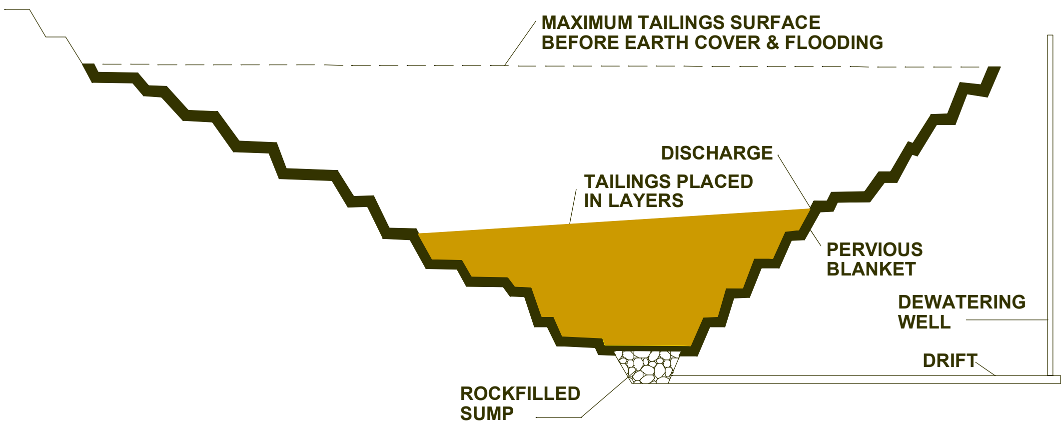

FIG. 11. Cross section of Rabbit Lake pervious surround tailings management system.

2.8. Key Lake: Dielmann Pit

A typical section through the Dielmann Pit tailings scheme is included as Fig. 12. This scheme, licensed in 1996, includes the pervious surround elements of the Rabbit Lake tailings management facility, in the deepest portion of the pit, but not in the upper sections. The proposal for decommissioning is to cover the tailings mass with a sand/till blanket and flood the pit with approximately sixty meters of water cover.

2.9. McLean Lake: JEB Pit

The JEB Pit, as shown in Fig. 13, is located in close proximity to a series of lakes with very high ambient quality water. Nonetheless, engineering analysis determined that environmental quality standards could be met using natural geologic barriers surrounding the pit, combined with careful process control to regulate the chemical quality of the tailings, thereby governing the long term geochemical interaction that will take place between the tailings and the surrounding environment. Process controls were established to minimize the solubility of arsenic, thereby reducing the source term in the tailings porewater to levels substantially lower than would be achieved without tailings conditioning.

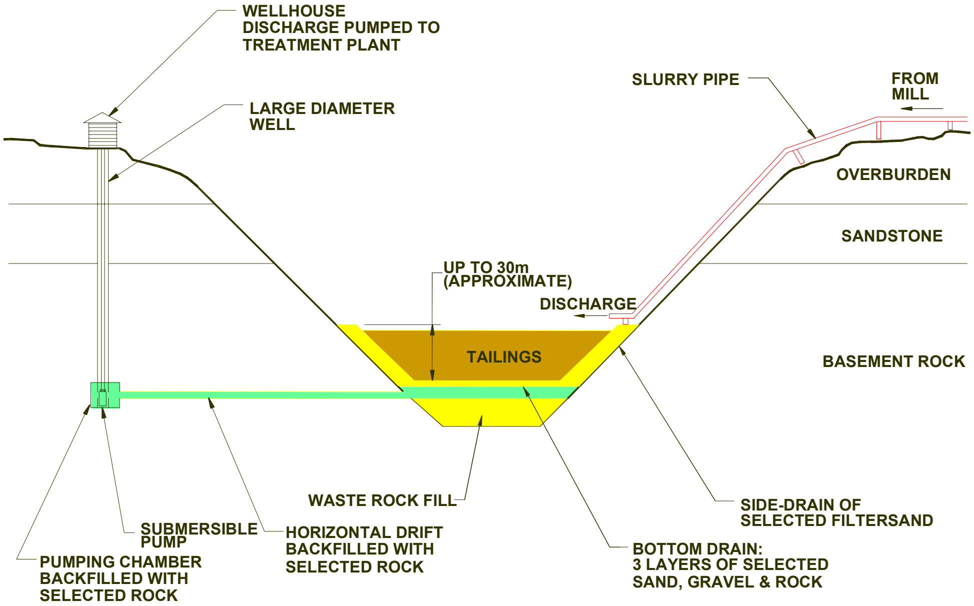

FIG. 12. Section through Key Lake, Dielmann Pit pervious surround tailings management system.

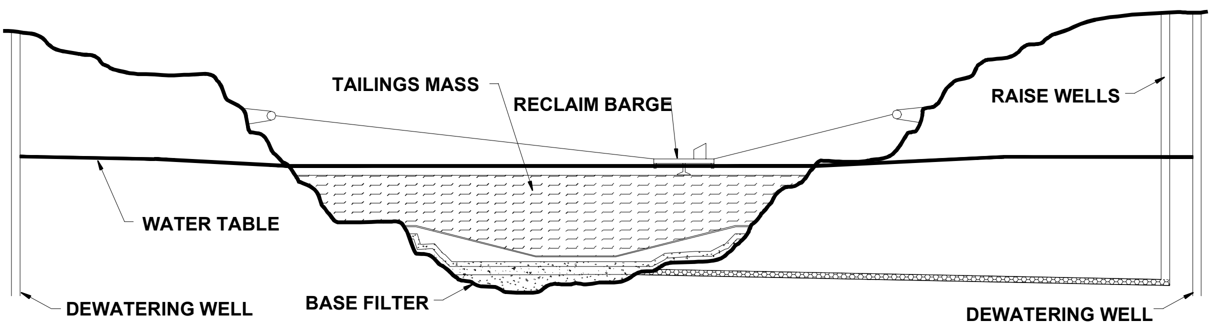

FIG. 13. Section thorough JEB Pit pervious surround tailings management facility.

The JEB Pit TMF will accommodate 15 years of production and be decommissioned by placing a thick soil and rock cover to consolidate the tailings leaving them as a low permeability mass surrounded by an active groundwater flow system through fractured sandstone.

3. PUBLIC ATTITUDES

Public protest, blockades and political dissent defined public attitudes toward further development of Saskatchewan uranium resources in the 1970's. Orphan sites, uncontrolled discharges and polluted surface water, were the legacy of the early mining operations. Little attention had been paid to environmental issues or waste management.

In response to public concerns, the Saskatchewan government appointed the Cluff Lake Board of Inquiry in 1977, under Justice Ed Bayda. Its mandate was to review proposals for a uranium mine in the Cluff Lake area and to advise on conditions under which the industry may proceed. Following the report of the Cluff Lake Board of Inquiry in 1998, the Mines Pollution Control Branch of Saskatchewan Environment and Resource Management was established in 1979 to ensure environmental protection at uranium mine sites. A second Board of Inquiry was established in 1979 to consider the Key Lake proposal. Other panels have been established including a joint federal-provincial panel in uranium mining in northern Saskatchewan, established in 1991 to consider five uranium mines and make recommendations with respect to their development.

Each inquiry or panel has resulted in new regulatory initiatives. Public input focused on key environmental quality issues while transparency was added to the regulatory processes. In addition, involvement of the local communities increased, through creation of Environmental Quality Committees, which provide direct oversight and liaison with residents in the mining region. A combination of progressively more stringent regulation, improved transparency, improved socio-economic conditions and focus on community participation has changed public attitude from distrust and opposition to participation and support. A key component in gaining this trust was emphasis on planned decommissioning to ensure long term safety and security of the waste management facilities.

4. CONCLUSION

Uranium mining started in Saskatchewan 47 years ago with a focus on low-grade deposits. Prior to 1977, the emphasis was on exploitation of the ore body and recovery of uranium. Tailings management was not considered and mine sites were simply abandoned when the ore body was depleted.

Comprehensive environmental regulations were first instituted in 1979 in an effort to build public confidence and to allow mining to proceed. Regulation has proceeded with improved technology, greater public participation and transparency. Regulatory emphasis has been on decommissioning and long term environmental safety.

Four distinct stages of tailings development have been noted in Saskatchewan uranium mines. The first stage began with uncontrolled discharge prior to 1977. The second generation included engineered surface facilities above the water table. The third generation included engineered pit disposal below the water table, incorporating the pervious surround system. The fourth generation facilities included natural geologic barriers and conditioning of tailings to control porewater chemistry, thereby reducing long term solute migration.

Considerable innovation has been applied to solving environmental issues related to uranium mill tailings management in Saskatchewan. Through a combination of careful operations, improved technology and rigorous engineering, a progressively greater degree of environmental protection has been delivered, even though ore grades and milling complexity have increased dramatically.

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Experience with water treatment and restoration technologies during and after uranium mining

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Abstract. DIAMO, state owned enterprise, has a wide experience in uranium mining with the use of classical deep mining, acid in situ leaching and uranium ore processing. The sandstone deposits in Straz block have been exploited since 1968. Geological and hydrogeological conditions of the deposits and the short distance between the deep mine and ISL wellfields requires pumping huge amounts of fresh and/or acid mine water, their treatment and subsequent discharge into streams. DIAMO developed and applied several technologies for different types of wastewater treatment from the start of mining. Practically all of these technologies are used in the current phase of uranium deposit restoration after mining. It is possible to apply these technologies both in the production phase and during the restoration of underground water. In some cases, it is very desirable to combine two or several of them.

1. INTRODUCTION

Since the late 60s, the DIAMO Uranium Mines in Czech Republic has used the in situ leaching (ISL) method along with traditional underground mining. Uranium deposits in the Straz block are found in Cretaceous sediments. Sediment layers consist mostly of sandstone and are located in two aquifers, which have separate geological and hydrogeological conditions. The uranium mineralization occurs in the bottom of the lower Cenomanian aquifer. The upper Turonian formation is a very important source of drinking water.

The operation of both mining technologies within a relatively small area requires pumping huge amounts of underground water, which contain certain impurities. It is necessary to clean this water before discharge to the river. The main types of water that require appropriate treatment technologies are the following:

- Neutral mine water that is pumped from the deep mine area, partly from a system of wells and partly from the mine drainage system. It contains radioactive elements and solid particles;
- Weakly acid water from ISL horizontal dispersion that is pumped from the mine drainage system. It is diluted leaching solution, containing sulphuric acid and products of the leaching process;
- Weakly acid water from ISL vertical dispersion that is pumped from contaminated parts of the Turonian aquifer. Its composition is very similar to the previous type;
- Technological water collected from the mill tailings pond. This water is the product of carbonate leaching of ores in the milling plant. The excess water is treated and discharged.

Strong acid solutions from ISL wellfields are the product of ISL operations. Cleaning these solutions is the most critical current problem. These very contaminated solutions can be treated only by a combination of treatment technologies.

2. NEUTRAL MINE WATER PUMPED FROM THE DEEP MINE AREA

The treatment technology for this water consists of sedimentation, flocculation, clarifying, filtration, ion exchange and sludge processing. The sludge from sedimentation and clarifying is thickened and deposited. The clear water is discharged into a stream.

The Central Decontamination Station (CDS) facility consists of two parallel lines. One of them includes an ion exchange operation for uranium separation. Treatment in the present CDS station is the final step in the mine water treatment process.

Water from the collection pipelines, is brought into two input rooms. The steam is then divided according to the uranium content in water. Another important criterion is the content of total dissolved solids (TDS). Barium chloride is added to both steams to separate the Ra from water. Radium co-precipitate into the crystal lattice of barium sulphate to form $Ba(Ra)SO_4$.

$$Ba^{2+} + (Ra) + SO_4^{2-} = Ba(Ra)SO_4$$

2.1. Accumulation and sedimentation

Maintaining a stable input to both treatment lines is the main aim of accumulation. Blending the streams also makes the quality more uniform. The highest amount of non-dissolved solids is separated during the accumulation because of very slow flow in the accumulation ponds. Five concrete ponds, which can be connected in different ways, are used for accumulation and sedimentation.

2.2. Flocculation

Fine colloidal particles, which do not separate by gravity in the sedimentation ponds must be coagulated processed before the next sedimentation. Hydrolysis of ferric sulphate $Fe_2(SO_4)_3$ gives ferric hydroxide:

$$Fe^{3+} + 3\ H_2O = Fe(OH)_3 + 3\ H^+$$

This hydroxide is insoluble and its precipitate has a positive charge. The fine colloidal particles with negative charge are adsorbed on its surface and bigger particles form. The level of coagulation depends on many factors; pH is one of them and it is also important for separation of heavy metals (Zn, Ni, Mn). These metals are separated in the form of hydroxides, carbonates and complex compounds. The pH is adjusted by the addition of $Ca(OH)_2$ before flocculation. Flocculation is carried out in cylindrical flocculation, tanks, which are divided by horizontal partitions with a stirrer in every section. Two parallel flocculation tanks are installed in every line and the number in use depends on the amount of water being treated.

2.3. Clarifying

Water from flocculation chambers enters the clarifiers. They provide continuous separation of suspended particles from water using principle of a floating sludge cloud. The floating sludge cloud is maintained by special built-in ring sludge tanks located on the inner circumference of the clarifier. Organic flocculent is added to improve clarification. Chain molecules of this flocculent absorb particles and create agglomerates. The clarifying process is accomplished by three clarifiers (1000 m^3 each) in every line. The number of clarifiers on stream depends on the amount of processed water. The piston rising rate in clarifiers must be less than 1.23 $mm \cdot s^{-1}$.

2.4. Filtration

Water from the clarifiers contains a small amount of solid particles that are separated on sand filters. The set of filters consists of 12 DDF filters (diameter 5000 mm), which are grouped into four sections with three filters each. Every section is able to work separately for both types of water.

2.5. Ion exchange station

The line processing water containing higher uranium content includes an ion exchange station operation. The ion exchange cycle incorporate the following operations: sorption — anion resin washing before elution — elution — anion resin washing after elution.

Uranium in the mine water is present as a complex anion form ($[UO_2(SO_4)_2]^{2-}$, $[UO_2(CO_3)_2]^{2-}$). Therefore, it is absorbed by on strongly basic anion resin AMP. This operation is carried out in fixed bed columns with resin volumes of 9 m^3. The Q_{max} space velocity is 30 $m^3 \cdot m^{-3}$ per hour. The sorption cycle time in every column is limited by sorption capacity, which depends on average uranium content in the water. The eluting agent is a solution containing 100 $kg \cdot m^{-3}$ NaCl and 10 $kg \cdot m^{-3}$ Na_2CO_3. The eluate is precipitated by NaOH. The $Na_2U_2O_7$ product is processed in the ISL chemical station.

2.6. Sludge processing

The sludge from sedimentation ponds and clarifiers is thickened in settling tanks and then fed to a filter press. The cake is deposited and filtrate is returned into the technological process.

2.7. Technical parameters

The output of each CDS line is 25 $m^3 \cdot min^{-1}$ of treated water. At present the feed rate is about 20 $m^3 \cdot min^{-1}$, and the average content of the main contaminants in feed is as follows:

	TDS	**SO_4^{2-}**	**NH_4^+**	**U**	**Ra**
		[$g \cdot m^{-3}$]			[$kBq \cdot m^{-3}$]
Type 1	600	370	2.0	1.6	27
Type 2	150	27	0.25	0.005	10

3. WEAK ACID WATER FROM ISL HORIZONTAL DISPERSION

This type of water is treated by neutralization with lime. The solid phase is thickened and deposited. The liquid phase is discharged after minimal additional treatment or is further treated in the CDS system. The main contaminants are uranium, radium, ammonia, heavy metals (Ni, Zn, Mn) and free sulphuric acid. The treatment of this type of acid water is based on neutralization by lime.

The sorption of uranium is carried out before the lime treatment. Subsequent technological operations ensure the elimination of ammonia, the precipitation of Ra and the separation of heavy metals in the form of insoluble precipitates.

The technology uses the following sequential operations:

(a) Neutralization and sedimentation
(b) Chlorination, separation of chlorine remains
(c) Sludge filtration

3.1. Neutralization and sedimentation

Neutralization is performed in two steps. Milk of lime is added to raise the pH to 6–7 in the first step. At the same time Ra is precipitated using $BaCl_2$ to form insoluble $Ba(Ra)SO_4$. Next additional lime is added to raise the pH = 11.5–12.0. The control of this operation has the main influence on the quality of following sedimentation and also on the filtration characteristics of the sludge. The precipitation conditions also determine the degree of heavy metals (A1, Fe, Zn, Mn, Ni) removal. The mixture of

sludge and water is separated in sedimentation tanks. A flocculent is added to improve sedimentation. The clear solution from both steps is pumped into a collection tank before chlorination.

3.2. Chlorination, separation of chlorine remains

Reaction of ammonia ion oxidation into gaseous nitrogen is described by the following equation:

$$3\ Cl_2 + 2\ NH_4^+ + 8\ OH^- = N_2 + 6\ Cl^- + 8\ H_2O$$

The basic condition for complete oxidation of the ammonium ions requires at least a stoichiometric ratio of chlorine and hydroxyl ions to the ammonium ions in solution. If this ratio is not fulfilled, the reaction does not go to completion and the resulting solution is a mixture of input and reaction agents. Resulting chloramines pass reversibly into NH_4^- ions and these ions cannot be technologically removed. Therefore an over-stoichiometric amount of Cl_2 (1.05–1.10) is added. The resulting hypochlorite is removed without greater technological problems using a dechlorination agent such as Na_2SO_3.

$$3\ Cl_2 + OH^- = 3\ ClO^- + 3\ Cl^- + 3\ H_2O$$

$$ClO^- + SO_3^{2-} = Cl^- + SO_4^{2-}$$

Chlorination is carried out by adding gaseous chlorine into the throughflow reactor. In view of the fact, that the outgoing mine water flow contains TDS, SO_4^{2-}, Cl^-, Ra contaminants and suspended solids, it is combined with neutral mine water for final treatment.

3.3. Sludge filtration

Sludge from sedimentation tanks is fed to a filter press and the cake (cca 30% of solids) is transported to the Straz mill plant tailings pond.

3.4. Technical parameters

The capacity of NDS is 6 $m^3 \cdot min^{-1}$ of treated water with content of TDS up to 10 000 $g \cdot m^{-3}$. At present it is working with a feed rate of 2.5 $m^3 \cdot min^{-1}$ and the average content of main contaminants in feed is as follows:

TDS	**SO_4^{2-}**	**NH_4^+**	**U**	**Ra**
	$[g \cdot m^{-3}]$			$[kBq \cdot m^{-3}]$
5350	3400	75	0.2	28

4. WEAK ACID WATER FROM ISL VERTICAL DISPERSION

Membrane electrolysis technology with reversation (EDR) is applied for the treatment of this solution. The diluate is discharged and the concentrate can be treated together with the strong acid solutions or the weakly acid solutions from ISL horizontal dispersion. The process can be divided into three steps:

(1) water pre-treatment
(2) electrodialysis with reversation
(3) diluate final cleaning

4.1. Water pre-treatment

The membrane technologies require complete separation of all solid particles from the feed. These particles can lead to a significant decrease of membrane function. The removal of solids is achieved by filtration on double-layer pressure filters and after that by filtration on cartridge filters.

4.2. Electrodialysis with reversation

The apparatus consists of sequential anionic and cationic membranes mounted in a frame between the electrodes. Several individual cells are connected to form two units. These units work in series with counter-current flow. The electrode polarity changes automatically after 15–30 minutes. Simultaneously, the input and output valves also switch. The change of individual chamber function results from this reversation. The main advantages of this system are as follows:

- minimizing of precipitate formation on the membrane surface,
- self-cleaning of the electrodes with the help of acid, which is produced during anodic operation.

4.3. Diluate final cleaning

The diluate from EDR is neutralized by addition of a 20% NaOH solution. It is then pumped into multi-plate settlers to separate the precipitated ferric and aluminium hydroxides. The thickened solids are filtrated on a filter press and deposited. The clean diluate is discharged into a stream.

4.4. Technical parameters

The capacity of EDR circuit is 2 $m^3 \cdot min^{-1}$ of treated water with TDS contents up to 3000 $g \cdot m^{-3}$ and a concentration factor CF = 4.0. At present 1.0 $m^3 \cdot min^{-1}$ is being treated. The average content of the main contaminants in feed is as follows:

TDS	**SO_4^{2-}**	**NH_4^+**	**U**	**Al**	**Fe**	**Ca**	**NO_3^-**	**Ra**
			[$g \cdot m^{-3}$]					[$Bq \cdot m^{-3}$]
960	650	28	0.1	32	3	140	30	30

5. TECHNOLOGICAL WATER FROM MILLING PLANT TAILINGS POND

The milling plant GEAM in Dolni Rozinka has been operating since 1968. The technology is based on carbonate leaching and the uranium is separated by ion exchange on anionic resin. The original project design envisioned a closed water circuit with a small water deficiency. This target was never fulfilled and there is an annual water surplus of about 300 000 m^3. The water is accumulated in tailings ponds and is partially recycled to the mill. The need to solve this problem has increased yearly. The remediation technology selected uses a combination of water pre-treatment, electrodialysis (ED) and thermal thickening (evaporation). Crystalline Na_2SO_4 is produced from the concentrated solution and sold for use in detergent production (see Fig. 1)

5.1. Water pre-treatment

Precipitation of Ca and Mg with NaOH and $NaCO_3$ is the first step of the water pre-treatment operation. Precipitated solids are separated in sedimentation tanks. Part of water is then fed to the accumulation tank and the remaining part to the electrodialysis unit.

5.2. Electrodialysis (ED)

ED requires complete removal of suspended solids and heavy metals, so the water is filtrated on sand filters. After acidification heavy metals (especially Mo, U and Cu) are sorbed on ion exchange resin Lewatit TP 207.

The next operation is coagulation with $Fe_2(SO_4)_3$ and filtration.

— After the pH adjusted to less than 2.5, the solution is fed to the ED unit, where countercurrent flow of diluate and concentrate occurs. The diluate is discharged into a stream and the concentrate is fed to the accumulation tank, which serves as a source of constant feed to the evaporation system. The pre-treated water, ED concentrate and the solution overbalance from ion exchange circuit are mixed and collected in the accumulation tank. The capacity of electrodialysis unit is about 12 m^3 treated water per hour, producing 9 m^3 of diluate and 3 m^3 of concentrate.

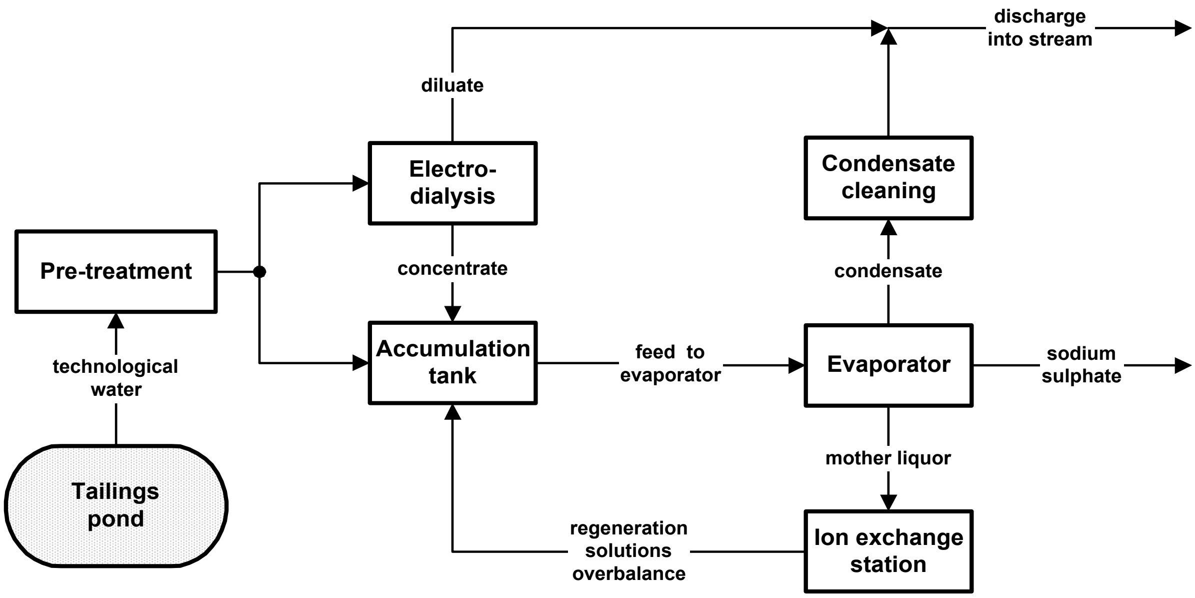

FIG. 1. Technological scheme of GEAM water treatment.

5.3. Evaporation

The evaporation system consists of eight evaporators connected in series. The last two evaporators work as both evaporators and crystallizers. The crystals of Na_2SO_4 are separated in a centrifuge and dried. Ammonia is cleaned form the condensate by desorption and then discharged into a stream.

The capacity of the evaporation unit is about 40 m^3 of treated water per hour; the annual production of Na_2SO_4 is 6000 t.

5.4. Technical parameters

The GEAM treatment system produces about 50 m^3 per hour of treated tailings water. The average concentration of main contaminants in feed solution is as follows:

pH	TDS	SO_4^{2-}	NO_3^-	Na	U	Ra
		[$g \cdot m^{-3}$]				[$Bq \cdot m^{-3}$]
7.9	26000	15000	600	7100	14	520

6. STRONG ACID SOLUTION FROM ISL WELLFIELDS

The treatment of this type of solution is the main problem of ISL mine restoration. The contaminated underground water contains up to 80 000 $g.m^{-3}$ of TDS, of which about 10 000 $g.m^{-3}$ is free sulphuric acid. Based on the chemical composition of these solutions it was decided to use a combination of treatment operations for salts removal. The Station for acid solutions treatment (SLKR) complex consists of the following units (see Fig. 2):

(a) Evaporation
(b) Crystallization and recrystallization of ammonium aluminium sulphate (alum)
(c) Reprocessing of alum to aluminium compounds
(d) Treatment of mother liquor

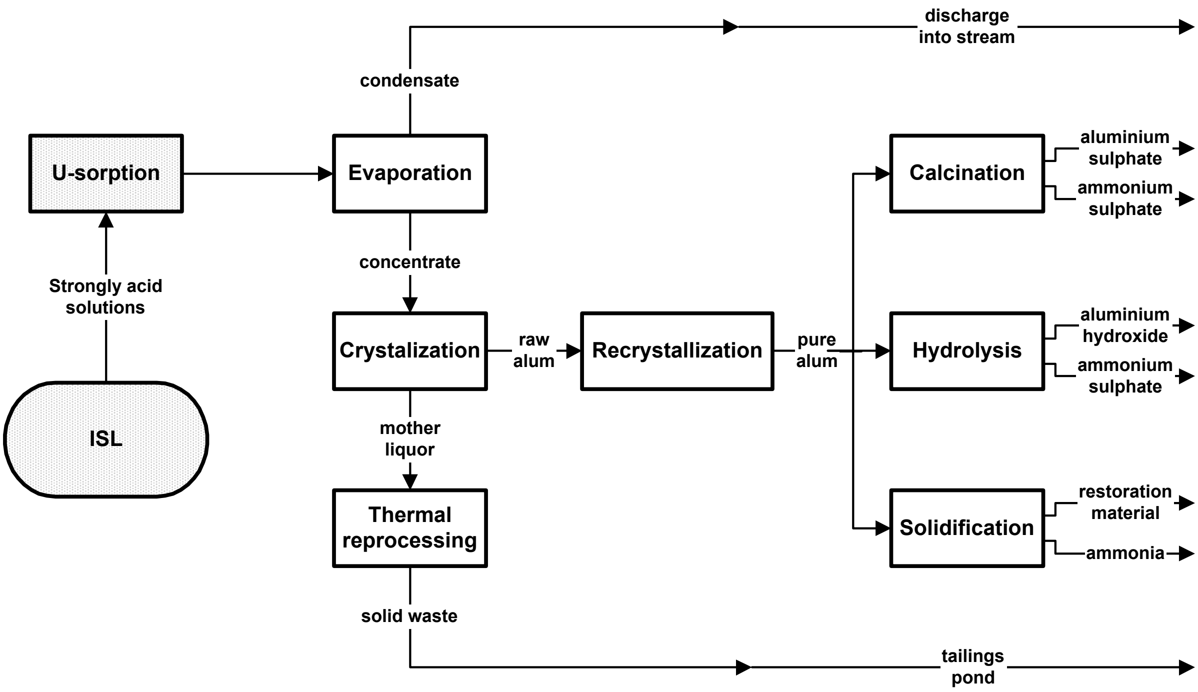

FIG. 2. Technological scheme of SLKR complex.

6.1. Evaporation

The feed is pumped through three in parallel plate and frame heat exchangers that recover sensible heat from the hot distillate. This raises the feed temperature to near boiling. The feed is then sent to a parallel arrangement of three falling film vapour compression evaporators. Each evaporator consists of a condenser and a sump. The condenser contains vertical heat transfer tubes within in a shell. The dilute feed is fed to the sump, where it combines with the concentrated recirculating liquid from the evaporator. The concentrated liquid is pumped to the floodbox at the top of the condenser. From there it is distributed evenly to the inside of each vertical tube, using patented flow distributors. A small portion of the liquid evaporates as it flows in a thin film down the tubes. The vapour exiting the tubes passes through mist eliminators on its way to the compressor. The vapour is slightly compressed to raise its temperature of condensation above the boiling point of the liquid inside the tubes. The steam then enters the shell side of the condenser, where it condenses on outside of the tubes, giving up its latent heat to the liquid falling inside the tubes. The resulting distillate is collected at the bottom of the condenser and after a pH adjustment it is discharged into the stream.

6.2. Crystallization and recrystallization of alum

A portion of the concentrated solution being recirculated in each evaporator is discharged and collected in the crystallization feed tank. This solution is combined with a solution of ammonium sulphate sufficient to make a stoichiometric solution of ammonium aluminium sulphate (alum), $NH_4Al(SO_4)_2.12H_2O$.

The concentrate is cooled by flashing the hot solution in two progressively lower pressure flash coolers, producing a large amount of alum crystals. Since solubility of this salt is strongly affected by temperature, crystals are precipitated by cooling the solution rather than purely by continued evaporation. Since the solution has been concentrated by evaporation at atmospheric pressure, the flash vessels are provided to keep the size of the equipment manageable. Multiple vessels also allow flashing at more than one pressure, which makes it easier to reuse flash steam and allows the design of an efficient vacuum system.

A wide bustle has been added at the top of the second flash cooler sump to provide a clarification zone where crystals may separate by gravity from the mother liquor. Clear liquor is removed from the process at this point and collected in a tank for the next treatment.

The raw crystals from crystallization are filtered and washed with clean distillate using centrifuges and then fed to the recrystallizer. The filtrate and various wash streams are returned to crystallization to improve recovery of ammonium alum.

The raw crystals from the crystallizer area are re-slurried with liquor from the recrystallizers' area and distillate from the evaporator system plus seal water purge from the vacuum pump. The slurry is then heated in two stages by direct contact with flash steam.

This mother liquor is then passed through a clarifier to remove sediments and insolubles. A filter press removes the solubles from the clarifier underflow sludge before disposal. Any remaining suspended solids in the clarate are removed by multimedia filters and cartridge filters. The filtered liquor then enters an electrochemical reduction system where ferric iron is reduced to ferrous iron. This treatment reduces iron impurity in the recrystallized solids. Much higher purity ammonium aluminium sulphate now crystallizes out of the purified mother liquor. These purified crystals are washed with clean distillate in dual/parallel centrifuges.

6.3. Reprocessing of alum to aluminium compounds

The products of crystallization are practically wastes unless further reprocessed; it was necessary to develop procedures for their conversion to commercial products or into products, which could be safely deposited in the environment.

Three technologies for decomposition of ammonium aluminium sulphate were developed in DIAMO and they are in the stage of verification and design at present:

(1) The calcination of ammonium aluminium sulphate proceeds as per the following equation:

$$2\ (NH_4)\ Al(SO_4)_2.12\ H_2O = Al_2(SO_4)_3 + (NH_4)_2SO_4 + 24\ H_2O$$

The capacity of the plant will be 60 000 t annually of reprocessed alum with production of about 20 000 t per year of $Al_2(SO_4)_3$ plus 8000 t per year of $(NH_4)_2SO_4$ for use in alum crystallization.

Operations will start in 2001, with full production capacity in 2003.

(2) The decomposition of ammonium aluminium sulphate by means of ammonia under atmospheric conditions with production of $Al(OH)_3$ proceeds as per the following equation:

$$(NH_4)\,Al(SO_4)_2.12\,H_2O + 3\,(NH_4)OH = Al(OH)_3 + 2\,(NH_4)_2SO_4 + 12\,H_2O$$

The capacity of the plant will be 100 000 t annually of reprocessed alum with production of about 30 000 t per year of $Al(OH)_3$, plus 58 000 t per year of $(NH_4)_2SO_4$, for use in fertilizer production. The projected start up date is 2004.

(3) The third option is production of remediation materials for use by DIAMO in reclaiming mud pits.

The capacity of the plant will be 30 000 t annually of reprocessed alum with the production of 40 000 per year of remediation materials plus 1000 t per year of NH_3 for use in alum crystallization or $Al(OH)_3$ production. Start up is expected in 2002·

6.4. Treatment of mother liquor

Treatment of the mother liquor seeks to minimize the production of solid wastes. The planned operation includes three stages of evaporation, crystallization and separation of solids. The solid wastes will be solidified or vitrified before deposition. The remaining liquid will be dried and the resulting solids will be calcinated. The solid products will be deposited in the Straz mill waste pond. The start of operation is planned for 2008.

6.5. Technical parameters

The capacity of the SLRK evaporation is 6.5 $m^3{\cdot}min^{-1}$ of treated water with a concentration factor of CF = 6.5. At present the evaporators are working at a feed rate of 6.5 $m^3{\cdot}min^{-1}$ and the CF = 5.5. The average concentrations of the main contaminants in the strongly acid solutions is as follows:

TDS	**SO_4^{2-}**	**NH_4^+**	**U**	**Al**	**Fe**	**Ca**	**NO_3^-**	**F^-**	**H_2SO_4**	**Ra**
				[$g{\cdot}m^{-3}$]						[$Bq{\cdot}m^{-3}$]
55000	36000	800	<1.0	4900	1500	2600	900	150	7000	30

7. SUMMARY

The above mentioned technologies cover the required water treatment for a wide range of contaminant types and concentrations. All these methods were developed gradually and upgraded during operations. The optimal conditions for their application and the functional limits were established and put into operation.

The application of water treatment technologies during mining activities is essential to fulfil the water discharge regulatory requirements and also to establish better conditions for the decommissioning and reclamation of uranium mines. Any delay in beginning initiating contaminant and water surplus removal can significantly complicate restoration. Water leakage and contaminant dispersion outside the boundary of the mining area produces unfavourable conditions for underground restoration.

DIAMO must now solve a complicated problem that results from the close proximity of deep mining and ISL operations in the sedimentary deposits of the Northbohemian Cretaceous. The restoration project has taken advantages of the operational experience with different water treatment methods. The appropriate use of individual technologies and the optimization of various flow sheet combinations should result in shorter restoration periods and cost reductions.

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Mine water treatment with yellowcake by-production

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Abstract. Mining and milling of uranium ore in Hungary was terminated at the end of 1997. From that time rehabilitation works have been carrying out, which include manly the relocation of different solid wastes, such as waste rocks, heap leached residues, demolishing of former industrial buildings, clean up contaminated sites. Overall rehabilitation of the tailings ponds has also started. At first step the ground water restoration system is under construction, aiming at protecting the drinking water aquifer situated in the immediate vicinity of the tailings ponds. Former mining activity has been carried out also in the vicinity of the drinking water catchment area, for protection of that is compulsory to maintain appropriate depression in the mine in question. This means that mine water has to be pumped out continuously and because of the elevated uranium concentration in mine water, the water has to be treated. Thus the water quality protection is connected with uranium removal from the mine water. Mine water treatment process developed is based on anion-exchange process and removal of the uranium from the eluates with hydrogen peroxide.

1. HISTORICAL OVERVIEW ON THE MINING AND PROCESSING ACTIVITY

Exploration of uranium ore started in Hungary in 1953. Soon after first air gamma measurements it became clear that near the town Pécs significance uranium deposit is situated. After intensive exploration works in 1954 a company was established and at the end of the fifties mining activity started.

During operation period about 46.8 million tons of rock has been removed from 5 shafts situated on the same mining district.

From the mined out rock 18 million tonnes as waste rock (U< 100 g/t) was placed on 10 waste rock piles (some of them were small). 7.2 million tons of low-grade ore (U=100-300 g/t) after crushing to -30 mm was treated by alkaline heap leaching on isolated area. Almost 19 million tons of ore (U=1000 g/t) was processed in the conventional mill built in 1962, using sulphuric acid for leaching.

During the mining activity approximately 64-million m^3 mine water was pumped out from the mines, from which about 30 million m^3 mine water were used in the mill.

The neutralised waste pulp from the mill was pumped to the tailings ponds (two tailings ponds were built). Total uranium production from the district was a little more than 20 thousand tons.

2. HYDROLOGIC CONNECTION OF THE MINES WITH DRINKING WATER CATCHMENT AREA

The company had 5 shafts, from which shaft No. 1 has a direct connection with the drinking water aquifer. Therefore even after closing the shaft No. 1 in 1968 for protection of the drinking water aquifer it was prescribed by the authorities to continue water pumping from the mine, for keeping water level in the former mine at 107 m below the surface, assuring appropriate depression around the mining area. This prescription is still in force. This is the reason why the water is still pumped out from the mine even after 32 years of its closing.

3. MINE WATER TREATMENT PROCESS

Composition of mine water is presented in Table 1. It can be seen that the pH of water is neutral, sulphate; bicarbonate, calcium and sodium are the dominant components. Arsenic and other heavy metals are present only in a very small concentration. Radium content is about 0.4 Bq/l, much below the discharge limit (1.1 Bq/l).

Historical data regarding the uranium concentration in mine water and the volume of removed water is presented in Fig. 1. Water has been pumped out from two levels (6th and 11th). It can be seen that the uranium concentration of water reaches 7-10 mg/l, the removed volume of water varies between 2.5–3.5 thousand m^3 per day. The elevated volume of water in the last years is due to the rehabilitation works carried out in the immediate vicinity of the mine (mine cavities has been used as a collecting reservoir for different wastewater).

TABLE I. COMPOSITION OF MINE WATER (1996-99)

pH	Na	K	Ca	Mg	Cl	SO_4	CO_3	HCO_3	TDS	Unat	Ra-226
	mg/l								g/l	mg/l	x10^{-4} Bq/cm^3
7.01	430	14	180	117	174	1066	<10	794	2.44	7.73	4.38

Trace elements

Al	As	B	Ba	Mn	Si	Sr	Se	Cu	Fe
mg/l									
0.118	0.09	0.081	0.070	0.4	71	10	0.041	0.003	0.5

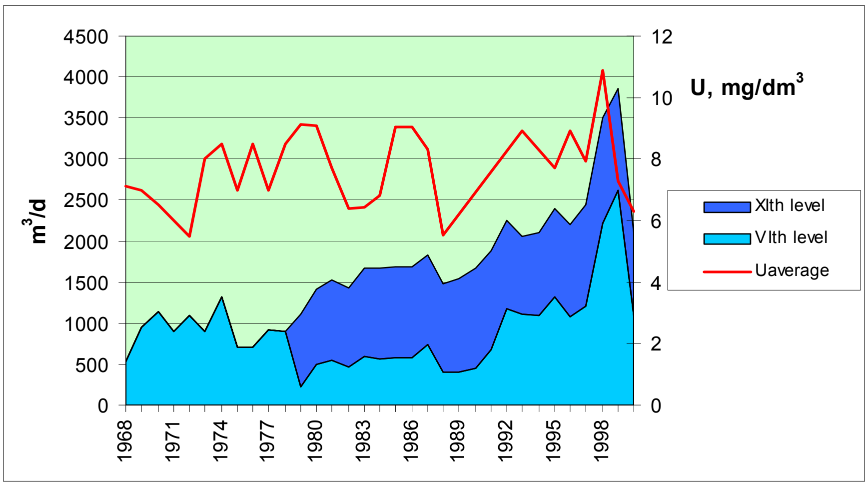

FIG. 1. Historical data.

3.1. Mine water treatment in the period of mill operation

Discharge limit for uranium is 2 mg/l. Because the uranium concentration in mine water is much higher, the uranium must be removed prior to discharge the water into the receiver.

Taking into account the composition of the water, anion exchange method was chosen the treatment. In the mill process Hungarian made anion-exchange resin Varion AP (with pyridine active group) has been used, that is why this type of resin was selected for mine water treatment as well.

For water treatment nine ion-exchange columns (each of them contains 10 m^3 of ion-exchanger) were built on shaft site, from which 6 or 7 of them were in operation. The loaded resin (10-12 gU/l) was transported to a central regeneration station for removing of the uranium. With 1 m^3 of resin approximately 1500 m^3 mine water was treated.

Regeneration was carried out by sodium-chloride solution (80 g/dm^3) containing sodium carbonate (5 g/dm^3). Pregnant solution (10-12 gU/l) was further processed in the mill.

Effectiveness of the ion exchange treatment plant is shown in Figure 2, where the concentration of uranium in the mine water and treated water is presented for the last five years.

It can be seen that the uranium concentration of the treated water decreased very below discharge limit reaching in average 0,7 mgU/l.

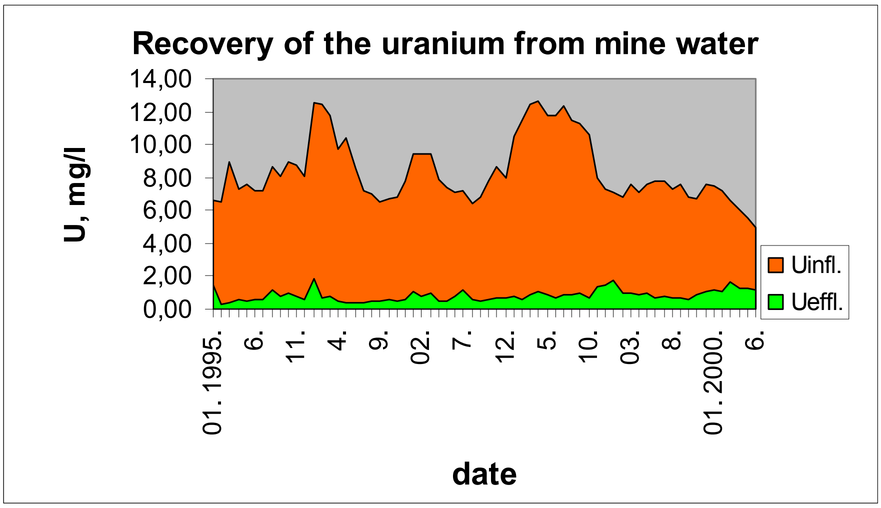

FIG. 2. Recovery of the uranium from mine water.

It is worth to mention that approximately 27 million m^3 of mine water was pumped out up to now and almost 150 t of uranium was removed from the mine water of the shaft.

3.2. Mine water treatment in the post closing period

By terminating the uranium mining the mine water from the shaft No. 1 must be furthermore removed because of high uranium concentration and the above-mentioned hydrological situation. Different options were considered for water treatment for the post-closing period. After all it was decided to keep the same ion exchange process for the water treatment that had been used in the mining period. Reason of that was the still high uranium concentration of mine water.

So for the post-closing period mine water treatment is based on the removal of the uranium by anion exchange process, elution of the loaded resin by sodium-chloride solution containing some g/l of sodium carbonate.

For the further processing of eluate two possible options were evaluated:

- to precipitate the uranium and solidifying and depositing it as a waste,
- to remove the uranium in form of commercial yellow cake.

Taking into account first of all environmental considerations priority was given to the latest option, that is to removal of uranium in form of commercial by-product.

As a matter of fact the ion exchange process is well known for the company so first of all the chemical processes of the further handling of the elutes had to be more deeply investigated and developed.

Precipitation of uranium in the mill earlier was carried out by lime milk. This process has some advantage comparing it with other processes (cheap, environmentally acceptable) but the quality of the yellow cake obtained by this method does not meet the specification requirements of the converters. Therefore a new yellow cake technology had to be developed.

Developing the new water treatment technology some investigations were carried out.

Changing of the pH of the mine water

For having more detail information about the water treatment process the change of the pH of water on different steps of ion-exchange process was investigated. It was observed that the pH of water was increasing during the process. Results of the observation for a given period are presented in Figure 4, where the pH of the original mine water and that of the water living the ion-exchange process are given. The data sow that the pH of the original mine water is a little below 7, but during the ion exchange process its value is increasing approximately to 7.3.

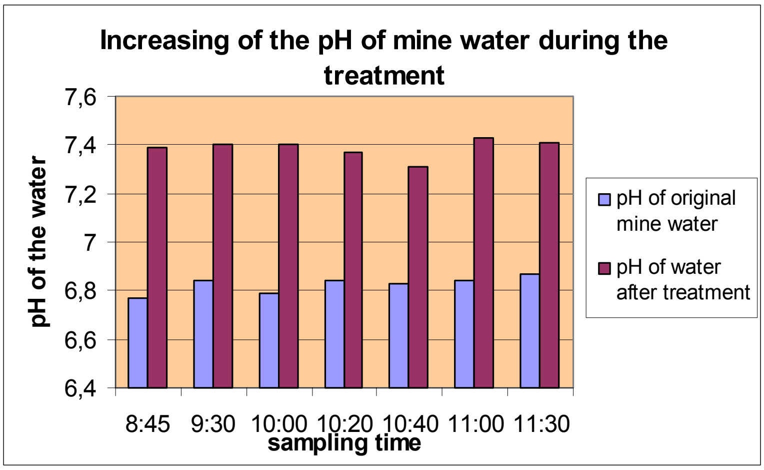

FIG. 3. Increase of the pH of mine water during the treatment.

Precipitate formation during the ion-exchange process

The mine water treatment process is simple but one operation problem should be pointed out. During whole 32 years period of mine water treatment it has been observed a brownish precipitate formation in the treatment system. The precipitate accumulated first of all in the ion-exchange resin bed and on the drainage filter elements. Composition of the precipitate is presented in table Y for main components. It can be seen that the main components are calcium, iron and manganese with an elevated concentration of uranium and arsenic.

TABLE II: AVERAGE COMPOSITION OF THE PRECIPITATE

Component	SiO_2	CaO	MgO	Fe_2O_3	**MnO**	**As_2O_3**	**U**
concentration,	8,8-12,9	8,7-21	0,8	6,7-17,4	3,45-7,1	0,031-0,078	**0,1-0,4**

Investigating the origin of the main components and the elevated arsenic and uranium concentration in the precipitate we come to the conclusion that the precipitate formation in the column is likely connected with the corrosion process in the ion exchange columns and other equipment made of steal.

Uranium is reduced by the zero valent iron and than precipitates. Arsenic also can be reduced and than precipitates by iron corrosion compounds.

This observation sows the importance of the using of corrosion-resistive construction material even when the mine water has pH near to neutral.

Other conclusion that the precipitate formed during the ion exchange process has to be carefully analysed for heavy and toxic metals because these elements can be accumulated in the precipitate even if their content in the mine water is low.

Precipitation of uranium peroxide

One of the key points was the selection of the precipitant for precipitation of uranium from the eluates composition of which is presented in table 3. Investigating different agents after all hydrogen peroxide was selected which precipitate the uranium in form of peroxide:

$$UO_2^{2+} + H_2O_2 + 2\ H_2O = UO_4\ x2H_2O + 2\ H^+$$

TABLE III. COMPOSITION OF THE ELUATE

Component	Concentration g/l
Uranium	10-12
Chloride	14-21
Sulphate	30-40
Sodium bycarbonate	30-40
Sodium carbonate	3-5
pH	8,5-9

Investigating the hydrogen peroxide process it was found that the carbonate complexes of the uranium must be decomposed prior to the precipitation of uranium. For this the eluates have to be acidified by sulphuric ore hydrochloric acid, presumably to pH<3. This operation should be carried out carefully to avoid the foam formation. The pH value of 3.2-3.5 should be maintained during the precipitation by adding sodium hydroxide.

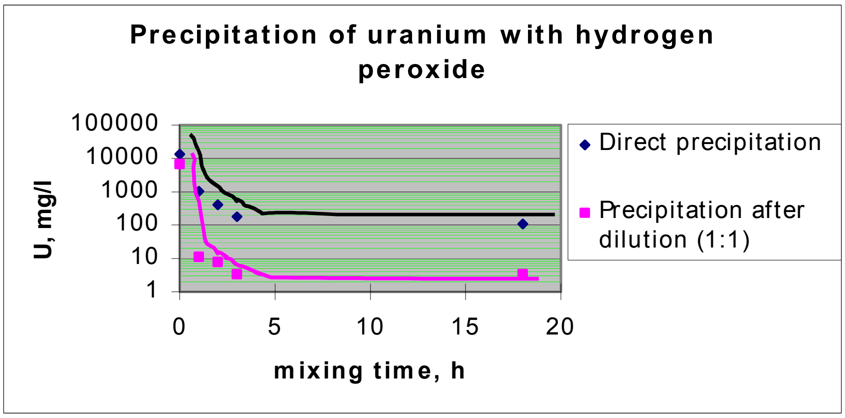

FIG. 4. Precipitation of uranium with hydrogen peroxide.

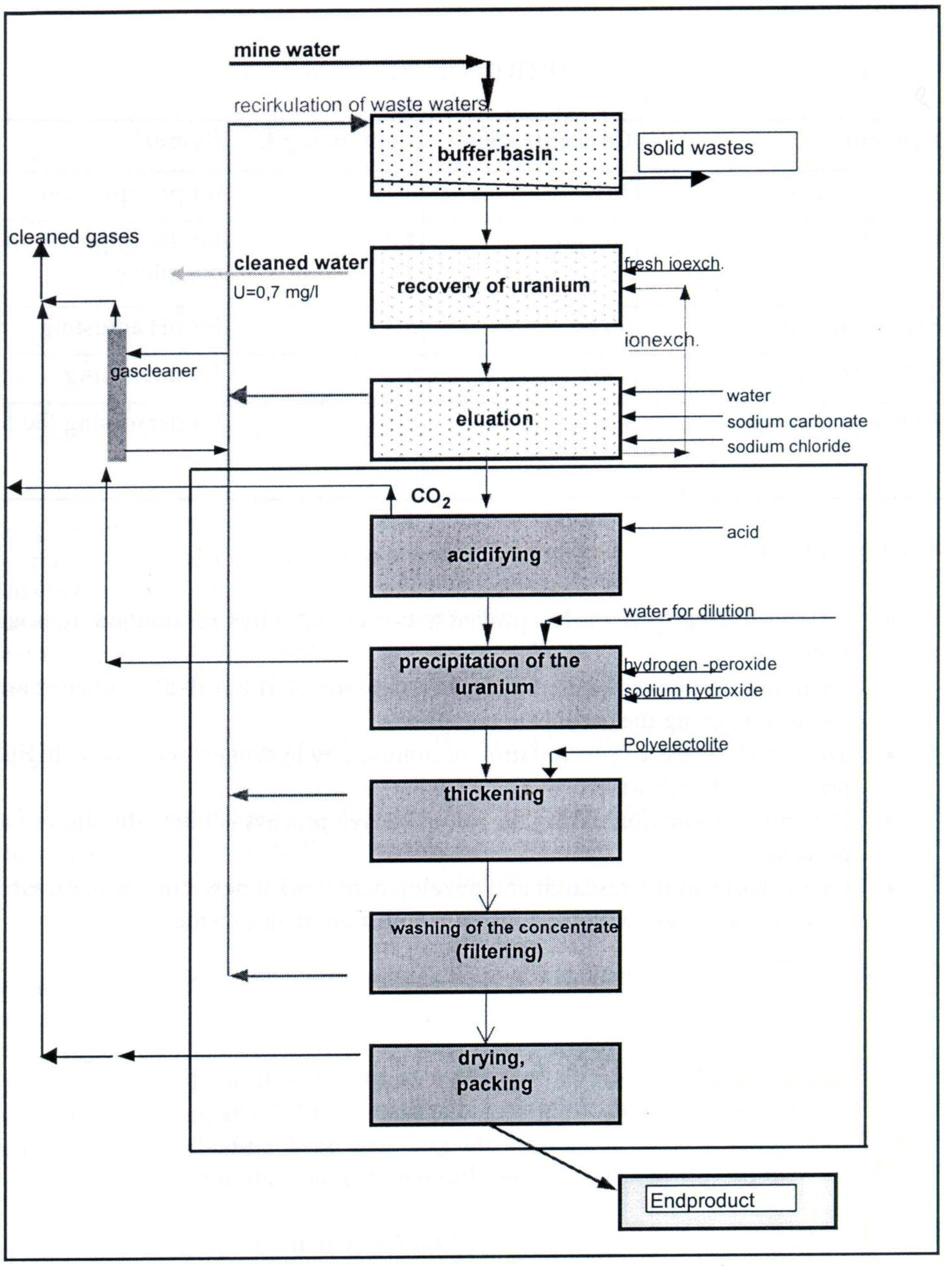

FIG. 5. Mine water treatment (main process units).

It was observed that the acidified eluates should be diluted with water for more complete precipitation of the uranium. Experimental data presented in fig. 4 show that the remained uranium concentration in the mother liquor is much less if the solution is diluted prior to the precipitation of uranium. These results can be explained also by complex formation of uranium with ligands (sulphate, chloride) present in the technological solution.

It should be mentioned that the hydrogen peroxide in the experiments was used in 20% excess to the theoretically needed value.

The precipitation in industrial scale should be carried out at ambient temperature, in continuous mood using four mixing reactors with 3-4 hours retention time and at pH 3.2-3.5.

On the bases of above-mentioned considerations and experimental results principal flow sheet of mine water treatment process was compiled. The process consists of the following main steps.

- Elevating the mine water to the surface by pumping (~110 m)
- Collecting the mine water in basin
- Uranium removal using Varion AP (Hungarian made pyridine-basic) anion exchange resin
- Elution of the loaded resin with sodium chloride solution (80 g/l) containing sodium carbonate (5 g/l)
- Acidifying the eluate for decomposing the carbonate complexes
- Dilution of the solution by water (1:1) Precipitation of the uranium with hydrogen peroxide
- Thickening of the precipitate
- Washing the concentrate for reducing the chloride, sulphate and other impurities
- Drying
- Packing the concentrate into standard drums.

The principal flow sheet of the process is presented in Figure 5.

On the bases of the above-mentioned principal flow sheet a new mine water plant has been built in this year. The plant is suitable for treatment 1.5 million m^3 mine water annually. It is expected that approximately 5-7 t of uranium in form of commercial yellow cake will be obtained as a by product during the water treatment. Composition of the uranium concentrate obtained by the precipitation using hydrogen peroxide meets all standard specifications of the converters. This is due to the low pH of the precipitation (pH 3.2-3.5) and the composition of original eluates.

Uranium content of the dried concentrate is expected to be on the level of 70%.

In Table 4 the planned specific consumption of the different material used in the process are presented.

TABLE IV. SPECIFIC CONSUMPTION OF THE REAGENTS

Reagent	**Concentration**	**Volume /kg U**	**Remark**
Hydrogen peroxide	30%	0.55 l	for precipitation
Acid (HCl)	365 g/l	4.2 l	for decomposing the carbonate complexes
Sodium hydroxide	66 g/l	5.3 l	for pH adjusting
Polielectrolite	3 g/l	0.1 l	for thickening
Anti-foam additive	1 g/l	0.1 l	for decreasing the foam formation

4. CONCLUSION

- Anion exchange process has proved to be very effective for uranium removal from mine water.
- Uranium can be precipitated by hydrogen peroxide if the alkaline eluates are prior neutralised for decomposing the carbonate complexes.

- The effectiveness of precipitation of uranium by hydrogen peroxide is higher if the eluates are prior diluted with water.
- Precipitate formation during the ion-exchange process is likely due first of all to the corrosion process.
- On the bases of the research and development work a new mine water treatment plant is under construction with capacity of 1.5 million m^3/a of water.

Tailings management at COGEMA Resources Inc.'s McClean Lake operation

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Abstract. The new JEB mill at the McClean Lake uranium mining operation commenced production in late June 1999. Some of the ores to be processed by this plant contain significant amounts of arsenic and nickel. Technological innovations and engineering design have been applied to enable these ores to be processed with the prediction of minimal environmental impact in both the short and long term. The Tailings Management Facility (TMF) associated with the mill represents the state of the art in the uranium mining industry for engineered tailings, deposition techniques and control of releases of soluble contaminants. The results of the first year of operation of this new facility are presented with particular emphasis placed on the control of soluble arsenic and nickel concentrations in the final tailings pore water.

1. INTRODUCTION

The world's most recent and modern uranium milling facility is located at the McClean Lake Operation in northeastern Saskatchewan, Canada, see Fig. 1. The McClean Lake Operation is jointly owned by COGEMA Resources Inc. (70%), Denison Mines Ltd. (22.5%) and OURD (7.5%) with COGEMA Resources Inc. as the operator. Mill operation commenced in late June of 1999 and has been operating at or above design production levels since January 2000. In the current configuration, the mill is processing the McClean Lake ore bodies at a current production rate of 6 000 000 lbs U_3O_8 per year. Planning calls for the future processing of ore from the Midwest and Cigar Lake mine sites. The operating life of the milling facility is expected to be approximately 40 years.

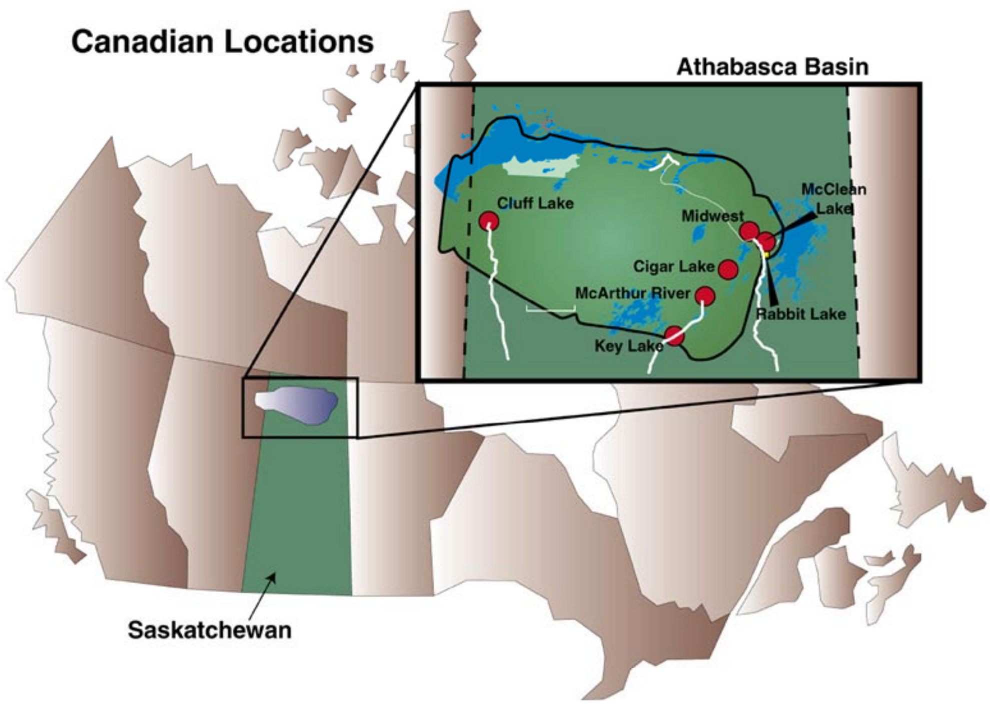

FIG. 1. Uranium production locations in the Athabasca Basin of northern Saskatchewan.

The nearby depleted JEB open pit mine has been re-constructed into the JEB Tailings Management Facility (TMF). The TMF has the capacity to receive about 1.8 million m^3 of tailings from the mill over its operating life. This is adequate for all the ores from the McClean Lake, Midwest and Cigar Lake projects. Adjacent to the TMF is a small lake, Fig. 2, locally known as Fox Lake. Earlier hydrology evaluations had indicated that over the long term (10 000 years) the presence of the placed tailings in the TMF may have a negative impact on the water quality of Fox Lake. The contaminants of concern were arsenic and nickel, which originated in the pore water of the placed tailings. As a result, COGEMA Resources has developed the tailings preparation process in the mill and optimized the design and operation of the TMF to minimize this environmental impact. It is now expected that none of the water quality parameters in Fox Lake will exceed the Saskatchewan Surface Water Quality Objectives over the long term (10 000 years).

This paper presents a summary of the first year of operation, with respect to arsenic and nickel removal from pore water, of this new Tailings Management Facility.

FIG. 2. Ariel photograph of the McClean Lake milling site showing Fox Lake in the foreground followed by the TMF and the ore processing plant.

2. TMF DESIGN

2.1. Post operational requirements

The key issue for the JEB TMF concerned the long-term hydraulic isolation of the tailings materials within the facility. As has been described previously in Ref. [1], two principle design parameters are relied upon for the long-term release of potential contaminants to the ground water flow system. These are physical containment controls and geochemical controls.

The first of these is site specific and involves the physical characteristics of the tailings compared to the local Athabasca sandstone. The tailings as produced during mill operations contain a significant amount of fine-grained materials. Consolidation of these materials produces a tailings mass of very low hydraulic conductivity, approximately two orders of magnitude less than the surrounding sandstone. Under these conditions for the long term, the consolidated tailings represent a relatively

impermeable plug and groundwater flows around the tailings mass. Contaminant release from the tailings pore water, Fig. 3, is then dominated by a slow diffusion process driven by the contaminant concentration gradient between the pore water of the tailings mass and the ground water of the surrounding host rock.

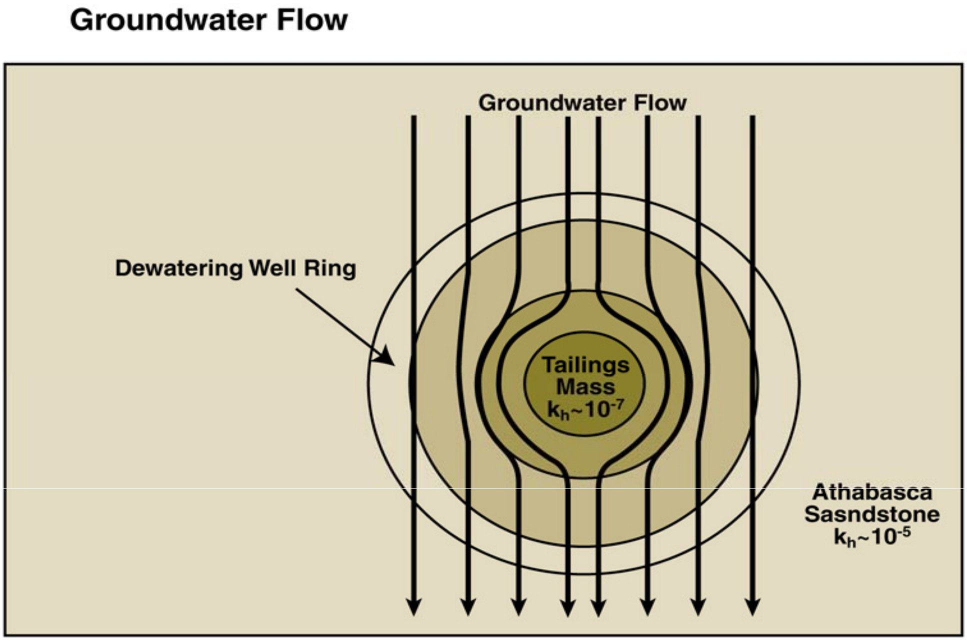

FIG. 3. Plan view depicting the principle physical containment control. Ground water flows through the sandstone and around the relatively impermeable tailings mass.

The second control on contaminant release is the tailings solids chemistry, which is designed to keep the concentrations of contaminants in the tailings pore water at such low levels that releases by the diffusion process over the long term are environmentally acceptable. The elements of arsenic and nickel have been shown to be problematic contaminants. Environmental objectives for these two elements require their concentration not to exceed 5 mg/L over the long term. To facilitate this environmental requirement, an internal operational objective of 1 mg/L has been implemented.

2.2. Operational period

COGEMA Resources has introduced new technology to the tailings preparation circuit in the mill for the long-term control of arsenic and nickel in the tailings pore water. The process is shown in Fig. 4. Total retention time for the neutralization process is approximately 3 hours with 1.5 hours reaction time a pH 4 and 1.5 hours at pH 8. A more detailed description of the process has been published elsewhere Ref [2].

The depleted JEB open pit mine was modified to suit the requirements for the TMF. The top perimeter of the TMF is approximately circular with a diameter of about 420 meters. The natural groundwater level is at or near surface. The total depth is about 118 m, with about 10 m of soil overburden above the sandstone formation. The structure penetrates the contact between the sandstone and the underlying granitic basement rock starting at a depth of about 85 m. To ensure hydraulic containment of tailings pore water during the operating period (40-50 years) a ring of de-watering wells have been installed around the edge of the pit, Fig. 5.

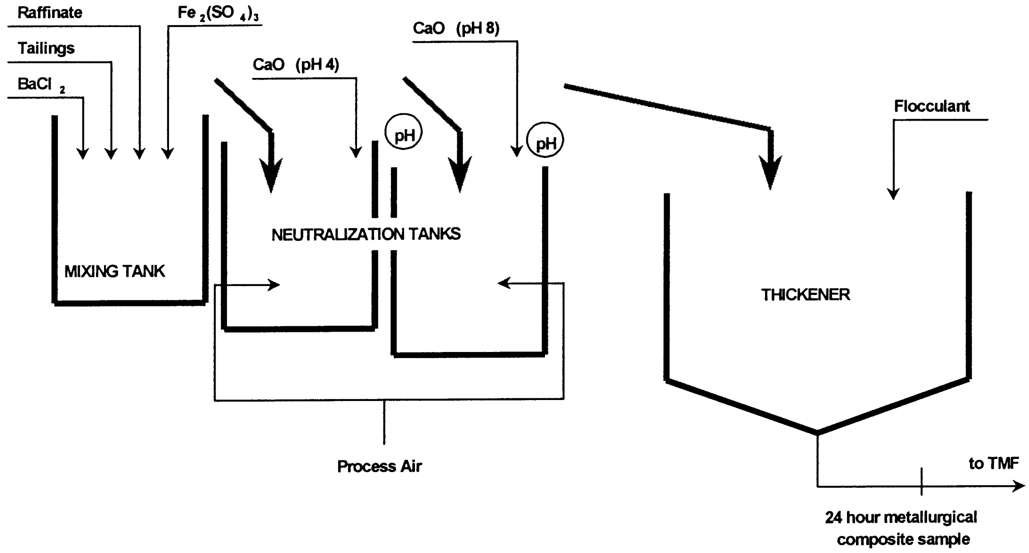

FIG. 4. Flow sheet for the tailings preparation circuit.

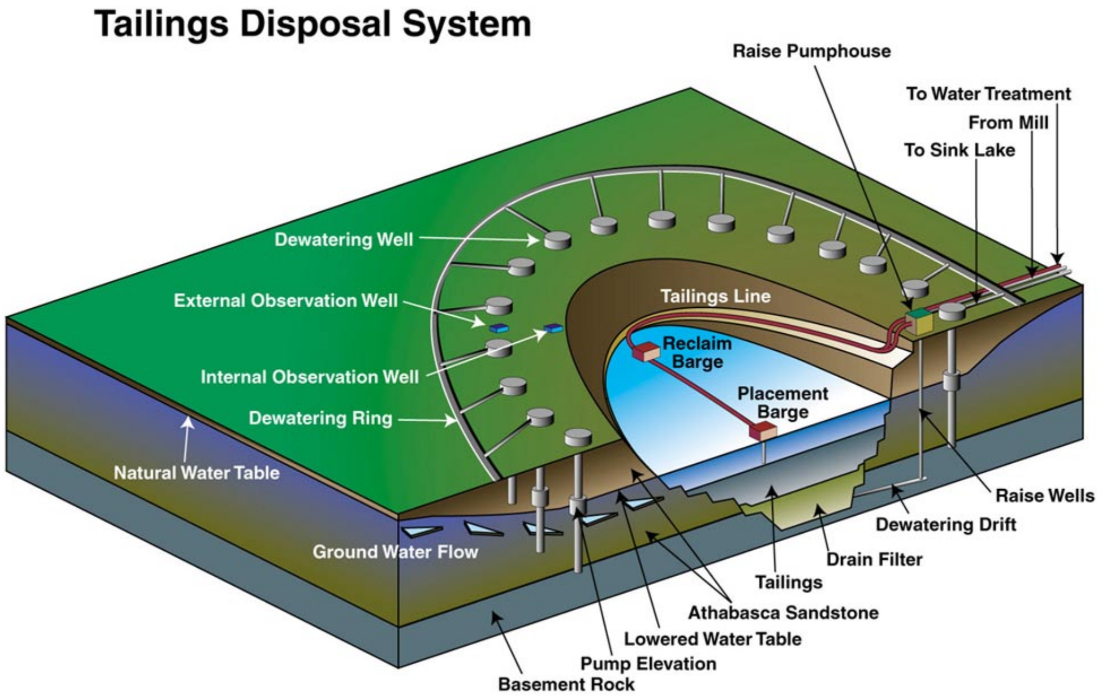

FIG. 5. Design and operational features of the JEB tailings management facility (TMF).

The submersible pumps in these wells are located at a fixed elevation slightly above the desired pond level. These act as the primary control on the TMF pond water level and to intercept clean ground water before it enters the TMF. To monitor ground water levels four observational wells (external) are installed within the ring. In addition, four internal monitoring wells are installed between the de-watering well ring and the pit. An under drain filter of sand and rock at the base of the TMF promotes drainage of tailings pore water, further accelerating tailings consolidation. Water flows through the under drain filter which is connected to a de-watering drift and raise system. Hydraulic confinement of TMF pond waters is ensured by maintaining the following water level hierarchy: exterior well > interior well > pond level > sump level.

The tailings lines from the mill run down the TMF ramp and onto a floating walkway leading to the placement barge. The discharge pipe is suspended below the barge and the tailings are released into the pond approximately 1 m above the existing tailings surface. This placement methodology minimizes particle size segregation and insures that relatively permeable pathways do not develop within the tailings mass. The reclaim water barge is used to precisely control the pond level by returning the mill tailings pumping water back to the mill.

3. TMF PERFORMANCE TO-DATE

3.1. Mill tailings preparation circuit

For the first year of operation, the focus has been to ensure that the tailings preparation process has been discharging tailings to the TMF that are meeting the arsenic and nickel pore water concentrations required for long term environmental protection. Figs. 6 and 7 are summaries of daily results for nearly seven months of operation of the tailings preparation process. The process has proven to be easily controllable, despite the fact that acid waste solutions as high as 2000 mg/L As have been processed. As can be seen from Fig. 6 the addition of ferric sulphate solution to achieve and Fe/As molar ratio of 3 to 4 has successfully reduced As and Ni concentrations in the final tailings pore water to approximately 1 mg/L feeding the TMF. Similarly, the sensitivity of the process to terminal pH at a fixed Fe/As molar ratio is shown in Fig. 7. This figure illustrates that soluble As and Ni pore water concentration objectives can be met within a reasonably broad pH window. Table 1 documents the monthly tailings preparation circuit performance for the year 2000 to-date with respect to soluble As and Ni.

3.2. TMF operation

Hydraulic containment of the TMF pond water has been continuously achieved. Table 2 confirms hydraulic containment for the month of April for example. Physical aspects of operating the TMF have been intrinsically simple and trouble free due to the fundamentally sound design of the TMF facility.

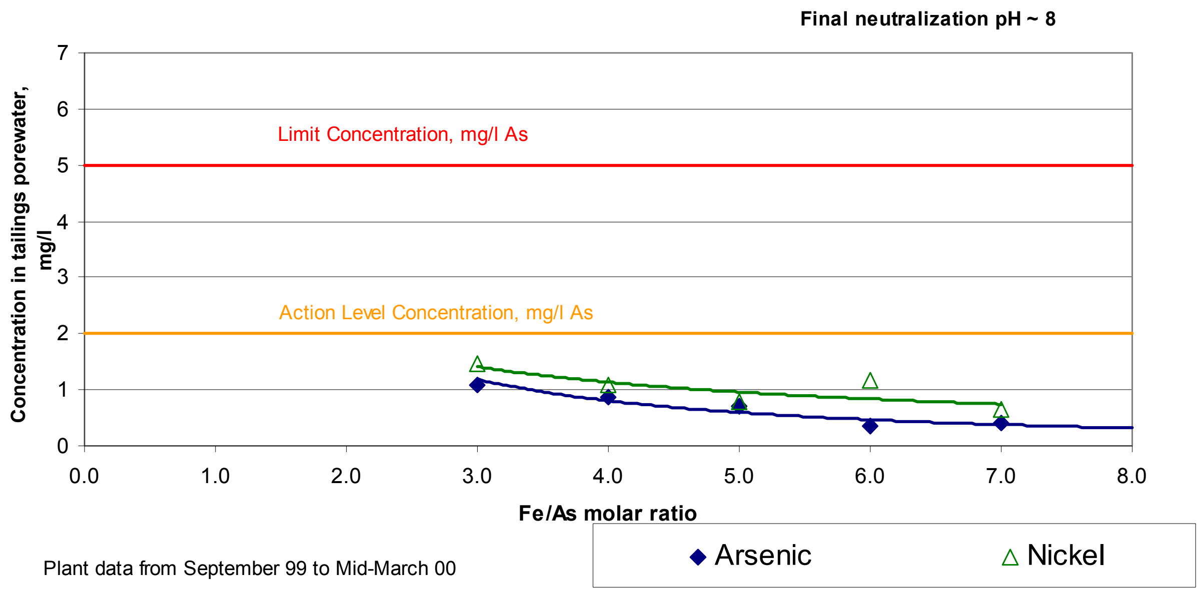

FIG. 6. Arsenic and nickel concentrations in tailings pore water as a function of molar Fe/As ratio at a fixed pH of 8. Each point is the average of daily readings over a 7 months operating period.

Fig. 8 illustrates the As and Ni concentrations in the TMF pond water since operations started to the time of writing. The arsenic and nickel concentrations in the pond water are significantly lower than the tailings pore water values feeding the TMF due to dilution by inflowing ground and surface waters. Pond water As concentrations rose shortly after start-up to approximately 0.2 mg/L As. They then decreased to about 0.04 mg/L As during the winter months and returned to their former level during the current summer. At this point, this variation is attributed to a temperature effect.

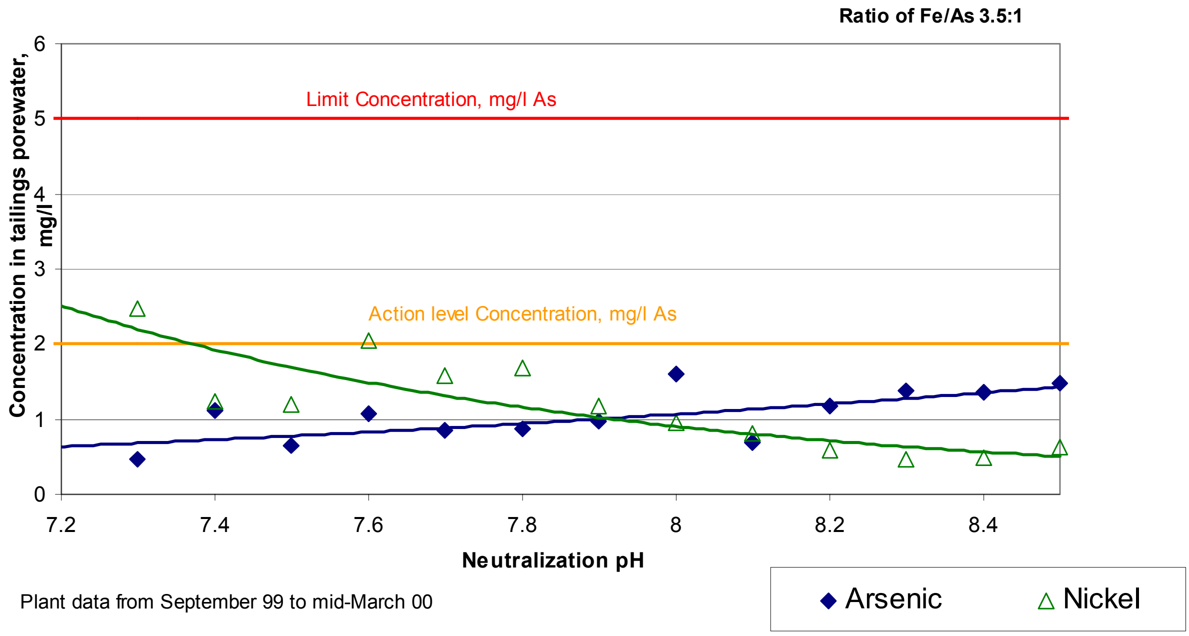

FIG. 7. Arsenic and nickel concentrations in tailings pore water as a function of terminal neutralization pH at a fixed molar Fe/As ratio of 3.5.

TABLE I. MONTHLY AVERAGE OPERATING DATA FOR THE YEAR 2000 TO-DATE QUANTIFYING ARSENIC AND NICKEL CONTENT IN THE TAILINGS PORE WATER DISCHARGED FROM THE MILL TAILINGS PREPARATION CIRCUIT

Month	Discharge from Tailings Preparation Circuit				
	(m^3)	(mg/L As)	(kg As)	(mg/L Ni)	(kg Ni)
January	19 751	1.43	28.2	0.76	15.0
February	20 101	0.92	18.5	1.15	23.2
March	21 623	0.69	15.0	0.76	16.5
April	22 791	0.36	8.3	0.36	8.2
May	20 954	0.27	5.7	0.28	5.9
June	21 324	0.96	20.6	0.45	9.5
July	20 886	0.95	19.8	0.59	12.2
August	20 474	0.77	15.8	0.43	8.9
Total/Average	167 904	0.79	131.9	0.59	99.4

TABLE II. EXAMPLE OF CONFIRMATION OF HYDRAULIC CONTAINMENT

April 2000	Average Elevation (masl)
Exterior Monitoring Wells	400.2
Interior Monitoring Wells	396.5
TMF Pond Elevation	392.2
TMF Raise Well Water Elevation	392.1

During the winter months the pond freezes and the water temperature drops to 0°C reducing the solubility of As. The summer operating temperatures reach 17°C. The Ni data in this figure exhibits a sharp rise in the month of September. This has been related to an abnormal release of ammonium sulphate to the TMF due to a mechanical failure in the mill. The temporary presence of ammonium ion increased the solubility of Ni in the TMF pond water.

Fig. 9 depicts the As and Ni concentrations in the TMF raise well water. This is the water that has passed through the filter and drift collection system. Both As and Ni concentrations behaved in a similar manner. For the first six months of operation, the As and Ni concentrations in the raise well water are similar to those in the TMF pond water. This is because the filter has not yet been covered with tailings and the raise well is drawing pond water through the filter. However, after about six months of placing tailings in the pond, a significant faction of the base filter has been covered and some consolidation of placed tailings has been occurring. Higher As concentrations are observed, particularly in January through March, from consolidation pore water drawn through the filter, drift and raise system. Since March however, both As and Ni concentrations in the raise well system have been slowly and steadily decreasing. It is currently thought that this reflects the fact that the surface area of the base filter is gradually being covered with placed tailings which steadily reduces the amount of pond water flowing through the filter into the raise well system. Table 3 provides a summary of the monthly TMF reclaim and raise well water quality data for the year 2000 to-date.

3.3. Soluble as balance

The TMF has been operated in a consistent manner for the year 2000. The pumps in the de-watering wells have all been set at 393.3 masl throughout this period. Fluctuations in pond water inventory have been relatively small. Using the information in Tables 1 and 3 and correcting for pond water inventory changes a solution balance for dissolved As was completed.

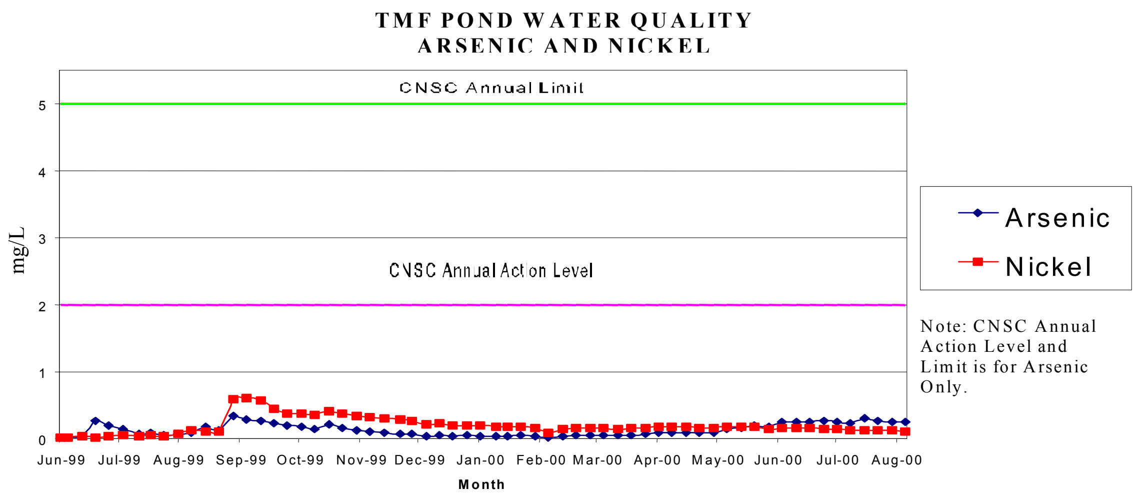

FIG. 8. Arsenic and nickel concentrations in the TMF pond water since operations began till August 2000.

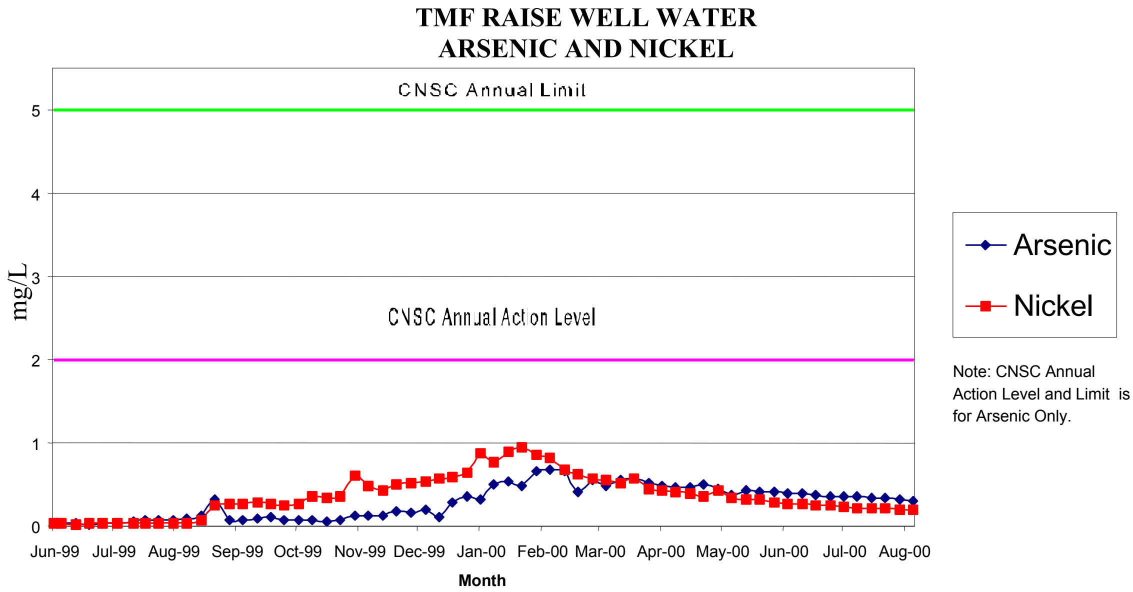

FIG. 9. Arsenic and nickel concentrations in the TMF raise well system since operations started till August 2000.

TABLE III. MONTHLY AVERAGE OPERATING DATA FOR THE YEAR 2000 TO-DATE QUANTIFYING ARSENIC AND NICKEL CONTENT IN THE TMF POND RECLAIM WATER AND RAISE WELL SYSTEMS

Mon.	TMF Reclaim Pond Water					TMF Raise Well Water				
	Volume	Arsenic		Nickel		Volume	Arsenic		Nickel	
	m^3	mg/L	kg	mg/L	kg	m^3	mg/L	kg	mg/L	kg
Jan.	142 379	0.04	6.1	0.20	21.2	4 520	0.40	1.8	0.67	3.1
Feb.	111 426	0.04	4.1	0.16	17.7	3 499	0.62	2.2	0.88	3.1
Mar.	87 512	0.04	3.9	0.15	13.5	3 688	0.50	1.8	0.61	2.2
Apr.	109 262	0.06	6.9	0.16	17.4	3 681	0.51	1.9	0.49	1.8
May	118 431	0.10	12.2	0.17	20.7	3 706	0.44	1.6	0.38	1.4
June	119 792	0.19	23.1	0.17	19.9	3 572	0.40	1.4	0.30	1.1
July	124 970	0.25	31.2	0.14	18.0	3 664	0.36	1.3	0.24	0.9
Aug.	101 865	0.27	27.2	0.12	12.2	3 416	0.32	1.1	0.21	0.7
Total	915 637	0.13	114.7	0.15	140.6	29 746	0.44	13.2	0.48	14.3

Table 4 documents the monthly pond water inventory changes. Included in Table 4 to complete the balance are the As contributions each month from ground and surface waters flowing into the TMF pond.

A summary of the balance follows:

Inputs:	Tailings porewater	131.9	kg As
	Ground/surface water	0.9	kg As
	Total input	132.8	kg As
Outputs:	TMF reclaim water	(114.7)	kg As
	TMF raise well water	(13.2)	kg As
	Total output	(127.9)	kg As
Pond Inventory Change:		(0.2)	kg As
Unaccounted Arsenic:		4.7	kg As

The total unaccounted arsenic over the period amounted to 4.7 kg As or 3.5% of the total fed to the TMF. This very close agreement, at least for this operating time period, indicates that there is no significant trend for solid arsenic to dissolve into solution after being placed into the TMF. The solid chemistry for arsenic in the placed tailings appears to be stable.

TABLE IV. MONTHLY AVERAGE OPERATING DATA FOR THE YEAR 2000 TO-DATE QUANTIFYING DISSOLVED ARSENIC INVENTORY CHANGES IN THE TMF POND WATER. CONTRIBUTIONS TO THE TMF POND WATER FROM GROUND/SURFACE WATERS IS ALSO CALCULATED IN THIS TABLE

Month	Pond Elevation Changes		Solid Tailings Volume Change		Net Pond Inv. Change		Ground/Surface Water Flow		
	masl[a]	m^3	tonne[b]	m^3	m^3	kg As	m^3[c]	mg/L As[d]	kg As
Jan	389.7	0	9 318	(3 451)	(3 451)	(0.1)	130 599	0.001	0.13
Feb	390.1	12 756	9 802	(3 630)	9 126	0.3	85 698	0.001	0.09
Mar	391.2	35 078	10 107	(3 743)	31 335	1.4	38 242	0.001	0.04
Apr	392.2	31 889	8 275	(3 065)	28 824	1.8	61 328	0.001	0.06
May	392.6	12 756	10 014	(3 709)	9 014	0.9	92 169	0.003	0.28
Jun	392.6	0	10 626	(3 936)	(3 926)	(0.8)	105 976	0.001	0.11
Jul	392.2	(12 756)	11 517	(4 266)	(17 022)	(4.3)	124 770	0.001	0.12
Aug	392.4	6 378	10 897	(4 035)	2 343	0.6	82 524	0.001	0.08
Tot/ave	391.6	86 101	80 556	(29 835)	56 233	(0.2)	721 207	0.001	0.91

[a] surface area of the pond at this elevation is approximately 31,889 m^2
[b] specific gravity of dry solid tailings is 2.7
[c] ground/surface flow is [reclaim flow + raise well flow - tailings flow - inventory change]
[d] ground/surface As concentration from average de-watering well analyses.

4. SUMMARY

These results represent the initial performance of the Tailings Management System at COGEMA's McClean Lake Operation. The system at this point is performing as predicted. However, it will take many years to validate the long-term performance of the TMF. Evaluations on rates of consolidation, degree of segregation during placement and long term pore water chemistry will be completed in future years.

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Waste management in the uranium companies of Niger

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Abstract. Two companies produce uranium (yellowcake) in Niger: the "Société des Mines de l'Aïr (SOMAÏR)" and the "Compagnie Minière d'Akouta (COMINAK)". The SOMAÏR opertion uses open pit mining whereas COMINAK employs underground mining. Uranium ores have been treated by SOMAÏR and COMINAK since 1971 and 1978 respectively. The wastes produced by the two companies will be managed to reduce health and environment impacts.

1. INTRODUCTION

Uranium production operations generate waste, which must be managed to minimize health and environment impacts. Waste management operations at SOMAÏR and COMINAK will be discussed.

2. WASTE PRODUCTION

During the uranium extraction and treatment operations, the principal inputs are [1]:

— Uranium ores;
— Sulphuric acid (75 kg/t to 80 kg/t);
— Nitric acid (10 kg/t recycled);
— Sodium oxidant (2.5 kg/t);
— Water (150 l/t).

SOMAÏR and COMINAK use the following sequence of extraction and treatment operations:

Mining → Crushing → Grinding → Leaching → Solid-Liquid Separation → Solvent extraction → Uranium recovery (yellow cake) →Tailings management.

The overall process produces both liquid wastes and solid wastes.

2.1. Liquid wastes

Liquid wastes include wastewater and others liquid effluents.

COMINAK, for example, treats 3.4 millions m^3/year of wastewater and also produces an annuam volume of 2.18 millions m^3 of other liquid effluents [2].

2.2. Solid wastes

The solid wastes include barren overburden, low grade uranium ore and mill tailings.

Table 1 gives COMINAK solid wastes production in 1997.

TABLE I. COMINAK SOLID WASTES PRODUCTION [2]

Waste Nature	Waste Quantity (year or grade)
Low grade uranium ore	423 561 tons (0.14%)
Heap-leach residues	401 894 tons (till 1990)
Mill solid wastes	9 millions of tons

3. WASTE MANAGEMENT

The management of wastes must minimize health and environment impacts.

3.1. Liquid waste management

3.1.1. Wastewater management

The wastewater is decanted for reuse in the mills. COMINAK, which uses 16 basins that cover an area of 44 ha to a depth of 4 m, recycles 3.4 millions m^3/year [2].

3.1.2. Management of others liquid effluents

These effluents are stored in evaporation basins. Table 2 gives the evaporation basin areas [2]. The local desert climate produces appreciable evaporation rates.

TABLE II. SOMAÏR AND COMINAK EVAPORATION BASINS AREAS

Companies	Evaporation basins areas (ha)
SOMAÏR	10
COMINAK	65

Each basin is lined with an impervious PVC membrane. The basins are situated about 2 km from the mill, in a clayey zone which provides additionnal protection against any contamination of the underlying aquifer. The hydraulic gradient is measured by piezometry.

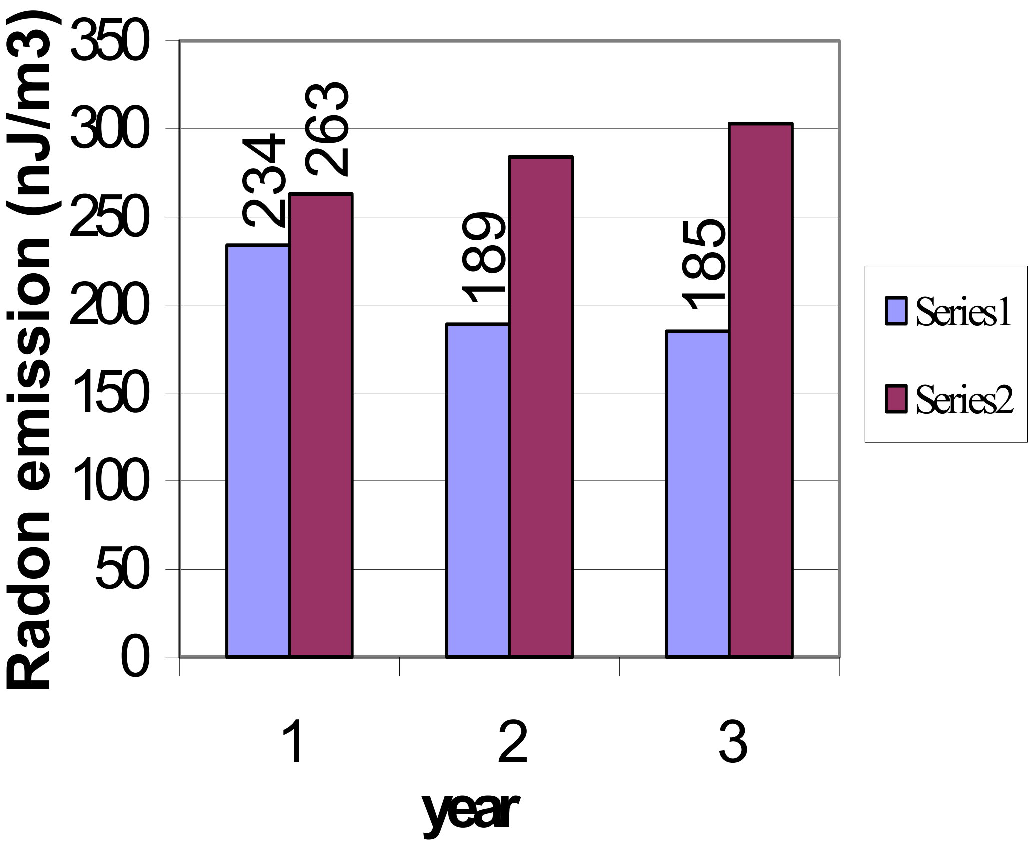

FIG. 1.Radon emission in SOMAÏR and COMINAK companies.

3.2. Solid waste management

Tailings require safe management because they contain long lived uranium and its daugthers, some of which, especially radium are toxic. Unless controlled, radium and its decay products may escape from the tailings and contribute to contamination and radiation exposure in the environment. The maximum values of radium emanation from the natural soils in SOMAÏR and COMINAK are respectively 1020 Bq/kg and 6240 Bq/kg [3] and [4].

The emanation of radon and thoron together with their long lived daugther products is the basis for the problem posed by mill trailings. Fig. 1 gives the mean radon emanation during 1997, 1998 and 1999 at SOMAÏR and COMINAK. To find a method for reducing this emanation, a pilot project to cover mill tailings has been initiated. The project seeks to determine what materials can be used to reduce the radon emanation to acceptable levels.

Natural background levels were not measured prior to operations; therefore, waste rock of low specific activity will be used. The following interactive process will be applied:

- Trial perimeter is defined;
- Points of radon measurement are identified by co-ordinate;
- Cover material is put in place to a known height;
- Repeat of the first measurements at the same locations;
- Comparaisons are made with the first measurements to determine the degree of attenuation;
- The process is repeated until acceptable levels are achieved [5].

A 1500 m^2 test plot has been completed and some measurements have been made. The cover materials used for this test plot were SOMAÏR and COMINAK barren overberdun [4].

4. HEALTH AND ENVIRONMENT PROTECTION

To comply with the requirements of Niger mining law 31 MMH of 79-12-5 SOMAÏR and COMINAK must ensure the safety of workers, the protection of population and the environment.

Potential transmission vectors (water, food and air) must be controlled to avoid health and environmental impacts. The current radium emanation from water is 0.02 Bq/l [3], [4], the maxium radon emanation is 11.46 mJ/m^3 [4] and the maximum radium level in vegetable and garden soil is 80 Bq/kg [4]. These values are acceptable because they are lower than the 31/MMH limits.

5. CONCLUSION

Uranium production at SOMAÏR and COMINAK produces a variety of wastes. Major efforts to improve the waste management technology and minimize health and environment impacts are in progress.

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Overview of IAEA activities in restoration of former uranium mining and milling sites

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Abstract. The IAEA has increasingly become concerned with the radiological and environmental impact of closed uranium mining and milling facilities. It is recognized that inappropriate practices in waste management and the lack of closeout plans have lead to environmental hazards and the potential for human exposure worldwide. In many instances the operators or those responsible for radiation and environmental protection lacked the experience in planning and executing remediation and restoration projects. Through a series of technical documents and other means, which are reviewed briefly in this paper, the IAEA strives to provide guidance and examples for the selection and application of adequate remediation technologies and restoration practices. Emphasis is put upon a comprehensive planning process leading to technology selection. This process commences with proper site characterisation on the basis of which a strategy is to be developed and finishes with post-closure monitoring as an integral instrument of quality control and quality assurance.

1. INTRODUCTION

In recent years the political and social climate in many countries calls for actions towards a cleaner environment. The political changes in Central and Eastern Europe (CEE) and the former Soviet Union have revealed the state of the environment in these countries. However, the heavy burden on the environment, resulting from an industry oriented mainly towards productivity, is by no means unique to these countries.

While it is recognized that many newer operational uranium mining and milling sites, particularly in the developed Member States, now comply with stringent environmental legislation, older and closed down sites still may pose a problem which needs to be addressed. The problems are aggravated by the circumstance that many countries with closed-down uranium mining and milling facilities do not have the adequate resources for site remediation. This paper is concerned only with the latter type of sites.

In response to this problem, the IAEA has developed over the past two decades a comprehensive programme aiming at the collation and dissemination of knowledge about *inter alia* uranium mining and milling sites [15], appropriate methods for their characterization, assessment of their potential environmental and radiological impact, and applicable methods for their close-out and cleanup [13,14,16], following internationally recommended safety criteria [3,5,6,7,8]. The objective is thereby to enable regions in the world with restricted resources and which are technologically less advanced to focus their efforts and choose appropriate strategies for abatement.

Table 1 illustrates the suite of environmental restoration related documents which have been developed by the IAEA, or which are currently under development.

2. SCOPING OF THE PROBLEM

The political changes not only brought forward the step-by-step disclosure of the radioactively contaminated sites, but also resulted in a condition in which these countries became receptive to co-operation. It was in these circumstances of change that the Agency decided to launch a Technical Co-Operation Project on Environmental Restoration in Central and Eastern Europe [15].

TABLE I. RELATIONSHIP BETWEEN RELEVANT TOPICAL REPORTS PRODUCED OR UNDER DEVELOPMENT

Safety	**Management**	**Databases**	**Technology**	**Special Topics**
Remediation of Contaminated Areas from Past Activities and Practices, Draft Safety Guide	Factors for Formulating a Strategy for Environ-mental Restoration TECDOC-1032	A Directory of Information Resources on … Environmental Restoration, TECDOC-841	Technologies for the Remediation of Radioactively Contaminated Sites, TECDOC-1086	Technologies for Long term Stabilization and Isolation of Uranium Mill Tailings, TECDOC in prep.
Management of Radioactive Waste from Mining and Milling of U/Th Ores Draft Safety Guide	Characterization of Radioactively Contaminated Sites for Remediation Purposes TECDOC-1017	Directory of Radioactively Contaminated Sites TECDOC in prep.	Technical Options for the Remediation of Groundwaters TECDOC-1088	Environmental Contamination by NORMs and Relevant Abatement Measures TECDOC in planning
	Compliance Monitoring for Remediated Sites TECDOC-1118	Restoration Costs TECDOC in prep.	Site Characterization Techniques Used in Environmental Restoration TECDOC-1148	Remediation of Sites Contaminated by Ha-zardous and Radio-active Substances TECDOC in planning
	Factors Impacting on the Environmental Restoration Practices TECDOC in prep.		Remediation of Sites with Low Levels of Disperse Radioactive Contamination TECDOC in planning	

The main focus of the project was the identification and characterization of radioactively contaminated sites. Before any action in regard to environmental restoration could be undertaken, the countries involved and the Agency needed to obtain an overview of the environmental status in each of the countries. During the implementation of the project, it became apparent that most countries in the region share the problem of contamination from uranium mining and milling. In the course of the project the emphasis shifted from scientific discussion to the identification of responsibilities, to planning activities, and to assessment of existing and needed resources for the eventual implementation of restoration plans.

Although these environmental problems are by no means unique to the CEE countries, a few distinctive features may raise additional complications. Unlike some countries in which mineral resources development occurred in remote areas, e.g. the USA and former Soviet Union, in the CEE countries these are typically located within or near well populated areas. Certain other factors also contribute to increased risk, namely:

- Long operational periods;
- Higher ore grade increases radiation dose rates from residues;
- Climatic conditions, e.g. rain, wind, are favourable for the dispersal of contaminated materials;
- Countries with limited resources can only allocate marginal resources to environmental restoration.

Some of the problems noted in [15] have been at least partially resolved, others persist: radon release, groundwater contamination, proximity of population to contaminated sites, lack of resources to conduct restoration, non-availability of disposal locations/alternatives, absence of regulations or regulatory infrastructure for restoration, misuse or removal of tailings for use in construction —

leading to high indoor radon exposures, absence of responsible operators, large inventories and areal distribution, lack of means to maintain institutional control.

3. INSTITUTIONAL ASPECTS AND SOCIO-ECONOMIC CONTEXT

Many Members States today have adopted the 'polluter pays principle', meaning that the originator of a contamination is responsible for adequate environmental protection and, if the occasion arises, remediation measures. Residues from uranium mining and milling, just as from any other mining activity, pose a particular challenge to the authorities when active operations have stopped and even the operators may have ceased to exist. This is particularly true for many CEE countries, including Eastern Germany, and CIS states [15]. Owing to the nature of such radiologically and otherwise relevant contaminations, the responsibility for making safe, cleanup and monitoring often rests with or, in the wider public interest, is assumed by the Government. The Government has to fund such activities through (regular) tax revenue. Limited income in any one year may hamper and delay remediation. Lack of government resources may also result in discontinuous and, hence, inefficient assessment and remediation activities. Similar constraints apply to private enterprises, where remediation funds typically need to come out of the annual (gross) profits or from (non-taxable) reserves if these are permitted under the prevailing legislation.

In some instances alternative funding can be sought, such as through the increase in market value of a property, following cleanup and re-development. Speculations on the property value may indeed influence the performance of a restoration programme as well as its end-point, for property value is closely linked to foreseen later land-use.

In the private domain and for new practices, or the further extension of licenses for existing practices, insurance cover for environmental liabilities are increasingly required by the licensing authorities in many developed Member States. Depending on the type and size of the operation, these may take the form of classical risk-type policies, obtainable on the insurance market, or the form of bonds.

An IAEA document currently under development discusses these non-technical factor influencing the decision making processes in environmental restoration [21].

4. MANAGEMENT OF MINING RESIDUES

As has been pointed out, technology and management know-how for the safe closure and decommissioning of mining and milling facilities and the management of related wastes exists. This knowledge, mainly with operating facilities in mind, has been summarized in several technical documents [1,2,6,13] and may serve as a benchmark for *ex post* handling of mining residues. In a remediation context, mining and milling residues pose particular engineering and logistic problems, mainly owing to their large volumes and to certain geotechnical and geochemical properties [2,4]. Typically, unlike in other environmental remediation situations, removal of the contamination, conditioning and disposal of residual wastes typically is not feasible anymore to any significant extend. Solutions have to be found which lead to a stabilization and containment of materials *in situ* or at least on site [16]. Although, for instance the use of residues for backfilling of open-cast mines in a remediation context has been shown in Germany and has been proposed in Slovenia. The long term integrity of engineered structures is of particular concern.

Potential hazards issuing from uranium mining residues include not the least general engineering safety risks, such as slope stability of spoil heaps, pit walls or dams, particularly when the operation had been prematurely stopped without adequate provisions for close-out. Conventional toxicological risks result from heavy metals and other potentially toxic inorganic or organic constituents of the mining residues, to which man and the environment might be exposed through water or air pathways. Radiological hazards can lead to comparable exposures and involve the non-volatile radionuclides as well as radon [11]. Like in other metal ore mining context, acid generation in mines and mining

wastes can constitute a major hazard and environmental impact in itself and it furthers the release of contaminants to the aqueous phase.

Mill tailings are/were often deposited in a rather haphazard fashion, utilizing, for instance, depressions in the landscape, perhaps improved by damming up valleys etc. [1,10]. Considering the finite lifetime of any engineered structure, this kind of disposal situation does not necessarily provide for a long term stable isolation. A current IAEA coordinated research project (CRP) addresses the problem [18]. The objective of this CRP is to develop techniques and management strategies that can be applied retrospectively to remediate existing tailing facilities.

5. IN SITU LEACHING

In situ leach (ISL) mining is defined as a mining method where the ore mineral is preferentially leached from the host rock in place, or in situ, by the use of leach solutions and the mineral value is recovered. The topic of *in situ* leaching mines has been taken up in two IAEA technical documents [9,12]. There is a clear division between practices of ISL in the USA and those in the Eastern European countries, Central Asia and China, the latter which all employed acid as a leaching agent because host rocks had only limited buffer capacity. The main conclusion from the IAEA documents were that the main advantage of the ISL method, as compared to conventional open pit and/or underground mining, is financial and the fact that hardly any tailings or other mining residues are produced. There is still no unified opinion on what is considered the best process causing the least harm to the environment. The operational phase can be designed such that little outside impacts arise and a significant number of ISL site in the USA using the alkaline leach process have been successfully restored. Removal or neutralization of residual process acids, however, has proven to be difficult or impossible, as the examples in Germany and the Czech Republic show. A significant part of the problem is poor control over the hydraulic system, when combining traditional underground mine works and ISL fields, as was the case in these two countries.

6. SITE REMEDIATION

Remediation activities typically tend to be technology driven, i.e. mainly by the technology which is available to the operator in question. However, this may not necessarily lead to an optimized solution taking into account all relevant factors. Integrated assessment and remediation programmes are required, which consider technical, environmental, socio-economic and perception factors [17]. Socio-economic factors are likely to be of particular significance where the mining is/was a major economic factor [14]. It is also important to recognize that in a uranium mining and milling context the radiological contaminants are not necessarily those of main concern. Heavy metals, arsenic, other inorganic and organic toxic compounds, and acid generating constituents in residues are often of much greater relevance. A newly initiated IAEA project will address the specific challenges posed by mixed contaminations.

In many cases the site remediation and restoration problems not only concern mining specific problems per se, but contamination problems of a broader nature. Consequently many of the IAEA documents addressing environmental restoration issues cover both, mining and milling sites, and other types of sites.

With a lack of proper record keeping or the loss of the respective records over the decades, it is often difficult to assert the extend of a contamination and its contaminant inventory. For this reason a proper site investigation, like for other types of contaminated sites, has to be carried out for mining and milling sites [20]. A CRP on site characterization methods has recently been completed [22]. Other technical documents discussing in more detail available remediation techniques for certain media, such as soils and groundwater, have been prepared [18,19]. Although [18] does not cover explicitly mining and milling residues, many of the techniques discussed are applicable to remove or contain contamination issuing from such residues. The technical document on groundwater

remediation [19] discusses actual or potential contamination and their treatment citing examples from Bulgaria, Germany and the Russian Federation.

7. TECHNICAL COOPERATION

In addition to developing guidance for the application of technologies in relevant fields and for the development of management instruments and strategies, the IAEA provides technical assistance to individual Member States. In recent years uranium mining remediation technology related projects have been undertaken *inter alia* in Slovenia, the Czech Republic and Bulgaria.

8. CONCLUSIONS

A large body of experience in dealing with the legacy form uranium mining and milling has been accumulated over the past two decades or so and is reflected in a collection of IAEA documents. It is important to note that the majority of environmental problems are by no means unique to uranium mining, rather they are common to all undertakings to extract materials from the ground. Even the radiological hazards are not unique to this kind of mining as the attention Natural Occurring Radioactive Materials (NORMs) and radon are attracting shows.

While today techniques and management schemes exist which make uranium mining and milling an environmentally benign process as possible, this is certainly not the case for many 'historic' operations. In order to reduce actual and potential environmental impacts, remediation measures have to be undertaken. The IAEA has collated a large body of experience in relevant technical documents, and continues to do so, and foster the exchange of knowledge between interested parties in this field.

ACKNOWLEDGEMENTS

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The legacy of uranium mining in Central and Eastern Europe — a view from the European Union

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Abstract. Throughout the countries of Central and Eastern Europe there was widespread mining and processing of uranium which has left a huge environmental and public health problem requiring urgent remedial action. The present paper outlines the situation from the perspective of the European Union by presenting a description of the assistance provided through Community funding and a summary of relevant European Union legislation in this field.

1. INTRODUCTION

A number of Central and Eastern European Countries (CEEC) are currently in discussions with the European Commission over future membership of the European Union (EU). These countries have come under close scrutiny by the European Institutions in recent years in order to assess their progress in implementing the necessary reforms before accession. Within the EU, environmental and public health issues have gained in importance over recent years, and this is also being reflected in the accession process.

One area of particular concern is the legacy from the extensive uranium mining activities in the CEEC, which includes numerous tailings ponds, low-grade ore heaps and abandoned mines, all posing an actual or potential radiological threat to the local population. The majority of these activities were initiated over 50 years ago by the former USSR for military purposes. In later years, following the transfer of the former USSR military-owned and highly secret companies to national governments, an increasing part of the uranium was used in the manufacture of fuel elements for national nuclear power programmes. Few, if any, environmental remediation measures were undertaken at the affected sites during this period. Furthermore, since the industry was State-owned and managed during the later years of operation, responsibilities for remediation now lie with the respective governments, who are faced with the problem of developing and implementing their own cost-effective programmes to rehabilitate the sites. However, not only are the financial resources in the region limited, but there is also a lack of local expertise in the field of site remediation.

2. EU ASSISTANCE

2.1. PHARE Programme

The PHARE programme [1, 2] administered by the European Commission is the main channel for the European Union's financial and technical co-operation with the CEEC. In the past, PHARE assistance has been provided to these countries to assess the situation at uranium mining and milling sites and identify the remediation priorities and objectives. More recently, PHARE funding has also been provided for actual implementation of remediation measures at a few individual sites. In line with general PHARE requirements, the projects have all been identified in proposals to the European Commission made by the beneficiary countries themselves.

2.1.1. *Nuclear safety programme*

One of the many multi-beneficiary programmes coming under the PHARE umbrella concerns nuclear safety in the CEEC [3]. Projects in this programme have concentrated mainly on safety aspects of nuclear power reactor operation in these countries. Nonetheless, between early 1997 and the second half of 1998, a project was financed entitled "Preparing remediation at Uranium milling and mining sites in the PHARE countries - provision of means to assess radiological risks".

The project was aimed at providing beneficiary countries with both hardware and know-how in the field of radioactivity measurement and dispersion via water and atmospheric pathways. The countries involved were Bulgaria, the Czech Republic, Estonia, Hungary, Poland, Romania and Slovenia. The supply of equipment under this project was dependent upon prior approval from the Commission services. One of the principal aims was to harmonize the measuring devices in use throughout the PHARE countries, and to this end a standard package of equipment was offered to each beneficiary. In addition, specialist measuring devices were supplied where specific needs were identified. The contractor, Wismut GmbH / Uranerz GmbH, went on to produce measurement guidelines and provide training in the use of the equipment supplied under the project.

2.1.2. *Multi-Country environment programme*

Most of the PHARE assistance providing for preparatory measures and development of remediation methodologies has been channelled through a Multi-Country Environment (MCE) programme entitled "Remediation Concepts for the Uranium Mining Operations in CEEC" [4].

Though this PHARE MCE programme was under the responsibility of Directorate-General IA (DG-IA) of the European Commission, everyday co-ordination of activities was performed initially by a Programme Co-ordination Unit (PCU) set up in Pécs, Hungary. Terms of Reference were drawn up in collaboration between the Commission, the beneficiaries and the Commission's independent project co-ordinator (KARUWEEG BV) and the projects were contracted following a procedure involving a restricted Call for Tender to a shortlist of interested companies. All companies had to demonstrate the required specialist expertise, experience and ability in the particular field, thus ensuring application of latest technology and current best practice. Involvement of local partners constituted a key aspect of all these projects.

Initially some €12 million was to be spent on this programme over a five-year period. However, owing to restructuring of the whole PHARE programme the funding was discontinued in 1998, leading to the closure of the PCU and the transfer of the remaining co-ordination activities to KARUWEEG BV.

TABLE I. OFFICIAL BENEFICIARY ORGANIZATIONS IN THE MCE URANIUM MINE REMEDIATION PROGRAMME

Country	Beneficiary
Albania	GJEOALBA, Rruga Sami Frasheri 33, Tirana
Bulgaria	Committee of Energy, 8 Triadiza Str., 1040 Sofia
Czech Republic	DIAMO s.p., 47127 Straz pod Ralskem
Estonia	AS SILMET, Kesk st. 2, Sillamae EE2010
Hungary	Mecseki Ércbányászati Vállalat, Esztergár Lajos út 19, 7633 Pécs
Poland	Wrocław University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wrocław
Romania	Compania Nationala a Uraniului s.a., 68 Dionisie Lupu Street, Sector 1 - Bucharest – 70184
Slovakia	Uranpres s.r.o., Frana Krala 2, 05280 Spisska Nova Ves
Slovenia	Rudnik Zirovski Vrh, Todraz 1, 4224 Gorenja Vas

This premature end to the MCE programme meant that only the first two phases, totalling some €4.64 million, have been completed. Nonetheless, these represent a very successful and worthwhile series of projects.

Access to the results and reports, including the database of liabilities, is subject to the normal rules applying to PHARE projects, requiring the prior approval of the beneficiary and the European Commission. In the case of the latter, there can be no objection to dissemination of the information to as wide an audience as possible. Within the CEEC, requests for information should be therefore, directed to the respective beneficiary organizations listed in Table 1.

2.1.2.1. Part A: Common activities in all CEEC

The first phase (Part A, duration two years), completed in August 1998, involved two regional projects to compile an inventory of and to categorize and prioritize all the uranium liabilities in the countries concerned.

Beneficiary countries: Albania[1], Bulgaria, Czech Rep., Estonia, Hungary, Poland, Romania, Slovakia, Slovenia

Project no. 1 Inventory of all uranium liabilities in nine CEEC.

Contractor	Uranerz, C&E Consult, IWACO
Budget	€1 million
Contracted	July 1996
Completed	July 1997

Main activities:

- to create a computerized inventory of all uranium liabilities in nine CEEC;
- to collect all essential data in order to ensure that the resulting database remains useful and relevant to the needs of remediation efforts in these countries.

Some 5779 individual or grouped uranium liabilities were identified in the countries concerned, covering some 90 districts and 210 fields. In total, there are 7161 separate objects including 3631 shafts and adits, 1487 dumps (covering a total area of 46 km^2 and with a total volume of 85 million m^3), 29 tailing ponds (total area 12 km^2, total volume 104 million m^3), 11 processing plants, 76 in-situ leaching fields (total area 21 km^2), 6 heap leach piles and approximately 2000 exploration objects (mainly boreholes).

Project no. 2 Data verification, categorization of liabilities.

Contractor	Uranerz, IWACO
Budget	€450 000
Contracted	August 1997
Completed	August 1998

Main activities:

- to verify the quality of the inventory database;
- to categorize the uranium liabilities;

[1] Although qualifying for assistance under the PHARE Programme, Albania is not an EU applicant country.

— to assess and categorize the environmental and health impacts of these liabilities;
— to make a compilation of relevant legislation / guidelines in the CEEC, and compare with those in EU, USA, Canada and Australia;
— to rank and prioritize the liabilities;
— to identify suitable pilot projects for inclusion in Part B of programme and to draft the Terms of Reference for three of these projects.

Of the 5779 liabilities, some 831 had sufficient data to warrant inclusion in the subsequent categorization and risk ranking exercise. These constitute the bulk of the major liabilities, for which about 90% of the required data are present in the database; this was considered sufficient to enable a meaningful comparative analysis to be performed. The screening was via statistical methods and expert opinion.

2.1.2.2. Part B: Pilot projects

The second phase (Part B, duration 2.5 years) consisted of seven pilot projects to provide technical assistance and specific training in the development of remediation strategies for the types of environmental remediation problems occurring frequently in the CEEC, with the emphasis on particular cases at specific sites. Another important objective was to stimulate the development of the national remediation programmes and support co-operation between the countries involved. For each project, at a specific site most of the other countries in the programme had co-beneficiary status, thus ensuring the maximum dissemination of information and sharing of expertise throughout the region. To this end, all pilot projects involved workshops attended by the co-beneficiaries.

The project proposals coming from the beneficiary countries were, in the first instance, evaluated and ranked by the PCU before passing to the programme's Steering Committee for approval. This led to the acceptance of four pilot projects, and Terms of Reference for three of these were drafted by the contractor in Part A of the programme. Later, three further pilot projects were approved by the Steering Committee. For each project the final Terms of Reference had to be approved by the respective beneficiary and a Pilot Project Guidance Group (PPGG) was established by the Steering Committee. The resulting seven pilot projects are described below.

Pilot project no. 1 Technical planning of long-term stabilization of tailing ponds.

Host country	Hungary (Pécs)
Contractor	Wismut, C&E Consult
Budget	€450 000
Contracted	May 1998
Completed	May 1999

Main activities:

— to develop criteria and identify key parameters for a systematic approach to the stabilization of the sludge interior of uranium tailing ponds in the CEEC;
— to apply this approach to the planning of the necessary measures for the long term stabilization of the tailing pond No.1 in Pécs.

Pilot project no. 2 Prediction of the development in time of the water balance of a tailing pond.

Host country	Czech Republic (Dolni Rozinka)
Contractor	Wismut, C&E Consult
Budget	€390 000
Contracted	May 1998
Completed	April 1999

Main activities:

— to define specific criteria for long term control of the water balance of tailing ponds, key parameters for a systematic approach to the development of a water balance and requirements for monitoring systems that can be applied to the remediation of all tailing ponds in the CEEC;
— to develop a suitable water management model;
— to list appropriate technologies for the treatment of contaminated water from uranium processing plants;
— to apply the above-mentioned approach to the planning of the measures for water management at the Rozna K1 tailing pond in preparation for further remediation activities.

Pilot project no. 3 Technical planning of underground mine rehabilitation.

Host country	Romania (Banat Region)
Contractor	Dames & Moore (Manchester, UK and Paris offices)
Budget	€450 000
Contracted	August 1998
Completed	October 1999

Main activities:

— to define all relevant physical, chemical, hydrogeological and hydrological key parameters characterising the conditions and the consequences of uranium mine flooding;
— to define specific criteria to be met over the long term and applicable in the remediation of uranium mines in the CEEC;
— to develop a systematic methodology for the planning of the flooding of underground uranium mines in the CEEC;
— to apply the methodology to the technical preparation of the remediation of the Ciudanovita mine in the Banat Region (SW Romania) and to provide a technical plan for the close-out of the mine, outlining the technical measures required to reduce the impact of mine flooding on the environment.

Pilot project no. 4 Concept and design of reshaping and covering the Sillamae radioactive tailing pond, particularly in relation to dam stability problems.

Host country	Estonia (Sillamae)
Contractor	Wismut
Budget	€448 000
Contracted	November 1998
Completed	September 2000

Main activities:

— to set up a systematic approach for reshaping and covering tailing ponds including the consequences regarding long term geotechnical dam stability;
— to perform a detailed design of both tailing pond covering and reinforcement, in particular applied to the complicated Estonian tailing pond at Sillamae.

Pilot project no. 5	Efficiency of former revitalization after uranium mining.

Host country	Slovakia (Spisska Nova Ves)
Contractor	AEA-Technology
Budget	€118 000
Contracted	December 1998
Completed	December 1999

Main activities:

- to develop a systematic methodology for the evaluation of the efficiency of historic remediation of uranium liabilities;
- to demonstrate the applicability of this methodology to a selected group of historically (partly) remediated uranium liabilities near Novoveska Huta.

Pilot project no. 6	Development of a comprehensive method for the impact assessment of smaller uranium liabilities and its application on the radiological effects created during uranium exploration in Albania.

Host country	Albania (various sites throughout country)
Contractor	AEA-Technology, UK
Budget	€185 000
Contracted	December 1998
Completed	September 2000

Main activities:

- the development of a systematic method for the assessment of the impact of smaller uranium liabilities in the CEEC on public health and the environment;
- the field application of this comprehensive method to assess the impact of the uranium liabilities in Albania.

Pilot project no. 7	Management and clean-up of ground and surface water polluted with radionuclides as a result of uranium mining and processing activities in Buhovo area.

Host country	Bulgaria (Buhovo)
Contractor	Harress Pickel Consult (German office, Köln)
Budget	€414 000
Contracted	December 1998
Completed	December 1999

Main activities:

- to develop a methodology for effective management of both the contaminated and non-contaminated waters in the area, either already affected or liable to be affected by uranium mining and milling activities, leading to a computer-aided system of decision-making enabling improved management support;
- to implement this methodology as a pilot trial in the Buhovo area;
- to develop, using the results of this pilot trial, a detailed plan of action for environmentally sound water management around Buhovo and to prepare the Terms of Reference for the necessary detailed engineering of the required technical work.

2.1.3. Funding of implementation projects

With the completion of these pilot projects, the MCE programme has now come to an end. It is expected that the momentum afforded by the acknowledged success of this programme will enable a more rapid transition to the next, and more costly, implementation stage. Estimates of remediation costs vary, but will probably amount to some tens of millions of euro per major site. Though this is often beyond the means of State budgets, other possibilities of funding and co-funding from EU financing mechanisms do exist.

The PHARE Large-Scale Infrastructure Facility (LSIF) [5] is currently co-funding remediation measures at the tailings pond at Sillamae, Estonia. The overall project, managed by the Nordic Environment Finance Corporation (NEFCO), is costing a total of €20 million of which €5 million is from PHARE/LSIF and €8 million from Estonian State funds, with the remaining funding from NEFCO and other international donors. The remediation measures to be applied are based on the results of the corresponding PHARE MCE pilot project (no. 4).

PHARE is also funding urgent environmental remediation of the tailing pond at Buhovo, Bulgaria. This investment project, for a total of €3.8 million, is one component of a wider programme managed by the Ministry of Environment and Waters as part of the National PHARE Programme for Bulgaria. Again, the work is based on the results of previous PHARE MCE studies (pilot project no. 7), and is to eliminate the risk of contamination of downstream waters with radionuclides seeping through the tailing pond dam and to take measures to prevent dam failure.

In a separate project at another site in Bulgaria, the complex tailing pond at Eleshnitsa located in the mountains upstream from the Greek border is the object of remediation funding as part of the PHARE Cross-Border Programme with Greece. The complete package of funding, approved in May 1999, totals some €25 million covering several sectors and involving various beneficiary institutions. The uranium mining sector comes under the responsibility of the Bulgarian Committee of Energy, for which PHARE will provide co-financing totalling €12 million for activities related to the closure of the uranium mines at Eleshnitsa and Dospat. The project will ensure full compliance with relevant European Union water and waste directives.

2.2. Instrument for Structural Policies for Pre-Accession (ISPA)

The Instrument for Structural Policies for pre-Accession (ISPA) [6, 7] is the European Commission’s principle co-funding mechanism to assist the ten CEEC in adapting their environmental and transport sectors in view of accession. Applications for co-funding under this programme need to identify clearly the connection with fundamental EU legislation in the field of environment or transport; in the case of environmental projects this usually means demonstrating a link with EU legislation in the area of water or air quality or waste management. For example, uranium mining remediation proposals would normally make reference to the criteria in the new Drinking Water Directive (see Section 3).

However, there is considerable demand for funding in this sector and it remains to be seen exactly what priority is placed on uranium mining remediation projects by the countries themselves. At the present time there are applications either planned by or already submitted from the Czech Republic, Hungary and Romania.

In the case of both PHARE/LSIF and ISPA, the success of the PHARE MCE Programme is evidenced by the willingness of the competent authorities in the countries concerned to structure their applications around the results and recommendations of the respective pilot projects.

2.3. DG-Environment's co-operation programme

Through its general concern for issues of nuclear safety and radioactive waste management in the CEEC [8], the DG-Environment is also becoming increasingly involved in the problems of uranium

mining waste. As a result, a small number of projects in this field have been and are being funded within DG-Environment's current Co-operation Programme in the field of radioactive waste, decommissioning and nuclear safety.

The most significant project to date involves co-funding of remediation measures at the last remaining tailing pond in Poland situated at Kowary in Lower Silesia. The contract was signed in March 2000 and the EC contribution will be €300 000, which is estimated to be one third of the final overall cost for complete rehabilitation of the site. Though the tailing pond is of small dimensions there are nonetheless fears regarding the dam stability owing to the steep-sided nature of the valley in which it is situated and the possible erosion by the adjacent mountain stream during times of heavy rainfall. Important input for the design stage of this project has also come from the Estonian MCE pilot project (no. 4). The EC contractor, responsible mainly for the design and construction of the pond cover, is G.E.O.S. Freiburg mbH, Germany. Work is due to be completed towards the end of 2001.

DG-Environment has also recently funded an important assessment of the numerous surface liabilities in Banat region of Romania using methodologies developed in the PHARE MCE programme (pilot projects nos. 5 and 6). The contractor in this case was the Romanian mining institute ICPMRR (Institutul de Cercetare si Proiectare Pentru Metale Rare si Radiocative SA), and the work complemented that performed in the corresponding MCE pilot project (no. 3). The results constitute invaluable basic data for the planned remediation work, and are considered essential input in any subsequent application for ISPA funding. In a follow-up to this work, another contract has now been signed with ICPMRR to perform a similar assessment of the surface liabilities near Barzava village in Arad County, Romania. The waste rock piles in question are in very close proximity to neighbouring dwellings and have undergone no remediation since they were deposited there more than 30 years ago.

Following the recent incident in Romania involving the collapse of the dam at the "Baia Mare" goldmine, DG-Environment is also becoming increasingly concerned by the environmental threat posed by all old mining sites and tailing ponds in general. This is likely to result shortly in new legislative initiatives in this area, though it remains to be seen to what extent uranium mining is also covered.

3. EU LEGISLATION

The principle items of EU legislation relevant to remediation of uranium mining sites include:

- *Basic Safety Standards Directive* - Council Directive 96/29/Euratom [9] of 13 May 1996 lays down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. The origin of these measures lies in the provisions of Chapter 3 of the Euratom Treaty [10]. The Directive presents the most recent set of basic safety standards, and effectively transposes into law the recommendations of ICRP 60. Member States had to comply with the provisions of this Directive by 13 May 2000. Ongoing uranium mining is included in the scope (Title II) of the Directive, and the legislation therefore provides protection to the workforce and public against the radiological threat from related activities. Past mining practices are also covered by the Directive (Art. 48), but not to the same extent as current mining activities. Article 53 of the Directive, concerning past practices, regulates only intervention measures (like demarcation of the site, monitoring of exposure, etc.). Remediation measures themselves are not regulated, and the Directive does not contain any specific binding target values in this respect. However, the Commission has recently published a report [11] giving guidance for remediation projects from the radiation protection perspective.

- *Drinking Water Directive* - Council Directive 98/83/EC [12] of 3 November 1998 on the quality of water intended for human consumption prescribes a total indicative dose of 0.1 mSv/year (excluding tritium, potassium-40, radon and radon decay products) for drinking water. This

Directive entered into force on 25 December 1998, and Member States have two years from this date to transpose it into national legislation and a further three years to ensure that drinking water standards comply with those set by the Directive (i.e. until 25 December 2003). The Directive has specific provisions for monitoring and remedial action in the event that the prescribed limits are surpassed. The provision of this Directive will have direct relevance to remediation at affected sites.

- *Landfill Directive* - Council Directive 99/31/EC [13] of 26 April 1999 on the landfill of waste entered into force on 16 July 1999 and EU Member States have two years from this date to transpose it into national law. The Directive does not cover landfills that have already been closed before this date. Also, it is not clear yet whether or how the Directive will apply to waste at uranium mining sites (mill tailings, low-grade ore heaps etc.), and the applicability to these mostly historic mining and milling deposits may need to be established on a case by case basis. However, assuming the Directive will also apply in these cases, there are minimum requirements that must be respected concerning protection of soil and water (e.g. maximum permissible permeability and minimum thickness of covering mineral layers). No matter what the applicability, the Directive does appear to provide good guidelines for planning, licensing and implementing of remedial measures.

These legislative items form just a part of the body of radiation protection and environmental legislation to be adopted by the applicant countries before accession to the EU. Further reading on all these aspects can be accessed via the DG-Environment Internet site [14].

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Uranium mining environmental restoration project (PRAMU)

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Abstract. The National Atomic Energy Commission (CNEA) started its activities 50 years ago and obtained significant results. At the present time, the CNEA is defined as an Institution of research and development in the nuclear field. It is also responsible for the management of radioactive wastes and the dismantling of nuclear and radioactive facilities. Mining and milling activities have been carried out during the past 40 years and at present the CNEA is undertaking the **Uranium Mining Environmental Restoration Project (PRAMU)**. The aim of this project is to restore the environment as much as is possible in all places where uranium mining and milling activities were developed when taking into consideration both economic and technical reality. First, the characteristics of the problems in each site are determined through appropriate studies which identify the existing or potential impacts, the possible pathways of contamination, etc. The sites being studied are: MALARGÜE (Mendoza Province), CORDOBA (Córdoba Province), LOS GIGANTES (Córdoba Province), HUEMUL (Mendoza Province), PICHIÑAN (Chubut Province), TONCO (Salta Province), LA ESTELA (San Luis Province), LOS COLORADOS (La Rioja Province). PRAMU seeks to improve the current conditions of the tailings deposits and mines and to ensure the long term protection of people and the environment. The CNEA is required to comply with all legislation that is in force and is under the control of various national, provincial and local State institutions. The main objectives of the project for the various sites are: (a) *Malargüe site*: to implement the actions necessary for environmental restoration and management of the tailings derived from the uranium ores processed in the industrial plant; (b) *Córdoba and Los Gigantes sites*: to design, engineer and execute the activities required for closure of the sites; (c) *Other sites (Huemul, Pichiñán, Tonco, La Estela, Los Colorados)*: to develop an environmental evaluation and, on the basis of the results obtained, to study technological options for the mitigation of both current and future impacts. Some actions related to the Malargüe closure are in progress.

1. INTRODUCTION

The National Atomic Energy Commission (CNEA) started its activities 50 years ago and obtained significant results. At the present time, the CNEA is defined as an Institution of Research and Development in the nuclear field, and it is also responsible for the management of radioactive wastes and the dismantling of nuclear and radioactive facilities.

To achieve its objectives several companies which were linked to CNEA in different ways, were created to carry out various roles such as UO_2 production, fuel element production and heavy water production etc. At present Argentina has two nuclear reactors generating electricity: Atucha I (340 Mw(e)) and Embalse (600 Mw(e)): A third is under construction: Atucha II (600 Mw(e)). These reactors use natural uranium as fuel and heavy water as moderator and coolant. With a total installed power of 940 MW(e), the annual consumption of uranium is about 150 t. When the third nuclear power plant becomes operational, the installed power will reach 1640 MW(e) with a consumption of 250 tU/year. The percentage contribution of energy from nuclear sources to the Argentine interconnected system is of 11.5%.

Mining and milling activities have been carried out in several provinces of the country during the last 40 years. Currently, the CNEA is undertaking the **URANIUM MINING ENVIRONMENTAL RESTORATION PROJECT (PRAMU)**. The aim of this project is to restore the environment as much as is possible in all places where uranium mining and milling activities were developed while taking into consideration both the economic and technical reality.

The sites being studied are:

— MALARGÜE (Mendoza Province)
— CORDOBA (Cordoba Province)

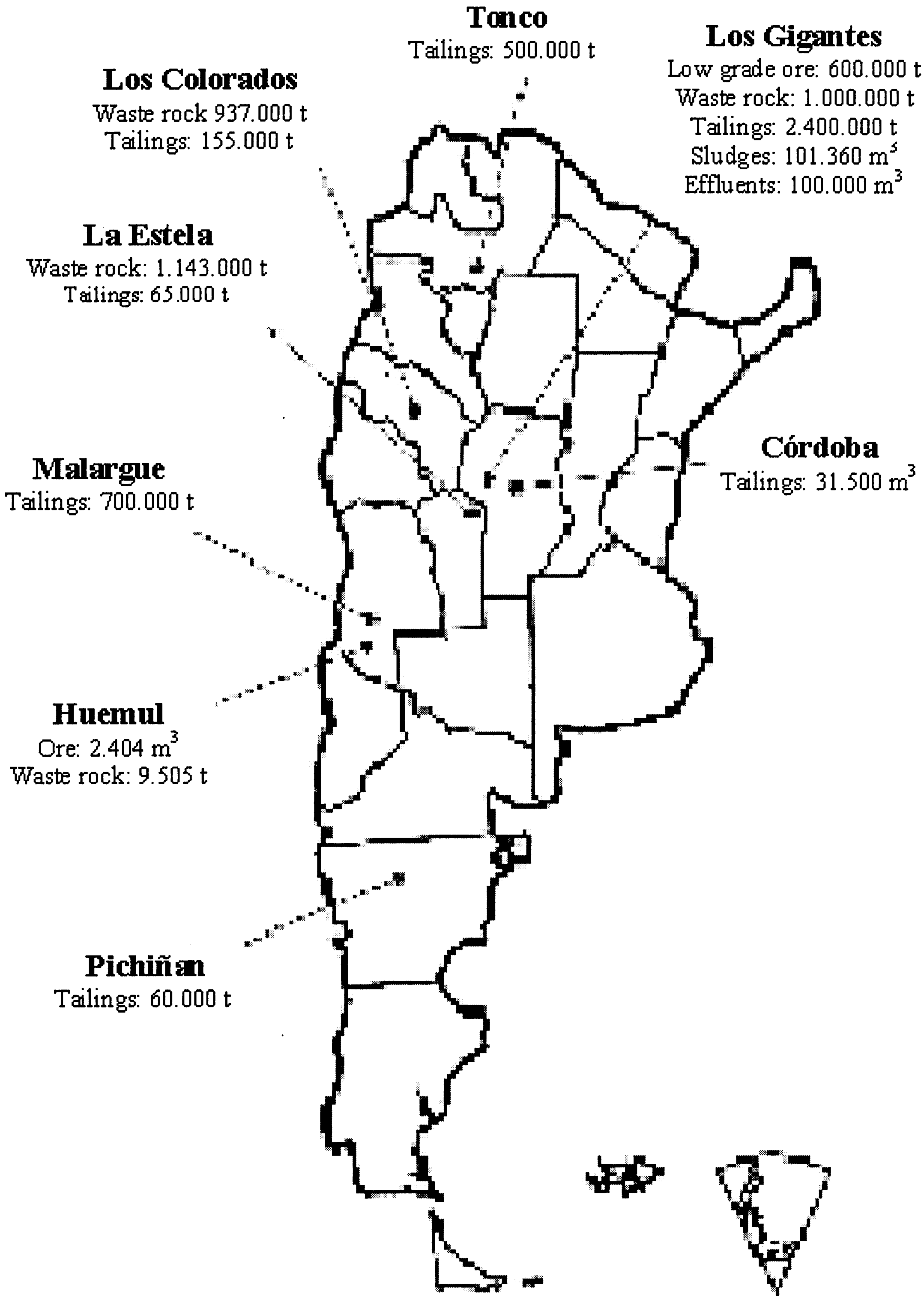

FIG. 1. Location of sites.

- LOS GIGANTES (Cordoba Province)
- HUEMUL (Mendoza Province)
- PICHIÑAN (Chubut Province)
- TONCO (Salta Province)
- LA ESTELA (San Luis Province)
- LOS COLORADOS (La Rioja Province)

Fig.1 shows the location of the sites.

2. ENVIRONMENTAL ASPECTS RELATED TO URANIUM MINING AND MILLING

Uranium mining and milling produce large quantities of radioactive wastes which must be safely managed. Uranium tailings and the associated liquids were produced from the ore treatment operations.

Uranium tailings contain about 85% of the radioactivity of the original ore, while approximately 15% of the radioactivity originally present in the ore is removed with the uranium. After decay of some short lived radionuclides, the final radioactivity of the tailings before discharge amounts to about 70% of the original values. However, the specific radioactivity of uranium tailings is fairly low and is similar to the activity of the original ore.

In spite of its low level, due to the long half lives of some thorium and uranium isotopes in the tailings, the radiological hazard will persist for long periods of time. Thus, to prelude adverse consequences and to minimize environmental impact, actions must be taken to properly close the facilities after ending operations. These actions will ensure that the facilities are kept in safe and stable conditions, and that releases of radioactive or other contaminants are kept both as low as reasonably achievable and below regulatory limits.

3. ARGENTINA: ENVIRONMENTAL POLICY

When implementing its activities the National Atomic Energy Commission (CNEA) is required to comply with all legislation that is in force and is under the control of various state institutions (national, provincial and local).

Fundamentally, all the activities that could generate any type of environmental radiological impact are governed by specific regulations established and monitored by the **Nuclear Regulatory Authority (ARN)**. Based on this mandate, all ARN activities are framed within a philosophy of protection of people and the environment and are directed towards establishing criteria for each activity.

ARN policy strives to improve the existing situation by setting out objectives for continuous improvement in the short term and to keep all involved populations informed of ongoing results. This policy advocates the rational use of resources while pursuing protection of the environment, the public health and the rights of the future generations. To achieve this objective, PRAMU seeks to improve the current conditions of tailings deposits, which, although currently confined and controlled, must be managed to ensure the protection of people and environment from potential future risks.

4. LEGISLATIVE AND REGULATORY FRAMEWORK

Nuclear activity is governed by the following legal regulations:

- Decree Law No.22.498/56, ratified by Law No.14.467.
- Law No.24.804 – National Law on Nuclear Activity – Establishes that "the National Government, through the National Atomic Energy Commission (CNEA) and the Nuclear Regulatory Authority (ARN), shall define the policy, and be responsible for research and development, regulation and surveillance functions in the nuclear field". All activity that can be developed commercially might be undertaken by the National State as well as by the private sector. In its turn, the Law No.24.804 assigns to the Nuclear Regulatory Authority (ARN), fundamentally, the faculty to "issue regulatory standards referred to radiological and nuclear safety".
- National Mining Code, through Law No.24.498, consider nuclear ores as minerals of first and second category as per article 205 of the Mining Code (Text enacted through Decree No. 456/96,

(B.O. 30/05/97)). The above mentioned Code, compels in its article 207, those exploiting mines containing nuclear minerals to present to the competent authority, a plan for the restoration of the natural space affected by the wastes and to neutralize, conserve or preserve liquid or solid tailings and other products having radioactive or acid elements.

- Law No. 25.018 establishes the regime of radioactive waste management, in order to preserve the environment, and creates specific rules on the subject.

5. PLAN FOR ENVIRONMENTAL MANAGEMENT OF URANIUM MINING

The CNEA will conduct the PRAMU project through a Project Executing Unit (UEP), specially created for this purpose. The project is staffed by professionals with experience in the mining and environmental operations. This UEP will be integrated within the functional structure of CNEA and will report to the top executive level.

To provide specific follow-up of environmental aspects, an Environmental Management Unit will be created within the UEP. It is anticipated that during project implementation the UGA will report to the UEP; afterwards it will be merged into the functional structure of CNEA to continue long term environmental control and monitoring.

A Project Implementation Plan has been established which delineates the main line of Project activities and estimates their duration.

6. REMEDIATION OF SPECIFIC SITES

6.1. Malargüe Site

The objective for Malargüe Site is to undertake the actions necessary for environmental restoration and the management of the tailings derived from the uranium minerals that were processed in the industrial plant.

The Ministry of Environment of Mendoza Province has approved the CNEA Environmental Impact Statement (Resolution 738/97). The approved plan for restoration of the Malargüe site specifies relocation of the tailings to an engineered on-site repository.

6.1.1. General information

The Complejo Fabril Malargüe (CFM) is located in Mendoza Province. A conventional processing plant was installed; the flow sheet was based on pilot-plant tests started in 1954. Ores from the Huemul-Agua Botada deposits and Sierra Pintada were treated, and 759 tU were produced. The production plant stopped operating in 1986.

6.1.2. Contamination sources

The quantity of solid wastes at Malargüe is about 700 000 t. The solid wastes are primarily tailings but also include precipitates originating from neutralization of acidic effluents from the processing plant. The wastes cover an area of approximately 6 ha.

The average concentration of radioactive elements in the tailings are:

— U: 155 μg/g
— Ra-226: 12 Bq/g
— Flux of radon-222 over the tailings: 6.1 to 10.1 Bq/m^2s
— Radon concentrations over the tailings: 584 to 5062 Bq/m^3
— Rate of dose over the tailings: 3.4 and 9.7 μSv/h

6.1.3. Estimation of risk

- — Background radiation outside the Site is approximately 0.1 μSv/h.
- — The equivalent dose for a hypothetical group based on the tailings would be between 10 and 89 mSv/y person.
- — A hypothetical population group located at the perimeter of the tailings would receive an annual dose equivalent to 5 to 6 mSv/y.

As a conclusion:

- The wastes deposited at the CFM represent a potential radiological hazard which must be mitigated. The radiological risk derives mainly from the wastes in themselves;
- At the present conditions, a hypothetical population group living permanently at the perimeter of the CFM tailings could receive a higher dose than the limit recommended. In contrast, a temporary presence does not imply receiving doses higher than the admissible ones;
- The effects of the radioactivity on the population of the city of Malargüe, due to the presence of tailings, are so low that with the present control technology they are admissible.

6.1.4. Mitigation proposal

The approved plan for restoration of Malargüe stipulates on-site relocation of tailings into an engineered repository. In 1996 the plant and auxiliary buildings were dismantled and demolished. Presently, the first part of site restoration activities are in progress, and the construction of a underground drainage line has been finished.

The drainage line has been installed upstream and along the edge of the proposed site. The objective of the drainage system is to capture upstream groundwater flow in order to lower the water table under the repository. According to the model used to design the underground drainage, ground water would raise to 1.5 m below the bottom of the cell, only one time in 1000 years. Fig. 2 shows the proposed location of the repository and also the location of drainage system. Fig. 3 shows construction details of the drainage line.

The tailings and contaminated soils management work requires performing the following tasks:

- — **Conditioning of the floor of the new site**: This task will be accomplished by (1) compacting the base (2) placing a compacted layer of gravel (3) Adding a compacted layer of soil and (4) placing a layer of compacted clay of low permeability.
- — **Tailings management:** (1) Tailings will be accumulated over the layer of clay. (2) Neutralization with lime and compactation will be completed (3) Contaminated soils and demolition materials will be placed into the tailings.
- — **Waste material cover:** (1) A layer of compacted clay, plus a layer of compacted top soil and finally a layer of rocks will be put over the tailings (2) An additional layer of top soil, which will serve as a base for an autochthonous pasture, will be put down over the rock. This cover will reduce both radon emanation and gamma radiation. The cover will also prevent the entry of the rainwater into the cell and will act as an erosion barrier.
- — **Decontamination and rehabilitation of the area:** (1) Areas impacted by industrial activity will be excavated and a top-soil cover will be added to meet regulatory requirements. The contaminated soil will be deposited in the tailings impoundment. (2) The area will be landscaped and reforested. (3) Limitations will be established to ensure continuity of the protection barriers.

Fig. 4 shows a profile of the proposal repository.

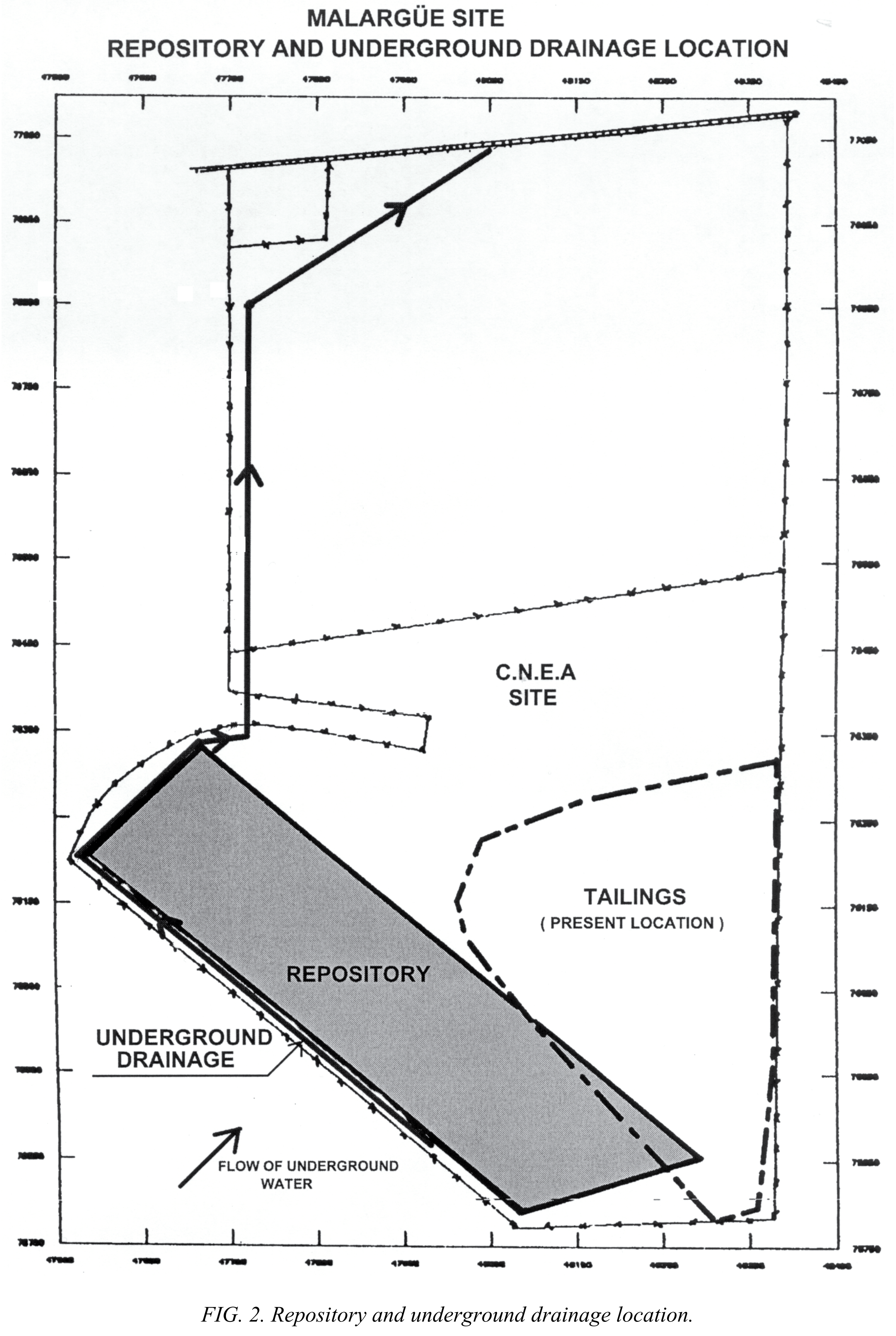

FIG. 2. Repository and underground drainage location.

FIG. 3. Underground drainage construction.

6.2. Cordoba Site

6.2.1. Objective

The objective for Cordoba Site is to design the engineering and execute the necessary activities for closure of the Complejo Fabril Córdoba (CFC) site.

6.2.2. General information

The Complejo Fabril Córdoba (CFC) site is located in the city of Córdoba. The complex covers 9.2 ha. The municipal rules specifies an urban use for the land where the Cordoba Site is located. The Complejo Fabril Córdoba operation was started in 1952 as a pilot-plant to study the production of uranium concentrates. In 1982, a UO_2 plant (150 Tu/y) began production. Total production of UO_2, up to December, 1998, was 1506 tU.

The Cordoba Municipality has imposed, through Ordinance 9652, a series of legal limitations on nuclear activities.

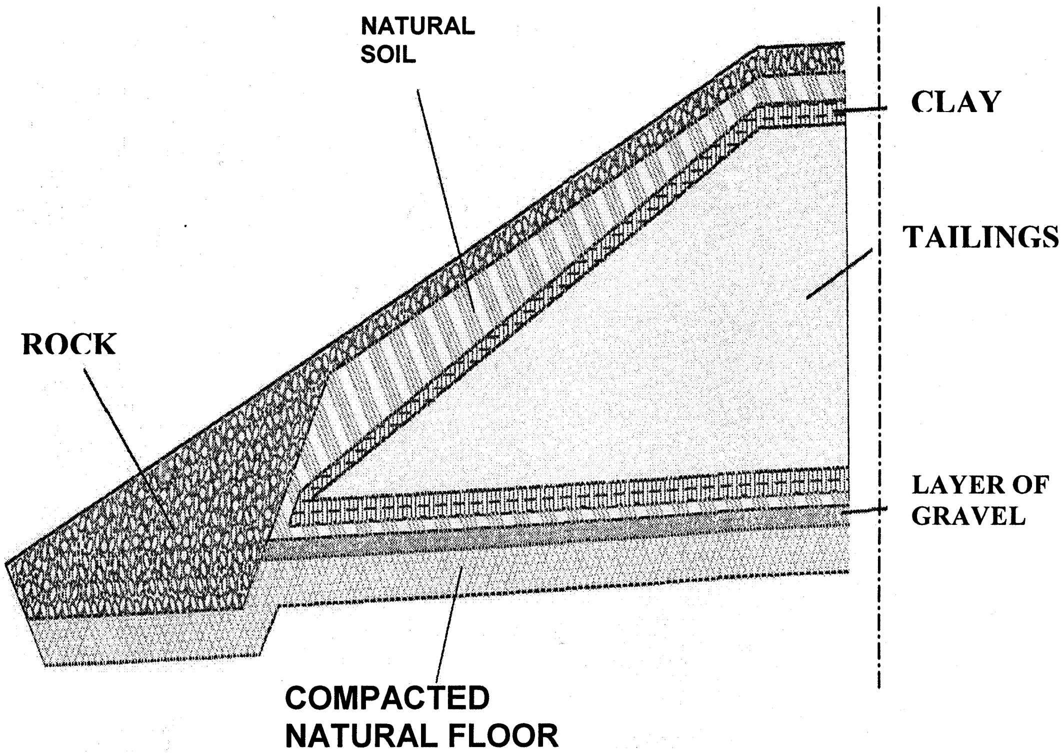

FIG. 4. Repository profile.

This ordinance requires relocation of the Complex within a time frame agreed to by the CNEA. In accordance, the CNEA has agreed to move the UO_2 plant and to remediate the area, which will be designated as a green space.

The Nuclear Regulatory Authority (RQ-85), has also requested the final management of mineral tailings deposited at the site.

6.2.3. Contamination sources

There are 31 500 m^3 of tailings deposited on the site. They come from experimental work on uranium mineral processing. The total quantity of material to be removed from the accumulation zone will be approximately 36 000 m^3, taking into account reclamation of the ground on which the tailings were deposited.
The chemical composition of the tailings is:

— Average U concentration: 337 ug/g
— Average concentration of Ra-226: 11 Bq/g
— Average emanation of radon on the tailings: 6.6 Bq/m^2s
— The average dose rate over the tailings is 4.94 μSv/h, with maximum values of 19.6 μSv/h
— The level of natural radiation or background out side the site is 0.11 ± 0,01 μSv/h

6.2.4. Mitigation proposal

CNEA has established closure procedures for the CFC. Demolition of buildings, tailings removal and area rehabilitation will be performed. The site will be handed over to the Municipality of Cordoba in accordance with the requirements of the national and provincial regulatory authorities.

The CNEA plans to move the tailings to an off-site location. Relocation of the tailing to the Camplejo Minero Fabril Los Gigantes (CMFLG) area is being considered. The CNEA has previously

undertaken uranium mining and milling activities at this location, which is about 100 km from the CFC. Alternative sites within a 50 km radius of Cordoba will also be evaluated. Other contaminated materials from the CFC will also be managed with the tailings.

6.3. Los Gigantes Site

6.3.1. Objective

The strategy for reclamation of the Los Gigantes Site is to first develop the engineering plan and then proceed to closure of the CMFLG site. Dismantling of the facility, management of the tailings and other wastes, and rehabilitation of the area will be undertaken.

6.3.2. General information

The Complejo Minero Fabril Los Gigantes is located in Cordoba Province, 100 km west of Cordoba city. The land where mining activities were performed is rented by CNEA from a Religious Order. The mining activities developed an open pit during the period 1982–1989. The mill produced 206.7 t U as ammonia diuranate. The plant closed in 1990.

6.3.3. Contamination sources

(a) Waste rock: 1 000 000 t
(b) Low grade ores: 600 000 t
(c) Sludges: 101 350 m^3
(d) Tailings: 2 400 000 t
U: 84 μg/g
Ra 226: 1.2 Bq/g
Emanation of radon: 0.33 Bq m^2s
(e) Effluents: 100 000 m^3
U: 0.05 ppm
Ra: 1 Bq/l
$NH4^+$: 250 ppm
Mn: 70 ppm

The dose rates from external irradiation over the wastes, range from 0.39 to 0.45 μSv/h. Off-site measurements, carried out to obtain back ground levels averaged 0.22 ± 0.03 μSv/h.

6.3.4. Mitigation proposal

For closure of the CMFLG, the following actions are proposed which will be submitted to national and provincial authorities for discussion and approval.

Effluents: Chemical treatment procedures for removal of Ra-226, $NH4^+$, and Mn have been developed. Release of the treated effluents to Cajon River will be proposed.

Main dam: After treatment of the existing liquid effluents, the main tailings dam area will be used to store the sludges and probably the tailings from the Cordoba Site. The height of the dam will be lowered to ensure stability.

6.3.5. Tailings

To provide additional stabilization of tailings, construction of several contaminant dams is planned. These dams will be placed in run-off channels to prevent the transport of the tailings downstream. The potential impact of seepage from the tailings is being evaluated.

6.3.6. Sludge dams (0, 1, 2, 3)

The management of these dams will be carried out by placing a layer of waste rock, which will protect the existing mineral tailings and also diminish radon emanation.

6.3.7. Open pit

Stabilization of the open-pit slopes, cleaning and compacting the bottom of the pit will be undertaken to achieve uniform run-off. This work will foster long term stability of the pit walls.

6.3.8. Low grade ore

Part of the low-grade ore will be moved to the main tailings dam area. Transferring this material will improve the stock-pile stability by allowing the existing slope angle to be lowered.

6.4. Other sites (Tonco, Pichiñan, Huemul, La Estela, Los Colorados)

6.4.1. Objective

The objective of PRAMU for these sites is to develop an environmental assessment and, on the basis of the results obtained, to study various technological options for the mitigation of existing and potential future impacts.

6.4.2. General information of the sites

Tonco Site
Located in Salta Province
Wastes:
Tailings: 500 000 t

Pichiñan Site
Located in Chubut Province
Wastes:
Tailings: 60 000 t

Huemul Site
Located in Mendoza Province
Wastes:
Ore: 2404 m3
Waste rock: 9505 t

La Estela Site
Located in San Luis Province
Wastes:
Waste rock: 1 143 000 t
Tailings: 65 000 t

Los Colorados Site
Located in La Rioja Province
Wastes:
Waste rock: 937 000 t
Tailings: 155 000 t

Uranium mining in the North Bohemia, Straz, Czech Republic and geological evaluation prior to remediation

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Abstract. The Straz uranium deposits are located in sedimentary rocks and within important aquifers. One of these is of drinking water quality. The deposits were exploited by both conventional and in situ leach (ISL) methods in two mines: the Hamr-North underground and the Straz (ISL) mine. They are located in an aquifer within sedimentary Cenomanian formation. Between 1967 and 2000 the Straz ISL mine produced over 16 000 tonnes U by injecting a total of 4.1 million tonnes of sulphuric acid, 315 000 t of nitric acid, 112 000 of ammonia, 26 000 of hydrofluoric acid, and 1400 of hydrochloric acid. This enormous amount of acid is creating a major rehabilitation problem and a potential risk for another aquifer: the Turonian drinking water quality aquifer. The problem is now being addressed by completing a complete hydrogeological assessment. Contaminated water is being treated to reduce the present contamination levels of 5-110g/l TDS to less than 10g/l TDS. The rehabilitation will be influenced by economic factors, as well as the development of new technologies.

The North Bohemian uranium bearing region was detected at the beginning of the 60s as a result of a systematic well log re-examination in the area Hamr na Jezere.

Based on geological exploration work the deposit area was identified as a stratiform deposit in sedimentary rock having sub-horizontal tabular position with variable changeable thickness. Uranium deposits of the Straz block in the northbohemian Cretaceous are fundamentally different from other formerly exploited uranium deposits in the CR. It is a region with complicated and unfavourable hydrogeological conditions for mining. Moreover, significant potable groundwater resources are located in the territory.

The deposits are generally flat or gently inclined with irregular mineralized thickness that varies from several dm to several m. Mineralization is associated with several kinds of rock such as sandstone, breccia, conglomerate, and siltstone in which fortress in pressure varies from 2 MPa to 30 Mpa.

Choosing a suitable mining method required the consideration of specific criteria, such as, an underground mining method that prevents subsidence or working with a deposit that has an impermeable strata above the mining area. These criteria limited the choices to either essentially complete backfilling in an underground mine or an in situ leaching technique.

Eventually both methods were used. The Hamr and Brevinste4 deposits were mined by underground methods and the Straz deposit by in situ leaching.

The “room and pillar” (panel and fill) method was chosen for the underground mining operation. This choice was based on tests conducted between 1972 and 1975. Specifically, the method adopted retains pillars to support the roof in the mined out area. The open space or room is then backfilled with a low compressable solidifying material that is brought into the mine from the surface. The mining thickness varied from 2.2 m to 5 m. Each mining block had a width of up to 250 m and a maximum length of 150 m.

Each room had a maximum width of 5 m. Both a three-room system and a four-room, system were used. With the three-room system, a 10 m pillar was retained between the rooms, and a 15 m pillar was retained when the four room system was used. Mining of the secondary room was initiated after the primary room was mined out.

If the mineralized thickness was greater than 5 m, the ore was mined by panel slicing, and the open space was backfilled before mining the subsequent panel slice.

For mining relatively narrow ore seams, a variant of the room an piller method was used, in which each mined out room was totally backfilled before proceeding to the next room. A long-wall technique similar to that used in coal mines was also tested.

Both dewatering of each mining block prior to actual mining and continuous mine drainage during operations was required. Dewatering was achieved both through drifts below the ore block and through drill holes above the ore block. During mining operations at the Hamr mine, it was necessary to pump approximately 15 m m^3 of mine water annually.

The underground mining operations produced about 42.3% of the total uranium recovered from the northbohemian area; the balance (57.7%) came from ISL operations.

After laboratory and field-test verification, ISL technology has been used since the second half of the 60s. The first batch of concentrate from leach field VP-3 was transported to the MAPE chemical mill in Mydlovary on 13 Dec.1967. Leach field VP-3 consisted of two interconnected 8 m hexagons. The field contained 12 wells (10 perimeter and 2 center wells).

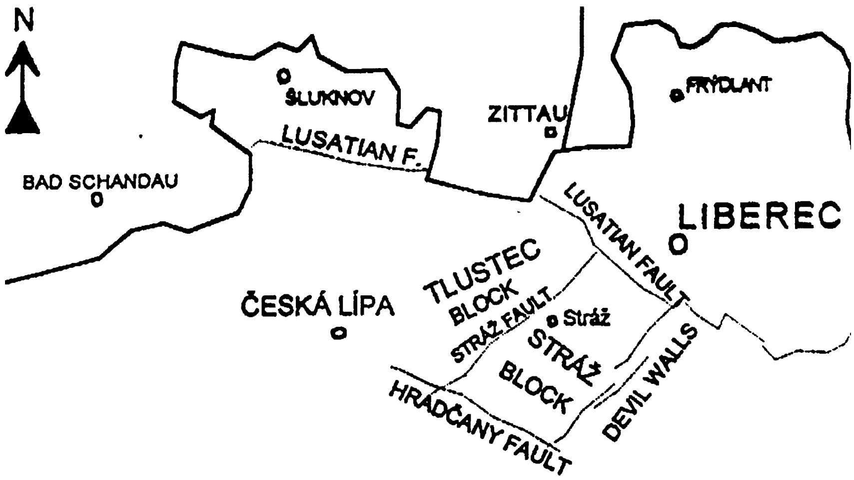

FIG. 1. Situation scheme of Nortbohermian area.

After 1971, the pace of ISL development increased significantly. Step by step, the ISL method gradually replaced uranium production from the traditional mining districts. Much of this change occurred when production stopped at the Hamr-North deep mine due to flooding when the mining operations crossed the saturated Agnes tectonic zone. In 1975, ISL operations covered a total area of almost 210 ha; in1980 the extent was over 300 ha.

Substantial changes in well construction have occurred. Single casing wells were replaced by double cased wells with outer casings. The small diameter pumping wells were replaced by wide-diameter wells.

The straz ISL operations below the Ralsko hill were stopped in 1993. In total it had 42 leaching fields containing 7500 wells and extended over 650 ha.

Between 1967 and 2000 the ISL mines produced over 16 000 t uranium. Reagent consumption totalled 4.1 million tons of sulphuric acid, 315 thousand tons of nitric acid, 112 thousand tons of ammonia, 26 thousand tons hydrofluoric acid and 1400 tons of hydrochloric acid.

ISL and deep mine production methods require different hydrogeological conditions for successful development:

— dry deposits benefit deep-mine operations;
— deposits with Cenomian water levels favour ISL operations.

The existence of both mining methods in a relatively small area led to ISL leach solution excursions towards the centre drainage of the deep mine. Thereby, the contaminants reached the so-called "dispersion area" of acid ISL mine waters. A stable situation was reached after installing a hydraulic barrier between ISL area and the deep mine. Water injection creates an artificial compressive watershed in Cenomanian aquifer.

The ISL wellfields were developed using a series of isometric polygon well patterns (at first hexagonal, later square) with varying distances between wells.

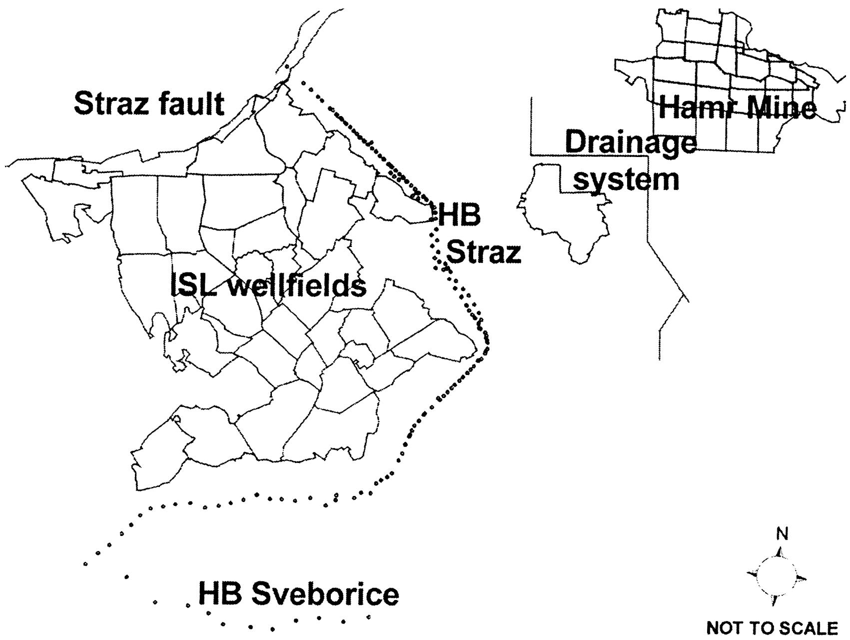

FIG. 2. Situation scheme of mining area.

A number of different well patterns were tried on one hectare plots of the leaching field. The highest density of 15 to 30 wells/ha was achieved using the square pattern; the lowest density of 4-8 wells/ha was realized with wide-spaced wells.

At present, the contaminated ground water in the Straz deposit and its surroundings (approx. 24 km^2 with about 270 mil. m^3) contains 4.8 mil. t of dissolved substances. Approximately 99.5% of dissolved solids are concentrated in the Cenomanian aquifer; the remaining 0.5% of the contamination is dispersed in 80 mil. m^3 of groundwater in the turonian aquifer.

The contaminated ground waters are not naturally attenuated in the aquifers. If the situation is not actively addressed, it will in time lead to dispersal of the contamination and to negative impacts on the groundwater quality over a wide area.

In 1996, a treatment facility (SLKR) was installed to decontaminate the acid solutions. One unit of this facility treats the turonian waters using membrane technology, and the second operation uses evaporation for the Cenomanian waters. At present, the SLKR operation is showing its positive influence by reducing the volume of the contaminated ground water in the cenomanian formation.

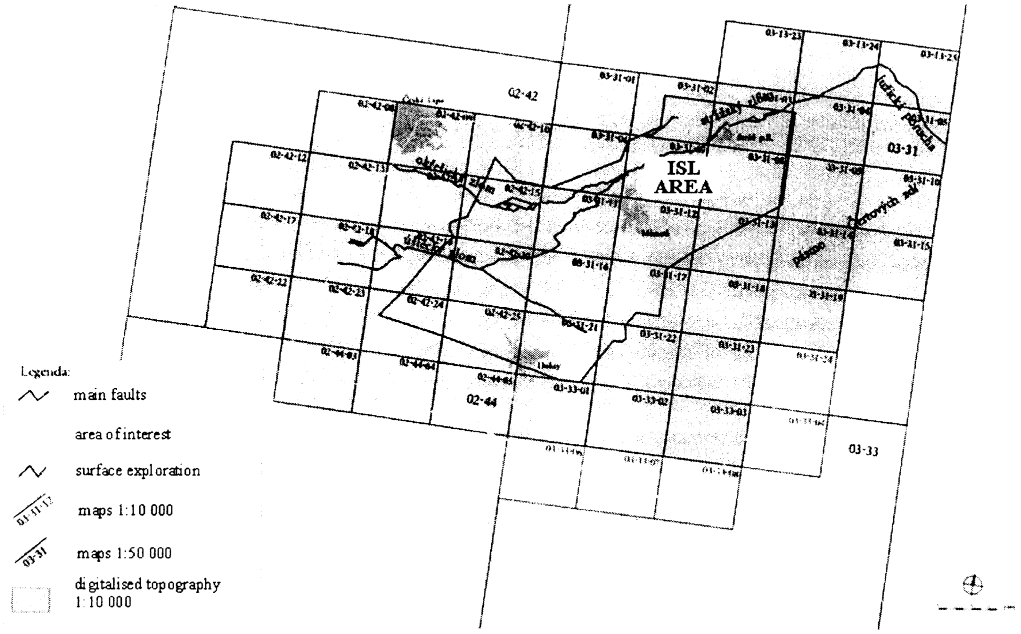

FIG. 3. Explored area.

The ISL production of uranium from the Cenomanian sandstones in Northern Bohemia was carried out in a part of the geological structure which has two main aquifers with one aquiclude between them. Mining activities have influenced both the quantity and quality of the groundwater. After 1990, the environmental point of view changed rapidly. During an analyses of ISL and deep mining impact, the large amount of contaminated water from ISL (approx. 200 000 000 m^3 having approx. 50 g/l TDS) was determined to be the greatest potential risk in the area.

At the beginning of the 1990's, extensive geological exploration work was done in the area south-west of the ISL plant, which is the direction of natural groundwater flow from the ISL area. This work was conducted to determine whether there was a geological risk that contaminated groundwater could transfer from the Cenomanian aquifer to the overlying Turonian aquifer or to the surface.

A complex of exploration methods ranging from small to comprehensive scale was established to qualify and quantify the risks. This complex approach answered the questions in a very short time. The applied methods had a logical sequence.

The first phase consisted of synoptic methods such as:

- satellite imaging photos and their evaluation,
- air-borne geophysics and their evaluation,
- re-interpretation of older geological and geophysical data,
- regional hydraulic mathematical models of groundwater flow.

The second phase concentrated on the areas, which appeared risky after the first phase. The work consisted of:

- surface geophysics,
- surface geological exploration

Phase 2 focussed on the most risky parts of the geological structures, such as faults with significant vertical movement etc. Results of this exploration were gradually put into the regional hydraulic mathematical model.

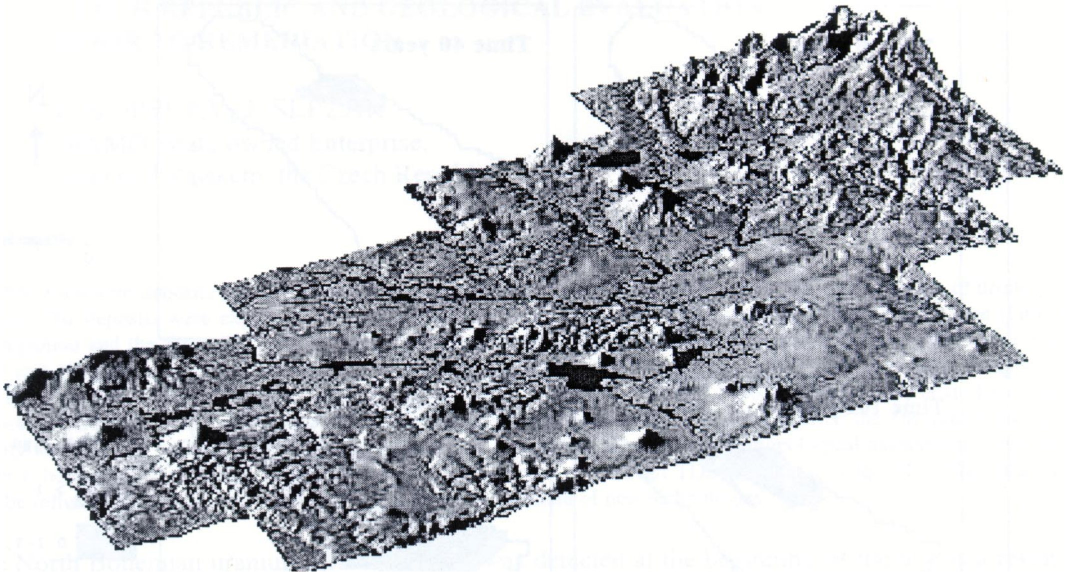

FIG. 4. Surface 3D map of the area from GIS data.

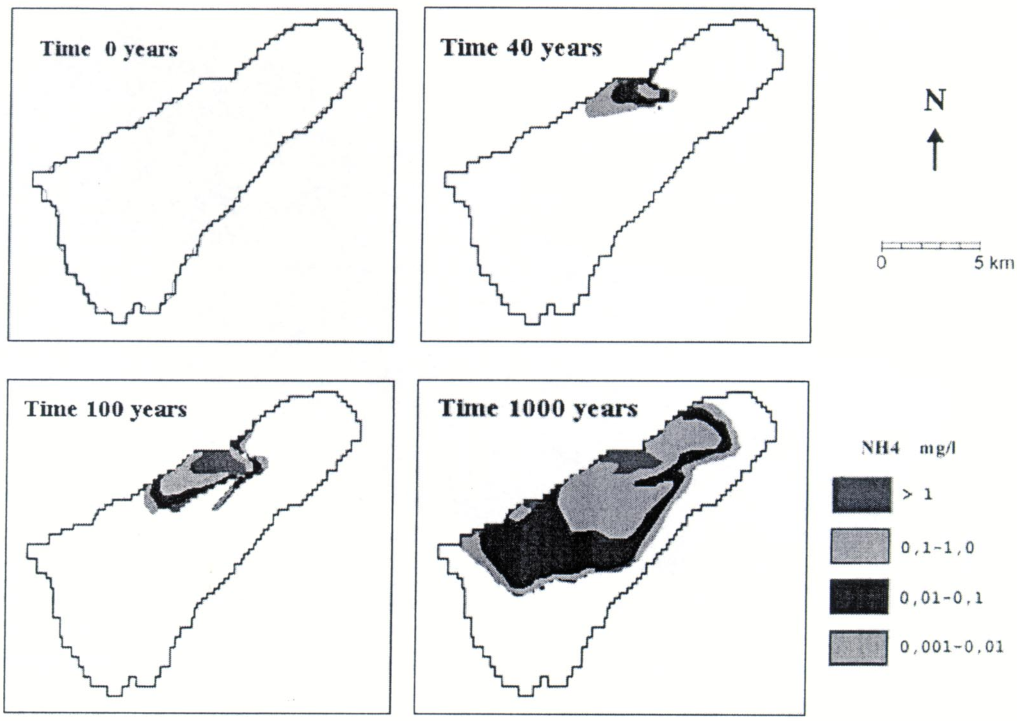

FIG. 5. Calculated contamination caused by ammonia ions in time.

The results showed the necessity for confining the contaminated groundwater to the ISL area and supported remediation targets such as:

- recovery of solutions from the cone of depression in the area of ISL,
- time-spatial course of contaminated water recovery,
- preliminary setting of limits for final content of contaminants.

The following main targets influenced the systematic implementation of the exploration work:

- **final exploration output** (more accurate structural-geological knowledge in the area of interest, determination of geological risk elements),
- **deadline for the problem resolution** (before decision on further remediation actions and setting the clearance levels),
- **financial requirements** (approximately US $1.3 million between 1992 to 1998. It was covered by the Ministry of Economics, Ministry of the Environment and by DIAMO itself),
- **initial knowledge of the geological and hydrogeological conditions** (different in individual parts of the area of interest – the highest level of knowledge was of course in the area of uranium deposits, the lowest level was in the former military training area situated SE),
- **availability of exploration methods** (there was sufficient number of external suppliers).

The results of exploration works showed the high importance of hydrogeological works for evaluation of old reminders, especially in sedimentary complexes.

Contamination caused by ISL operations constitute a potential risk to the Turonian aquifer water sources in the area ($n*10^2$ km^2) over a long period of time ($n*10^2$–10^3 years). The area and time will be influenced by final clearance level for the Cenomanian aquifer. It is expected the water must be treated to reduce the present contamination levels (5-110 g/l TDS) to less than 10 g/l TDS. The remediation will also be influenced by economic factors, time and development of new treatment technologies in the future.

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Use of special oedometer tests for the remediation of large uranium mill tailings impoundments at Wismut, Germany

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Abstract. The paper presents the use of recently developed special oedometer tests for designing the remediation of large uranium tailings ponds at WISMUT, Germany. Uranium ore mining and milling in eastern Germany by the former Soviet-German WISMUT company lasted from 1946 to 1990. Wastes from the hydrometallurgical uranium extraction processes were discharged into large tailings impoundments covering a total area of 5.5 km^2 and containing about $150 \times 10^6 \cdot m^3$ of uranium mill tailings. Tailings pond remediation is ongoing by in-place decommissioning with dewatering by technical means. Geotechnical properties and the most suitable so-called non-linear finite strain consolidation behaviour of fine uranium mill tailings are described. Decommissioning techniques comprise, among others, interim covering of under consolidated fine tailings, contouring of tailings surfaces and final covering. Contouring, in particular, has a huge potential for optimization in terms of cost reduction. For contouring total settlement portions, the spatial distribution of differential settlement portions and the time-dependent settlement rates, especially of the cohesive fine uranium mill tailings are of critical importance. A new special oedometer KD 314 S has been developed to generate all the input data needed to derive the fundamental geotechnical relationships of void ratio vs. effective stress and of permeability coefficient vs. void ratio for consolidation calculations. Since December 1999 the new special oedometer KD 314 S has been working successfully on fine uranium mill tailings from both acid and from soda alkaline milling. Results coincide with non-linear finite strain consolidation theory. The geotechnical functions derived were used as input parameters for consolidation modelling. An example of the consolidation modelling on Helmsdorf tailings pond is presented.

1. INTRODUCTION

A new special oedometer test apparatus, called KD 314 S, has recently been developed at WISMUT for special consolidation testing on weak or pulpy uranium mill tailings. Results from these special oedometer testings are needed to reliably characterize the time-dependent consolidation behaviour of fine uranium mill tailings, which is of fundamental importance for the remediation of the large uranium tailings ponds at WISMUT.

The automatic special oedometer test apparatus KD 314 S was jointly developed by WISMUT and WILLE Geotechnik, Göttingen in 1998/99 (Fig. 1; Fig. 2). Technical optimization of the apparatus for conducting consolidation tests on fine uranium mill tailings was carried out in a diploma thesis [1] developed at WISMUT with the support of the Technical University of Zwickau (FH), Germany in 1999. In addition, the testing procedure has been adopted by WISMUT for generating all geotechnical input data needed for consolidation modeling on fine uranium mill tailings.

Since December 1999, several special oedometer testing campaigns have been carried out on uranium mill slime tailings from different tailings ponds at WISMUT. Some of the results are presented below.

Fine grained, cohesive uranium tailings of weak or pulpy consistency covers a huge area on the WISMUT tailings ponds. Fig. 3 presents a 3D-model of Helmsdorf Tailings Pond (area: 2.05 km^2, tailings volume $45 \times 10^6 \cdot m^3$). Cohesive fine tailings in the pond area are characterized by an undrained

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shear strength values below 5 kPa near the surface. Such tailings cover about 0.70 km^2 of the Helmsdorf tailings pond. The entire Helmsdorf tailings pond is to be covered during remediation. High absolute settlement segments and local differential settlement segments must be taken into account due to covering requirements. To significantly reduce remediation costs it is of critical importance to know exactly the geotechnical consolidation characteristics of these fine uranium mill tailings.

Conventional oedometer test procedures were found unsuitable for accurately determining the consolidation characteristics of such fine tailings materials. In the past, it was impossible to fill the oedometer cell with tailings pulp and run a conventional oedometer test successfully. The new special oedometer test KD 314 S was developed to address this problem.

in the foreground: electromechanically driven automatic press with oedometer cell (red tube)

in the background: oedometer testing controled by steering computer

FIG. 1. Special oedometer test apparatus KD 314 S.

oedometer cell (internal diameter: 200 mm, max. samples height: 190 mm) measured test parameters:

at the bottom:

base loading force (0...15 kN, three sensors à 0...5 kN)
pore pressure (0...300 kN/m^2, accuracy 0.6 kN/m^2)

on top: surcharge loading force (0...10 kN) and settlement (mm)

FIG. 2. KD 314 S Oedometer cell.

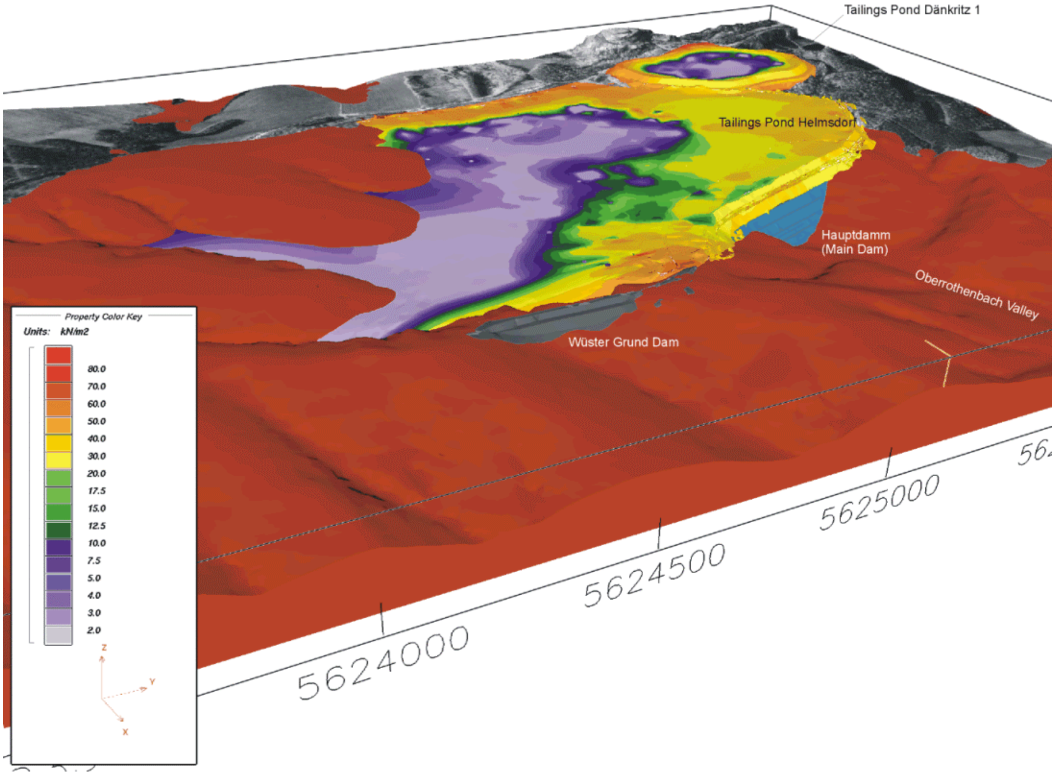

FIG. 3. Model of 3D-distribution of undrained shear strength (in kPa) in Helmsdorf (205 ha) and Dänkritz 1 (27 ha) tailings ponds (3D-model covered with airborne photograph in the background; software: EarthVision).

2. BACKGROUND OF URANIUM MINING AND MILLING HISTORY AT WISMUT

In eastern Germany, uranium ore mining and milling by the former Soviet-German WISMUT company lasted from 1946 to 1990. Wastes from the hydrometallurgical uranium extraction processes were discharged into large tailings impoundments covering a total area of about 5.5 km^2 and containing about 150 × 10^6·m³ of uranium mill tailings.

Uranium ores were milled by acid leaching or soda alkaline leaching. Acid milling pulps were neutralized before discharge into the tailings ponds. In addition some of WISMUT's tailings ponds were used as water storage basins. Currently only residues from water treatment are still being discharged into two of WISMUT's tailings ponds.

Near Seelingstädt/Thuringia two old open pits were covered by waste dumps and dams before tailings deposition started. Trünzig A and Trünzig B tailings ponds were filled in the 1960s. Culmitzsch A and B tailings ponds were filled from 1967 until 1991. The tailings ponds near Seelingstädt cover a total area of nearly 3.5 km^2.

Near Crossen/Saxony, the Helmsdorf tailings pond was constructed and filled during the period from 1957 until 1990 in a valley. Two smaller tailings ponds Dänkritz No. 1 and No. 2 were constructed and filled earlier in the 1950s within old open gravel pits.

Controled by the milling/discharge history and the discharge pattern, different tailings materials with spatially varying geotechnical properties were deposited in each tailings pond. Because the historic discharge patterns varied, beach zones of sandy tailings, transition zones with interlayering of coarse and fine tailings and fine tailings zones containing thick homogenous fine tailings developed in each tailings pond. As shown in Fig. 3, beach zones in the Helmsdorf and Dänkritz-1 tailings ponds are

characterized by undrained shear strengths above 15 kPa. So-called transition zones are characterized by shear strength variations between 5 and 15 kPa. Fine tailings zones show shear strength values that are usually below 5 kPa in the upper most tailings near the surface.

The total amount of uranium in the solids deposited in the WISMUT tailings ponds is 15.3×10^6 kg. The total amount of radium in the solids is 1.5×10^{15} Bq and the average Radium concentration of solids is 9 Bq/g. The Helmsdorf tailings pond also contains 7.6×10^6 kg of arsenic in the solids.

3. REMEDIATION OF WISMUT's LARGE URANIUM MILL TAILINGS PONDS

Remediation measures started in 1990 with defence measures against acute risks, together with complex environmental investigations and preparation of the first site-specific remediation concepts. Currently, none of the tailings ponds present any acute danger to human health or the environment. Based on extended investigation programmes, WISMUT has decided to start preparations for using the remediation option of in place dry decommissioning with partial dewatering by technical means.

Decommissioning techniques for the dry option comprise, at least the following activities: (1) initial defence measures against acute dangers, (2) removal and treatment of pond water, (3) interim covering including technical dewatering of (unconsolidated) fine tailings, (4) reshaping of tailings dams and contouring of interim covered tailings surfaces and (5) final covering and landscaping including revegetation.

As a first defence measure, interim covering started in 1990 on sub-aerial sandy tailings surfaces of the so-called beach zones to guarantee dust control and to significantly reduce radon exhalation from the tailings surface.

Removal and treatment of pond water has lowered the water level progressively in the past. More and more fine tailings surfaces lost their water cover. Currently, all of the pond water has been removed from several tailings ponds at WISMUT.

From a geotechnical perspective, interim covering of poorly consolidated fine tailings is the next and most decisive step of the overall decommissioning technology. Various interim covering methods were tested successfully at WISMUT in the past. By 1995 the entire Trünzig A tailings pond (total area 0.67 km^2) had received an interim cover. WISMUT is currently placing interim covers on the transition zones and fine tailings zones of all other tailings ponds. Currently there is no acute danger from dust pollution, and the radon exhalation rate on sub-aerial cohesive fine tailings surfaces is limited. Because of these effects, interim covering of the fine tailings surfaces is not primarily an acute defence measure but works as a first stable platform for further remedial measures.

Prior to interim covering of the fine tailings area, the drying-out of sub-aerial fine tailings surface has been used primarily to improve trafficability. Interim covering measures on fine tailings surfaces start with the placement of (1) geotextile, (2) geogrid and/or (3) combined geomaterials like drainmats on the dried "tailings crust". Technical dewatering is enhanced by stitching vertical wick drains into the tailings. Loading of the tailings surface is carried out by progressively placing (thin) earthen layers using common earthwork machines like small dozers or hydraulic excavators.

The next remediation step is contouring. Reshaping the dams is done to guarantee long term stability and long term erosion control of the dams and their final cover. Contouring the pond area prepare for later final covering. Contouring creates a long term stable surface contour to ensure future surface runoff from the final cover. At the Trünzig A tailings pond, WISMUT will start reshaping the first tailings dam this year. It is anticipated that contouring the pond area of the Trünzig A and B tailings ponds will begin in 2001.

The contouring step, in particular, has a huge potential for optimization of cost reduction. Cost-optimization of contouring means minimization of the cut and fill materials that are needed to reach

remediation objectives. To design for contour after total settlement, spatial distribution of differential settlement characteristics and time-dependent settlement rates, especially of the cohesive fine uranium mill tailings, are of critical importance. The Helmsdorf tailings pond encloses an area of about 2.05 km^2. Its fine tailings area covers about 0.70 km^2.

Reducing the average thickness of earthen cover layers required for contouring by only 1 m of thickness on an area of 0.5 km^2 means a reduction of approximately 3.3 million EUR. Therefore, the needed thickness of contouring should be minimized locally on each part of the tailings pond. The requirements are based on sophisticated calculations of time-dependent settlement rates and spatial differences of absolute settlement in each segment of the pond area. This is of critical importance for cost-optimization. This cost-optimization can only be carried out correctly if the consolidation behaviour of the fine tailings can be predicted exactly.

The KD 314 S special oedometer test was developed to accurately measure the consolidation behaviour of fine uranium mill tailings. From the test results, all input parameters for consolidation and settlement calculations on fine uranium mill tailings can be derived. Tailings consolidation properties are presented below.

Final covering is the last remediation step. The final cover must ensure long term stability of the reshaped dams and contoured tailings. It must control infiltration, and prevent erosion in the long term. The cover should also guarantee stable revegetation. At WISMUT's tailings ponds, final covering of contoured tailings ponds and dams will be completed within a few years.

4. GEOTECHNICAL CHARACTERIZATION OF FINE URANIUM MILL TAILINGS

Uranium tailings were generated by acid or alkaline leaching. Huge settlement variations and considerable spatial differential settlement can be expected in tailings pond areas where thickened fine tailings were deposited under the water table. Since deposition, these areas have never been influenced by air drying or any surcharge loading. Therefore interim covering refers to the initial loading of these slimes.

Typical physical properties of fine tailings are presented below for the alkaline slime tailings of the Helmsdorf tailings pond Helmsdorf:

- grain size: 60 ... 80% silt fraction (0.002...0.063 mm)
  20 ... 40% clay fraction (<0.002 mm), nearly no sand fraction
- water content: w = 70 ... 140 weight % of solids mass
- void ratio: e = 2 ... 4
- liquid limit: LL = 45 ... 70 weight%
- plasticity index: I_P = 22...40 weight%
- Consistency index: $I_C = -4 ... -0.1$ (liquid consistency acc. to Casagrande liquid limit test)
- Undrained shear strength near surface 0 ... 5 kN/m²

Cohesive fine uranium mill tailings are typically silts or clays of high plasticity. Consistency under field conditions is often weak or pulpy. The typical mineralogical composition of the Helmsdorf fine tailings is 40 ... 50% muscovite-illite, 20% quartz, 15% chlorite, 7% feldspar, 5% dolomite, 3% calcite, some kaolinite.

The permeability coefficient is low and depends on the in situ void ratio. It varies in the range of 5×10^{-8} to 5×10^{-10} m/s. Compression index C_C of fine tailings increases with increasing distance from the original discharge location. In the fine tailings zone, the compression index increases from $C_C = 0.30$ next to the beach zone up to $C_C = 0.55 ... 0.65$ in the distal tailings zone. The time-dependent consolidation behaviour of fine uranium mill tailings cannot be described exactly by conventional Terzaghi consolidation theory. A much more realistic determination of the time-

dependent consolidation behaviour is given by the non-linear finite strain-consolidation theory as described by GIBSON et al. (1981) [2]. This geotechnical consolidation behaviour is of fundamental importance for remediation progress.

Conventional theory, which holds that deformation and pore pressure dissipation have a one-to-one coincidence is not valid! This can seriously effect laboratory determinations of strength parameters and stability calculations [3]. It should be noted that non-linear finite strain theory predicts a progress of settlement that is substantially faster than predicted by conventional Terzaghi theory. On the other hand, pore pressure decrease occurs substantially slower. In addition, fine tailings may be under consolidated. In this case self-weight consolidation and settlement under surcharge loading are additive, which increase this geotechnical problem. Fig. 4 presents an example from SCHIFFMAN et al. (1984) [3] of a consolidation calculation for loading a marine clay with 200 kPa. In Fig. 4 one observes that the degree of settlement is faster than the degree of pore pressure decrease, as was stated above. Such consolidation behaviour is typical for mine waste (mill) tailings and natural cohesive marine sediments being deposited under water [3].

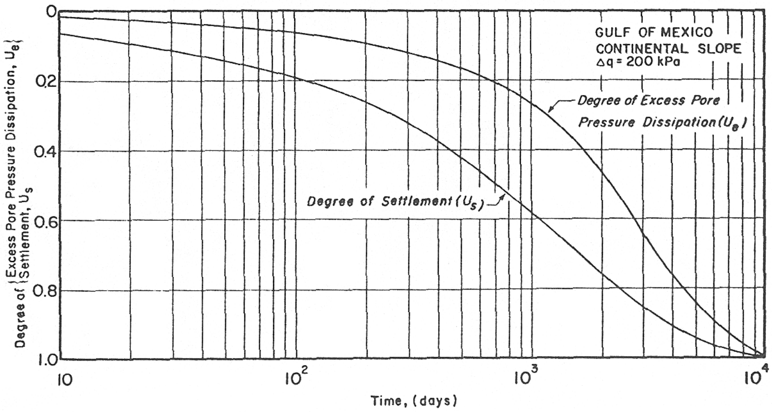

FIG. 4. Diagram of degree of time-dependent settlement and degree of pore pressure decay acc. to non-linear consolidation behaviour of a marine clay form the continental slope of the Gulf of Mexico [3].

5. RECENTLY DEVELOPED SPECIAL OEDOMETER TEST APPARATUS KD 314 S

Standard lab compression tests, such as the DIN 18137, were found to be unsuitable for investigating pulpy cohesive soils for a number of reasons. These tests cannot measure pore pressure during testing. Samples must have a flat shape with a height vs. diameter ratio of less than 1 to 5. Otherwise the geometry of a “high” sample would effect the measurement of loading pressure on the sample. In international geotechnical investigation campaigns on tailings ponds, these effects have often not been taken into account properly.

The task to be solved was to design and construct an improved compression test apparatus and to develop a methodology for deriving all the input data needed for non-linear finite strain consolidation calculation and modelling on fine uranium mill tailings. Geotechnical input functions, which should be derived from the special oedometer test results, are the relationship of void ratio to effective stress and also the permeability coefficient to void ratio.

The automatic oedometer test apparatus KD 314 S was jointly developed by WISMUT and WILLE Geotechnik, Göttingen in 1998/99 (see Fig. 1 and Fig. 2). The lab test was optimized for pulpy fine uranium tailings in a diploma thesis developed at WISMUT with the support of the Technical University of Zwickau (FH), Germany in 1999 [1]. The apparatus consists of an oedometer cell, a consolidation press with an electromechanical driving mechanism and a PC for test steering (see Fig. 1). The KD 314 S oedometer cell is based on a similar oedometer cell, that had been developed earlier to carry out consolidation tests on fine soft harbour slimes by the Bundesanstalt für Wasserbau (Federal Bureau on Hydraulics Construction, Hamburg, Germany). Only oedometer cell dimensions

and measurement principles were adopted from the aforementioned apparatus. The new special oedometer KD 314 S test works automatically. It allows software-controlled testing and continuous measurement of all parameters of interest that are related to the material behaviour of consolidating fine-grained uranium mill tailings. Usually, samples with a 200 mm diameter (314 cm^2) and about 150 mm in height are tested.

The ratio of height to diameter of the sample varies during testing from 1:1.33 up to 1:5. This must be taken into account for evaluation of the test results. Parameters measured during testing include settlement value, surcharge pressure (load) on top, base pressure at the bottom of the sample as well as pore pressure. Based on these parameters it is possible to eliminate the effect of the test sample geometry.

Tailings samples can be loaded gradually in response to the gently with respect to non-linear consolidation behaviour of the fine slime tailings. Usually one starts with 1 kPa surcharge pressure. Subsequently, surcharge loading is applied to conform with the consolidation behaviour of fine tailings and according to the requirement of suitable covering technology. Typically loading is done in steps of 4, 8, 12, 20, 50, 100, 200, 300 kPa of surcharge load.

6. GEOTECHNICAL RESULTS OF SPECIAL OEDOMETER TESTS

Since December of 1999 the new special oedometer has been used regularly and many measurements have been made on the consolidation behaviour characteristics of fine uranium mill tailings at WISMUT. Results have confirmed the applicability of the KD 314 S oedometer test for fine-grained, especially weak or pulpy, uranium mill tailings. Tailings samples were loaded gradually to conform to the non-linear consolidation behaviour of the slime tailings. All the data needed to determine input parameters for further calculations of time-dependent dewatering and consolidation of such fine tailings were measured directly and automatically.

Very high sample compaction was observed for pulpy fine tailings samples. A surcharge loading of only 10 kPa on pulpy fine tailings samples often produces a 25% reduction in samples height. A final loading of 250 kPa often reduces the sample height up to 50% and more. This leads to a varying sample geometry. To determine the effective consolidating stress in the sample, one has to eliminate the effect of the sample's geometry. Therefore, base pressure is measured time dependently.

The diagram of Fig. 5 presents measurement data for the time-dependent settlement of fine uranium mill tailings when using a 25 kPa surcharge loading. The plot illustrates that the degree of settlement is faster than the degree of pore pressure decrease. This is typical for non-linear finite strain consolidation behaviour. It is the same consolidation behaviour as presented on Fig. 4 and described by SCHIFFMAN et al. (1984) [3] as typical for mine waste (mill) tailings and natural cohesive marine sediments.

Based on the measurement results, one can determine the compression curve (void ratio vs. effective stress) and the permeability coefficient vs. void ratio relationship of fine tailings. Typical testing results are presented in Figures 6 and 7. Fig. 6 shows a typical curve of void-ratio vs. effective stress (load: 5 ... 250 kPa) Fig. 7 shows the permeability coefficient vs. void ratio relationship derived from the time-settlement curves of each loading step.

This function can be used to predict settlement rates using conventional consolidation calculations. In fact, this function does not represent the true permeability coefficient because pore pressure decay is slower than that of the settlement rate. Because of this, one determines a filter velocity.

For non-linear finite strain consolidation calculations, true permeability coefficient data are needed. For this permeability coefficient, each loading step must be determined from time-dependent pore pressure decay or by correcting the time-settlement data in accordance with the observed delay of pore pressure decay (see Fig. 5).

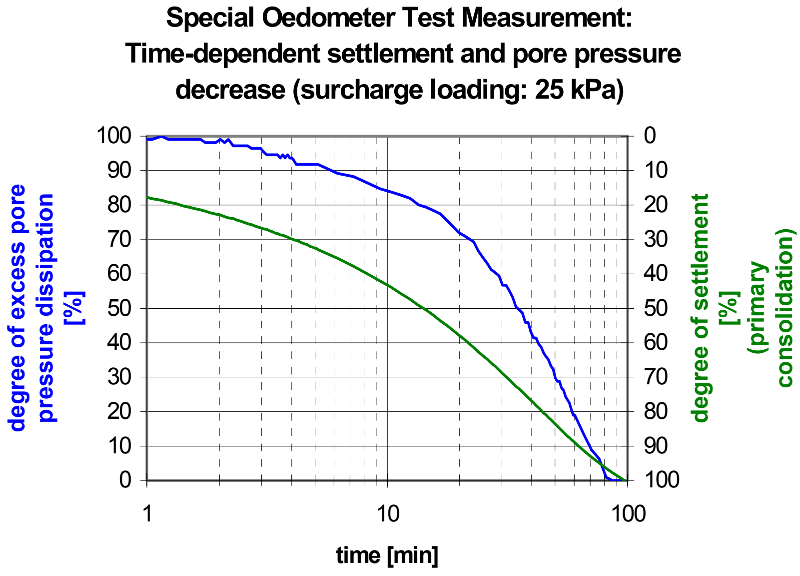

FIG. 5. Diagram: Example of measured time-settlement data on fine uranium mill tailings (WISMUT; Dep. of Eng.; geotechnical lab).

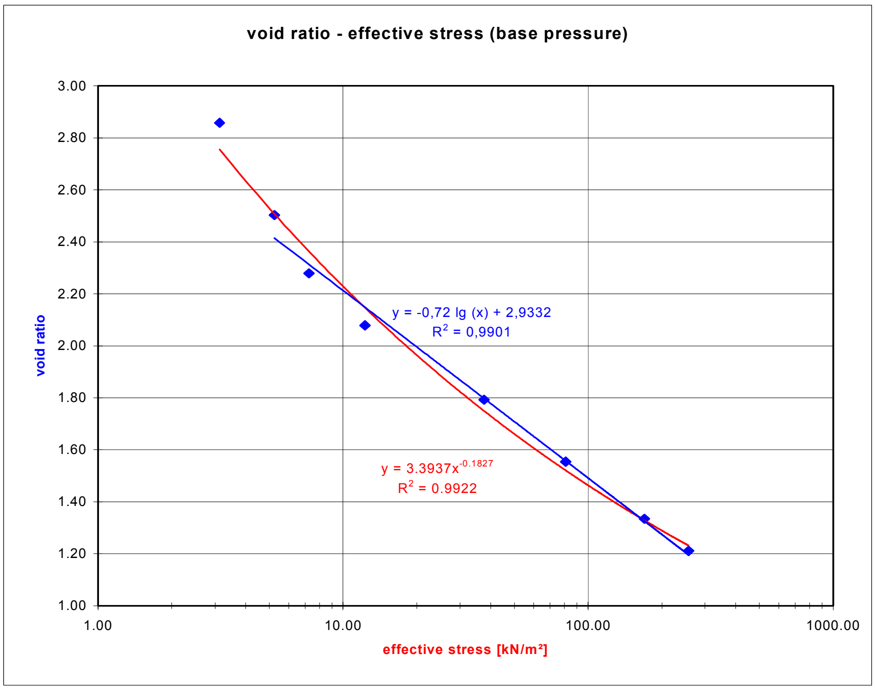

FIG. 6. Diagram: void ratio - effective stress relationship derived from load – settlement analysis.

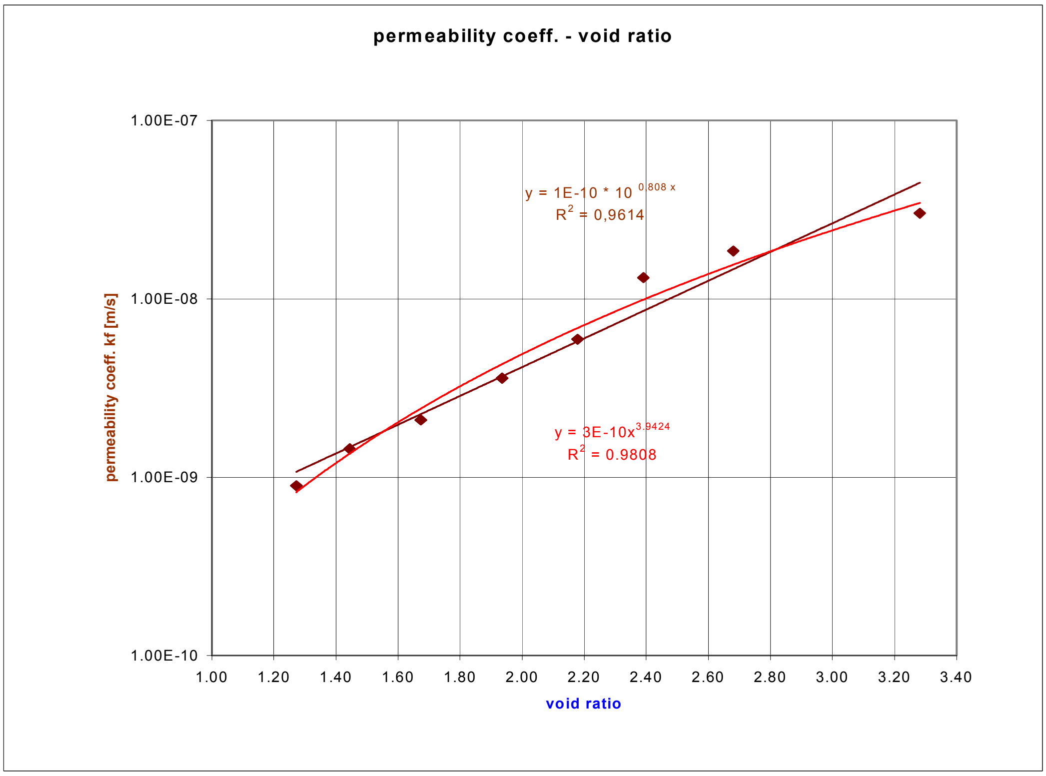

FIG. 7. Permeability coefficient – void ratio relationship derived from time-dependent settlement analysis.

7. USE OF SPECIAL OEDOMETER TEST RESULTS

The results obtained have already been used successfully as input data for consolidation modelling on the Helmsdorf tailings pond. Non-linear finite strain theory was applied in one-dimensional computer code. Spatial distribution of the total settlement values were illustrated using the software Earth Vision (see Fig. 8). The figure shows the areas, which have a total settlement of greater than 2 m beneath a final cover that would produce a loading of 100 kPa. Total settlement as well as time- dependent development of settlement must be taken into account when designing and planning the surface contour of the final cover for optimum remediation. The final cover must guarantee a stable surface runoff over the long-term. Based on these settlement calculation results, contouring will be optimized and the volume of cut and fill materials removed will be minimized. Therefore, results from the recently developed new Special Oedometer Test Apparatus KD 314 S will distinctly minimize remediation costs.

Special Oedometer Test KD 314 S can be used to measure the geotechnical compression or consolidation behaviour for all sorts of cohesive soils or tailings. In addition, the permeability of pulps and pulpy slimes can be measured reliably as a function of the void ratio of the “soil” or as a function of the solids content of the “pulp”. This testing method is able to work at the boundary between soil and pulp material. The Special Oedometer Test KD 314 S is a very helpful tool for readily determining the geotechnical tailings properties required for designing, planning and operational control of recent and future mill tailings impoundments.

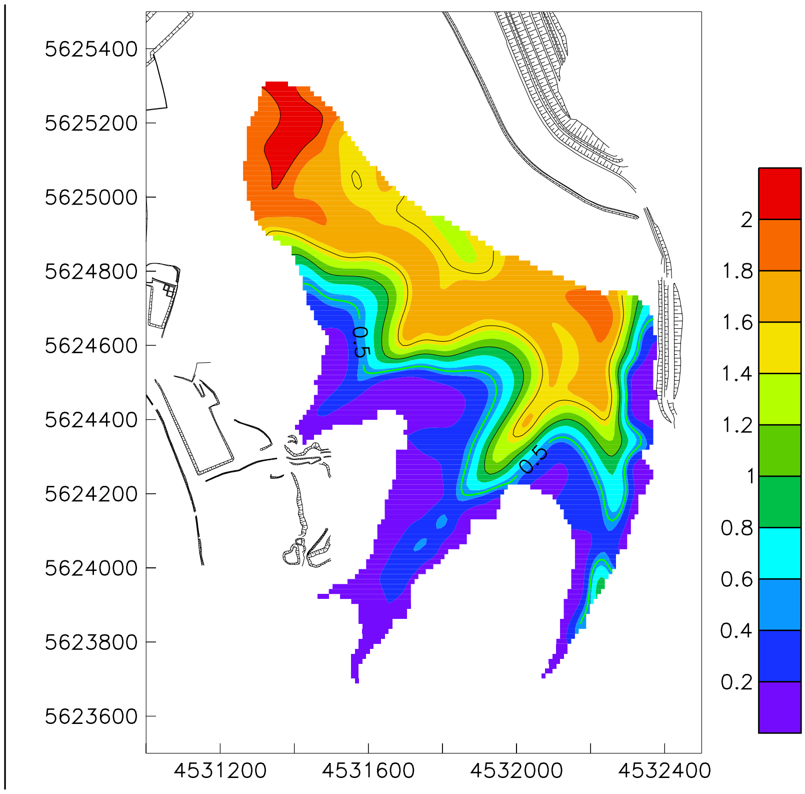

FIG. 8. Tailings Pond Helmsdorf: Spatial distribution of settlement portions under a cover load of 100 kPa in the fine tailings zone as derived from non-linear finite strain consolidation modeling.

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Experience with restoration of ore-bearing aquifers after in situ leach uranium mining

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Abstract. In many cases the most important environmental issue for in situ leach uranium mining technology is the impact on groundwater. Usually the greatest issue is the chemical condition of the ore bearing aquifer following the completion of leaching. Based on experience gained during post leach monitoring, it has been found that in properly selected sites the impact following leaching is greatly reduced because of the process of self restoration, otherwise known as natural attenuation. This paper provides ground water monitoring data from 1985 to 1997 following completion of leaching at the Irkol uranium deposit, Kazakhstan. It shows the evolution of the pH, and other chemical parameters over this period. The monitoring results demonstrate that at this site the process of natural attenuation appears to have effectively reduced the impact on groundwater at the site, as well as to keep contaminated leaching fluids from moving more than a few hundreds of metres from the wellfield.

For objective reasons, a contradictory situation has been long formed in the world commercial production of non-ferrous metals in which the supply of metals grows while the primary production goes down. The ore used in the production of non-ferrous metals is becoming lower grade. Therefore, in order to maintain and increase an appropriate level of the metal output, ores have to be mined in larger quantities.

Mining equipment for ore production is increasing in capacity, and more toxic agents are being used for ore dressing and concentrate production. A large quantity of fuel and flux is also used in metallurgical plants to produce increasing volumes of concentrates. This results in a growing negative impact on the environment. One way of reversing this situation may be the comprehensive use of geotechnical methods for mineral production and processing.

The geotechnology is a complex of processes and operations with a minimal impact on the environment. The geo-technology, in situ leach (ISL) mining may be considered to be the safest mining method with regards to the environment. The environment is a large system which is formed as a result of interaction of its three subsystems, namely, ecology, man and technology. It is difficult to underestimate the role of in situ uranium leaching in the solution of a large social problems by freeing people from working in radioactive dusty mines and open pits.

In situ metals leaching is a mining method using selective transfer of the useful component into the liquid phase within the ore followed by processing of the pregnant (production) solution. This method enables one to apply one of the basic hydrometallurgical process – **percolation** taking place within the ore occurrence. It should be noted that this method uses only natural processes. They are intensified due to the oxidation-reduction in the hydrochemical environment caused by the action of reagents – sulphuric acid in sulphuric acid leaching, and either ammonium or sodium bicarbonate in carbonate leaching.

Recently, as a result of the development of metal mining by ISL at ore deposits located in aquifers, the question of groundwater restoration after completing mining has become of increasing interest.

The environmental disturbance of ISL mining is characterized as the following:

— All operations are conducted within ore occurrence without any substantial site development. The ISL mining does not cause any significant mechanical disturbance of the surface and

subsoil (as compared to conventional mining). When mining roll front type (bed infiltration) deposits using a system of wells, such disturbances do not take place.

— During leaching of roll front type deposits the ISL process is performed as a closed cycle based on the balance of the volume of injected and recovered solutions. Pumping to recover the solution develops a cone of the depression in the groundwater in the vicinity of recovery wells. During this process a closed hydraulic contour is formed in the ISL leaching area. This prevents any migration of solutions outside of the leach area. Along the border of the leach field is formed a strong acid-alkaline barrier beyond which any substantial flow of the acid ISL solution is prevented.

— ISL processes (both acid and carbonate) cause substantial changes in the ground-water chemistry in ISL leach fields. They may increase the concentration of the total dissolved solids by up to ten times. These components include aluminium, iron, nitrates, heavy metals, microelements and also radionuclides.

Such increases in total dissolved solids are relatively short-lived and strictly limited in area. Nevertheless, under the current environmental law, special water users – such as ISL project – must provide continuous monitoring of the water resources (aquifers) and take measures to ensure the water quality of the aquifers return almost to the pre-mining baseline conditions after the completion of mining.

At present, there are two main restoration methods in the technology of groundwater treatment from man-caused contamination. The first method utilizes physiochemical and biological treatment of the contaminated aquifers and groundwater, with or without pumping the water to the surface. The second method includes treating the water mainly in place. These technological processes are difficult to carry out. They are rather costly and not very efficient and both ultimately require the construction and maintenance of radioactive waste storage site. Costs of the above water treatment methods are high amounting to 20-50% of the final ISL product (i.e. uranium cost).

When choosing optimal methods for the ground-water restoration, first of all, we should define whether we understand the impact of the ISL process on the environment. The authors, who have a large experience in ISL production, contend that mining of the roll front type uranium deposits affects only the aquifer hydrogeochemistry by changing its oxidation-reduction state. Quantities of sulphates, (during acid leach) or carbonates, (during alkaline leach) introduced during the ISL process are very small compared to their natural quantities in the water and rocks involved in the ISL process.

Following the impact caused during leaching, reduction of the natural reduction-oxidation aquifer conditions start, and this is followed by demineralization of the groundwater.

To better understand this process, from mid-1980s, a group of scientists and experts in uranium production conducted theoretical and experimental studies of the behaviour of the residual ISL solution after the completion of mining. The major conclusion of the studies is that the ore-hosting epigenetic zoned hydrochemical medium is resistant to intensive ISL impact. The groundwater system tends to return to pre-mining condition by self-neutralization, or “natural attenuation”, once the introduction of leaching solution is suspended. It has been demonstrated at several test sites that a slow but irreversible neutralization of ISL leaching solutions takes place in aquifers containing residual solution plumes after leaching is stopped. This process is based both on the action of natural geochemical barriers, which are an integral factor of the epigenetic chemical zoning of such uranium deposits, and barriers that result from the mining itself.

At the **neutralization** (alkaline) barrier it has been observed that pH increases from 2.0-2.5 to 7.5-8.5 mV due to a reduction in the content of potential acidifiers (iron disulphides and other), and an increase in the content of neutralizers (carbonates, chlorides, alkali earth, chips of feldspar grains,

montmorillonite and hydromica clays and other). In this zone, the formation of insoluble cement and gypsum take place, accompanied by isomorphic absorption of strontium, barium, radium and other heavy metals. At the same time, the precipitation of aluminium and iron hydroxides take place. These precipitates also absorb light and heavy metals. Bicarbonates are neutralized to carbonates forming almost insoluble calcium and magnesium dolomites. Ferrous iron is hydrolysed to ferric iron, which forms a strong reduction barrier.

The **reduction** barrier is characterized by a decrease of the oxidation-reduction potential from 350-450 to 0-150 mV. In this zone, the carbon substances, pyrite sulphur, bitumen, organic substances, hydrogen and hydrogen sulphide in the unoxidized rocks precipitate uranium, radionuclides, molybdenum, arsenic, selenium and tellurium. When the content of carbonaceous matter and phosphates increases, a **sorption** barrier is formed which also absorbs a number of microelements and radionuclides. Therefore, both reduction and sorption barriers develop near the limit of the ISL field.

A special role in purification of the groundwater from sulphate and nitrate enrichment belongs to spore forming bacteria. Such bacteria spores occur in unoxidized sands of host aquifers. With a pH value of 6-7, mineralization of the groundwater is close to the nutrient medium for the bacteria reproduction. In the presence of soluble organic carbon the vital activity of bacteria becomes more intensive.

Both laboratory and field tests in the wells of Severny and Yuzhny (i.e. North and South) Karamurun deposits have demonstrated that sulphate reducing bacteria adapted to sulphate media (pH 3.7 to 5) decrease the content of sulphates in the ore solutions from 10 to 0.5 g/l. At these sites the content of sulphates is halved from 5.4 to 2.7 grams/litre over a few months.

On the basis of these theoretical conclusions monitoring was conducted at test and commercial production sites in the CIS republics (Uzbekistan, Kazakhstan, Ukraine) and in the U.S.A. The largest scale and most detailed studies of the natural hydrochemical processes and self-purification (i.e. natural attenuation) of the stratal water contaminated by the products of sulphuric acid uranium ISL were carried out at the Irkol deposit in Kazakhstan and Yuzhny Bukinay deposit in Uzbekistan. Similar surveys have been conducted at the Yuzhny Karamurun and Uvanas deposits in Kazakhstan.

Based on the results of the long term monitoring, it was established that mineralization of the residual solution is reduced due to hydraulic dispersion, molecular diffusion, physical and chemical reactions with host rocks, mechanical sorption and monatomic ion exchange. The rate and efficiency of the process, first of all, depends on the sorption properties of the aquifer host rocks. The presence of residual carbonates significantly accelerates the process of natural attenuation following sulphuric acid ISL The other positive factors are a low thickness of the ore-hosting horizon and increased depths of deposit, where increased temperature and pressure help catalyse and accelerate the process.

The results of 13 years of monitoring of the self-purification process at the Irkol deposit supports the authors conclusion. The Irkol deposit is located in Kzyl-ordinskaia oblast in Mining Group Number 6. The detailed exploration was finished in 1985. Ore occurs in sands of Cretaceous age, at a depth ranging from 390 to 700 m. The average depth is 400-450 m. The reserves are 21 800 t U with an average uranium content of 0.042%. The ore is non-calcareous with a CO_2 content of 0.2%.

Here, over two and a half years, a full-scale in-situ sulphuric acid leach test was carried out at the depth of 450 meters. 65 tons of uranium were mined at the site with a recovery of 80%. Following completion of leaching from 1985 to 1997, systematic sampling of the remaining residual leach solutions was done using recovery and monitor wells. The monitoring was carried out every half year to determine the concentration of a large number of components remaining in the solutions.

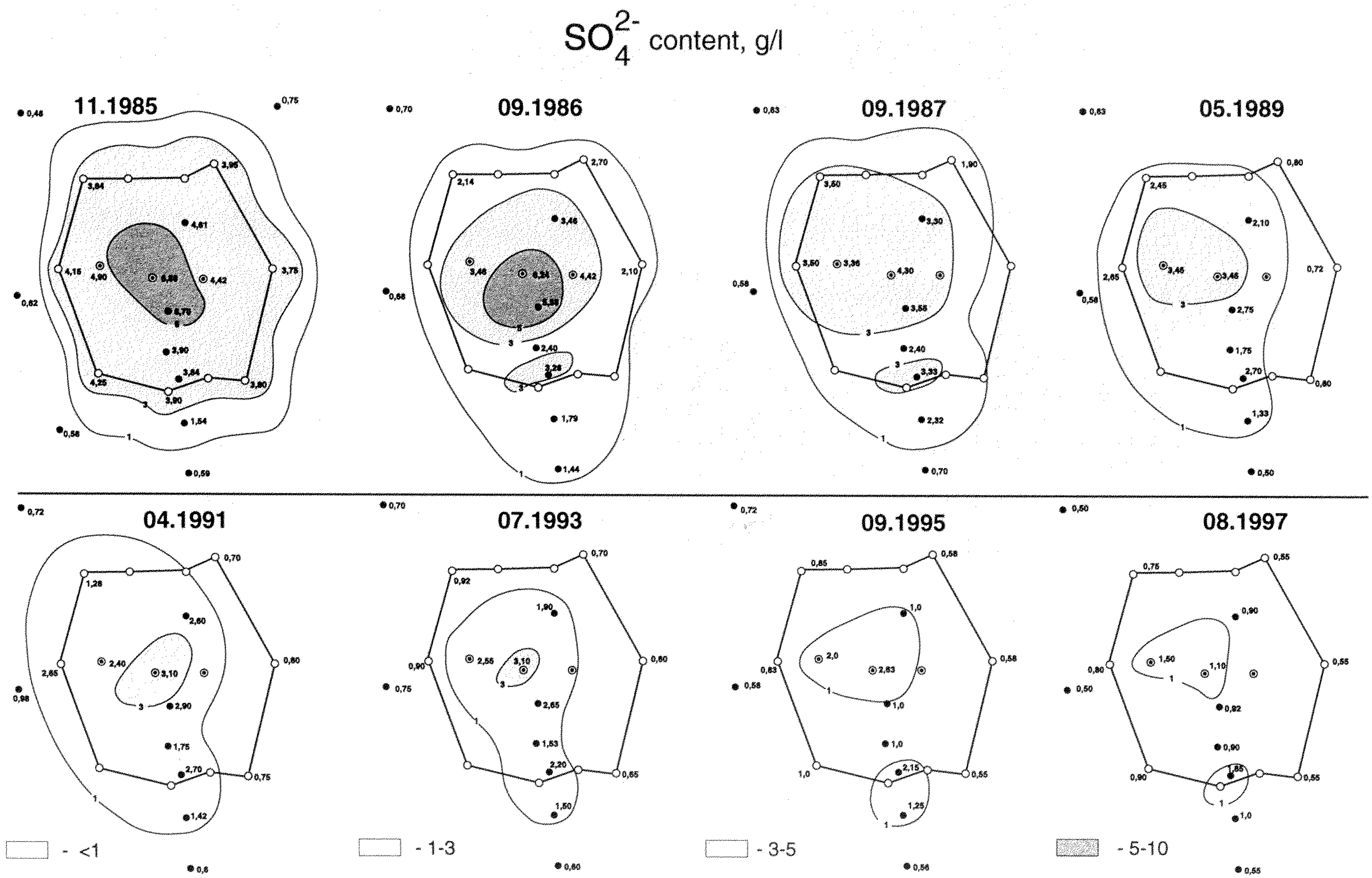

FIG. 1. Sulphate concentration (SO_4^{-2} grams/litre, (g/l)) in residual leach solution at the Irkol, Kazakhstan ISL wellfield following completion of injection of leach solutions in 1985.

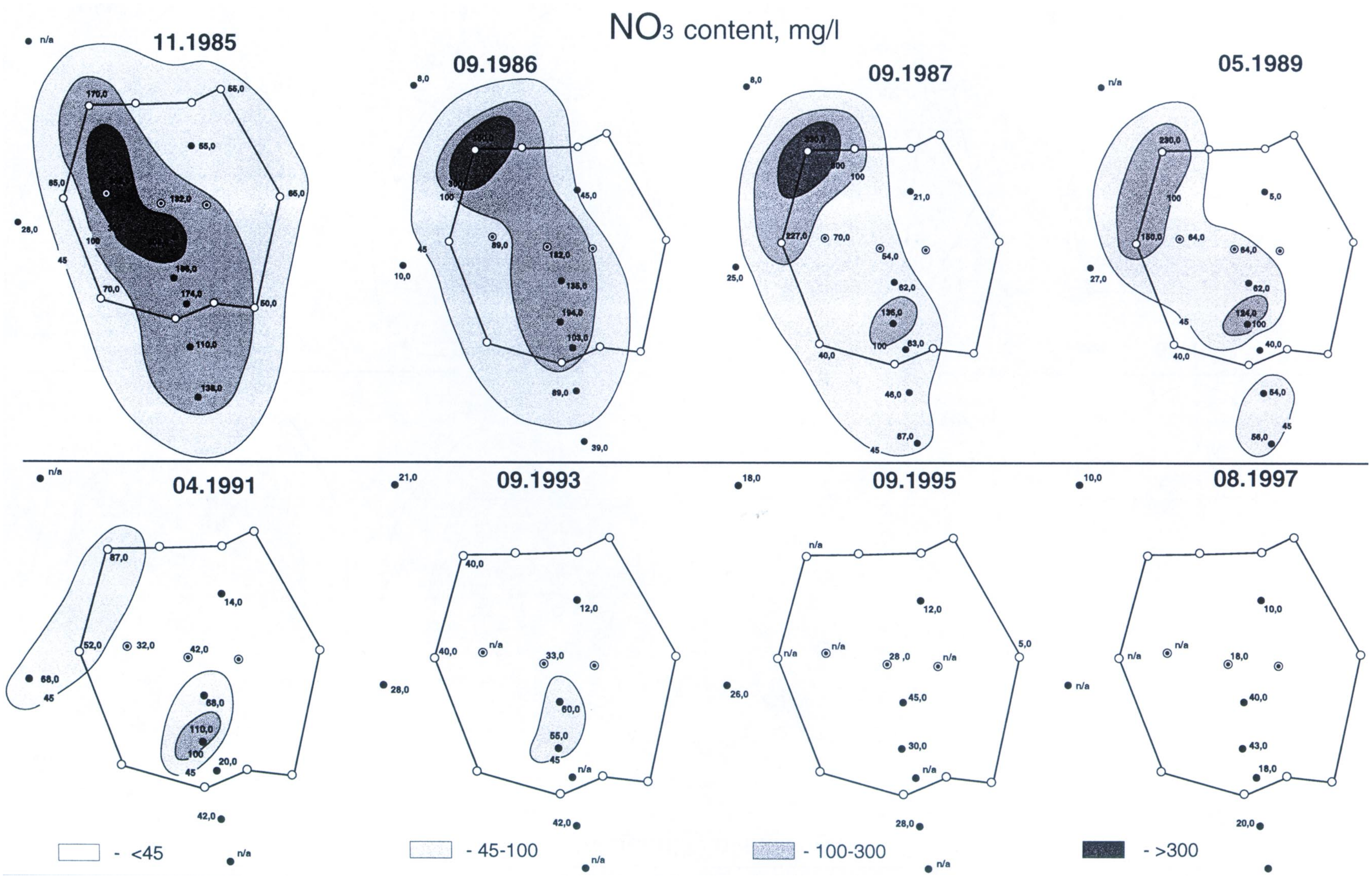

FIG. 2. Nitrate concentration (NO_3, milligrams/litre) at the Irkol, Kazakhstan ISL wellfield following completion of injection of leach solutions in 1985.

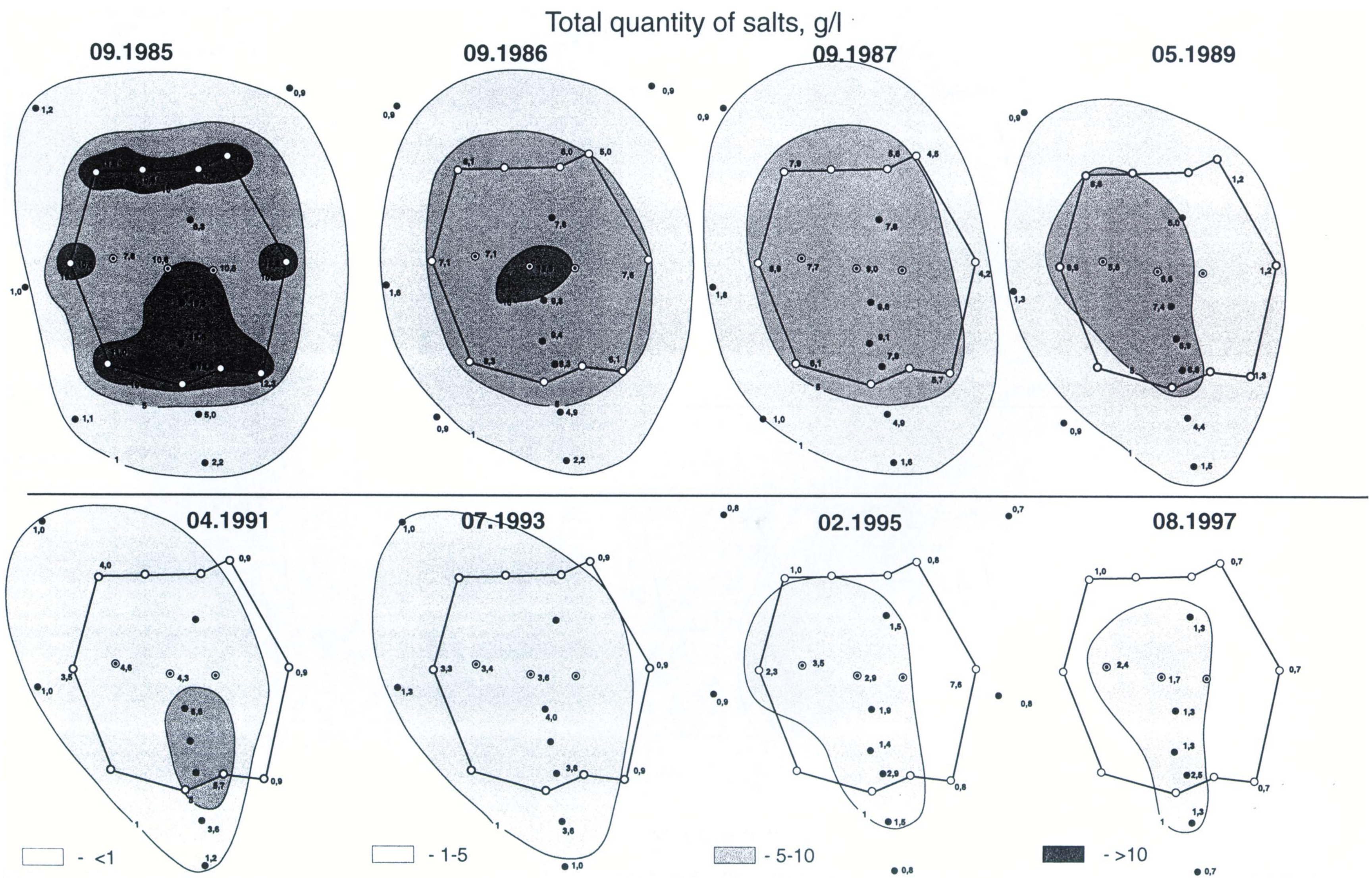

FIG. 3. Concentration of Total Dissolved Solids (TDS, g/l) at the Irkol, Kazakhstan ISL wellfield following completion in injection of leach solutions in 1985.

It was decided that it would be sufficient to demonstrate the behaviour over time of the main and long-lived products of leaching and the pH in the former leach area. The concentration of uranium was also monitored. At the completion of mining, the following values were observed:

pH – 2.5;
Sulphates – 6.9 g/l;
Nitrates – 360 mg/l;
U – 57 mg/l;
Total mineralization – 15.3 g/l.

Over 13 years, almost complete natural attenuation of the residual ISL solutions took place. This include sulphate ion (Fig. 1), nitrate ion (Fig.2), total contents of the other salts including iron, aluminium, magnesium and the heavy metals (Fig. 3) and also radionuclides of the uranium and radium group (Fig. 4) took place. Over this period, the pH of the medium increased to 7.5-8.0 (Fig. 5) and the oxidation-reduction potential decreased to the background value – 120 mV. As a result the area of the leach-field aquifer of approximately 20 000 m^2 nearly returned to the baseline hydrogeochemical state which existed prior to mining.

At the Yuzhny (South) Bukinai deposit (Uzbekistan) similar monitoring was conducted for 11 years after the ISL mining had stopped. Over this period, 50-60 % of the process of self-purification of the residual solutions took place.

The collected data demonstrate that the natural hydrogeochemical neutralization of the residual solutions after in-situ sulphuric acid uranium leach is **a method of restoration of the groundwater** of ore-bearing horizons. The costs are mainly incurred by installation of a monitor well system and carrying out a regime of hydrochemical monitoring until complete demineralization of the residual solutions to the required level. In comparison with active restoration using the pump and treat method and/or chemical precipitation, natural restoration of groundwater is 10 to 100 times less expensive.

The sole, but rather significant negative aspect of the self-restoration method is that this method is slow. Tens of years are required for returning to the baseline chemical condition of the groundwater. This factor caused us to organize a test to intensify this process at the Yuzhny (South), Bukinai and Severny (North) Karamurun deposits using forced filtration of ISL residual solutions outside of the area of their initial location of the ISL field.

To promote the transfer of the contaminants in the residual solution from the liquid to a solid phase, the solution was pumped from the ISL well-field area to an adjacent area of unoxidized rocks. The fluids were allowed to flow through the unoxidized rocks. For this purpose, a system of special monitor and injection/production wells was installed adjacent to the leach field. The distance from the mined deposit to the recovery wells was determined by calculations based on concentration of the dissolved contaminants, the reduction and sorption properties of rocks in the demineralization area and the contrasting level of natural geochemical barriers. Formation water from the opposite side of the plume, or a part of the plume were simultaneously injected.

The main result of these experiments resulted in the conclusion that percolating the residual ISL solutions through rocks unaffected by ISL returned the concentration of the dissolved elements back to the background level. Water circulation through unoxidized rocks has been determined as the most effective method of natural attenuation.

The method ensures total ground-water restoration within a relatively short period of time (i.e. from a few months to two or three years, subject to the size of the site to be cleaned). The costs are mainly related to the drilling of wells, pumping and chemical monitoring. This method of restoration of ore-bearing horizons following acid ISL uranium mining has been patented by a group of research workers that developed the technology.

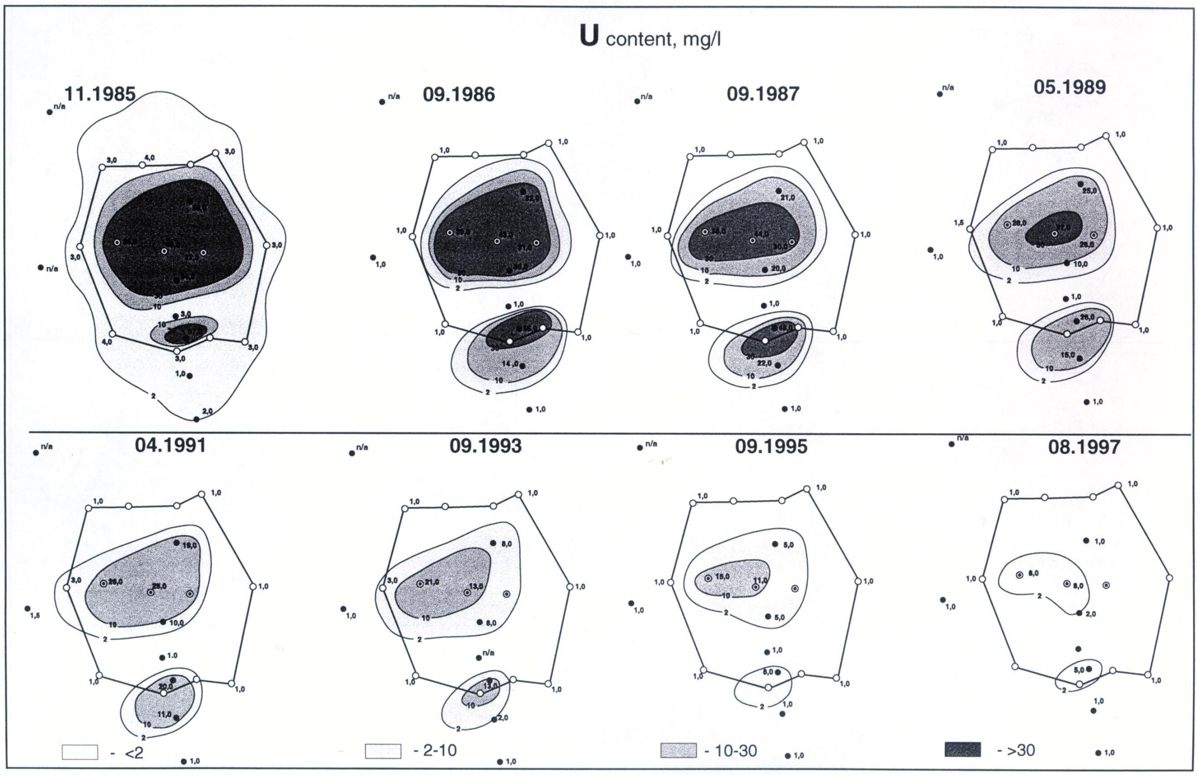

FIG. 4. Uranium concentration (U, g/l) at the Irkol, Kazakhstan ISL wellfield following completion of injection of leach solutions in 1985.

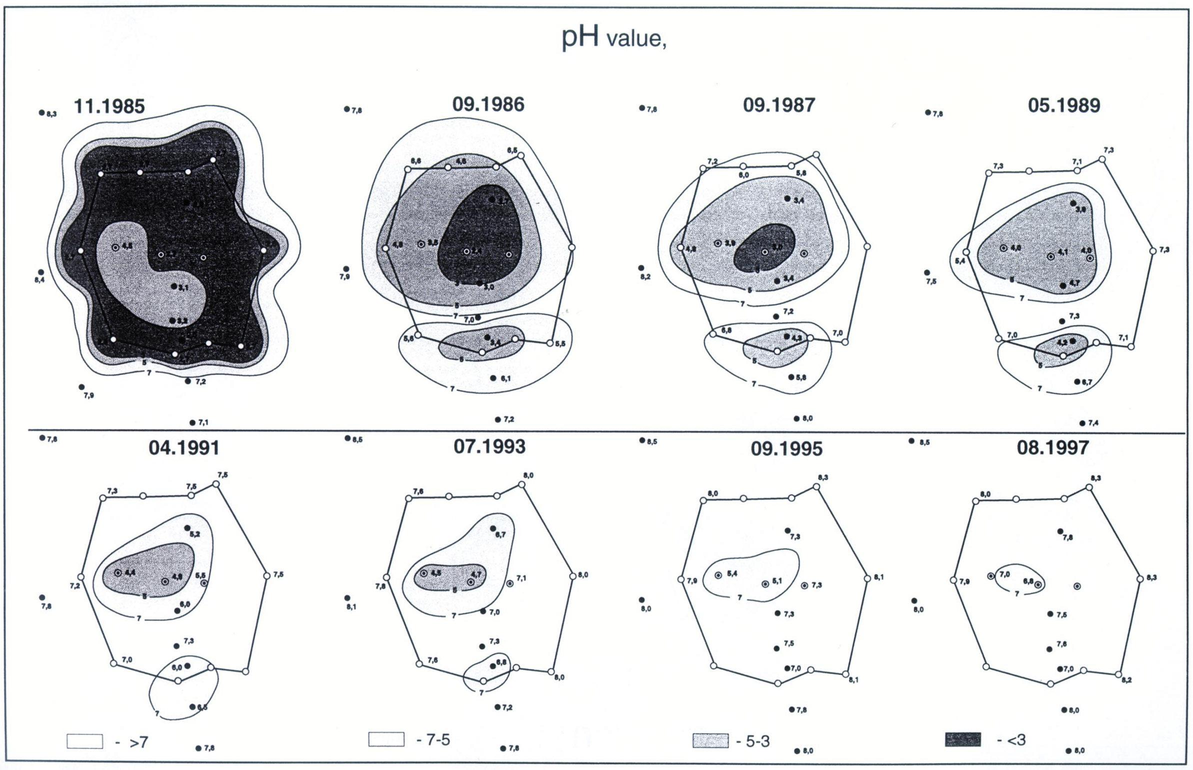

FIG. 5. Value of pH of residual leach solution at the Irkol, Kazakhstan ISL wellfield following completion of injection of leach solutions in 1985.

Environmental protection at ISL uranium mining sites in Uzbekistan

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Abstract. The ecological aspects of uranium mining with particular focus on in situ leaching (ISL) are addressed in the paper. As compared to conventional mining methods, from the ecological point of view, ISL has proved to be advantageous. Innovations developed and introduced in the Navoi Mining and Metallurgical Combinat (NMMC) with the purpose of reducing the impact of the uranium production cycle on the environment are described.

In the Republic of Uzbekistan uranium is currently produced in the form of protoxide-oxide U_3O_8 by production facilities of the Navoi Mining and Metallurgical Combinat (NMMC). All deposits currently under development are located in the Central Kyzylkum Desert and belong to deposits located on a stratum oxidation zone, (or roll-front type boundary).

During its 40 years of production activity, NMMC produced uranium using all mining methods including underground and open pit mining, and in situ leaching through a system of wells (ISL). ISL mining was first introduced in 1962. Later, with modifications, its application increasingly expanded and since 1994 it has become the sole method for recovery of uranium in the Central Kyzylkum. All open pit and underground uranium mining was stopped in that year.

When NMMC used conventional mining methods it encountered all of the ecological problems associated with these techniques: very large areas of land surface were disturbed; waste dumps were buildup; radioactive wastes were accumulated in the form of mineralised, but below cut-off rock dumps and hydrometallurgical tailings. Significant volumes of underground waster were discharged on surface with the purpose of draining shafts and very large dust emissions took place in pit blasting operations. The effective aggregate exposure doses from all man-caused radiation hazards for mining personnel in underground mines was about 20–40 mSv/year.

Since the complete change to ISL mining and shutdown of all underground and open-pit mines, the environment within the NMMC's activities area is no longer affected by the reported negative factors associated with conventional mining. The radioactive impact on human beings has been greatly reduced.

Such significant changes in the ecological situation took place because the ISL process has a number of advantages as compared to conventional mining techniques. This is not only from the point of view of economy, but also from the point of view of the reduced environmental impacts of the process. In the ISL process a number of laborious and ecologically intensive operations related to both mining and processing of uranium are eliminated from the production circuit.

Particularly, significant changes occurred in the radiation conditions in the territory affected by the uranium production facilities of NMMC. All decommissioned mines and open pits have been closed and reclamation of the mines and disturbed lands are in progress.

Since 1994, the company has been carrying out activities aimed at closing out the tailings impoundment of the Hydrometallurgical Plant #1 (HMP#1) in Navoi using a low-cost method. The concept of the method follows. In 1994 the uranium mill commissioned a circuit for processing gold ore. The tails from the gold processing are used to cover the radioactive tailings accumulated during the past years of uranium ore processing. This cover prevents radioactive dust formation, while reducing radon emissions from the surface of the tailings.

TABLE I. CALCULATION OF ANNUAL EFFECTIVE DOSE FOR PERSONNEL EMPLOYED IN ISL URANIUM PRODUCTION IN THE NAVOI MINING AND METALLURGICAL COMBINAT (MEASUREMENTS TAKEN IN 1999–2000)

DIRECTIVE DOCUMENT: СаиПиН No.0029–94: EFFECTIVE EXPOSURE DOSE NORM=20 mSv.year

Project NMMC	Radiation factor measurement points	Exposure to external radiation		Equivalent equilibrium concentration of Ra decay against products in the air		Aggregate α activity of long life radionuclides in the air		Exposure to internal radiation	Effective exposure dose from production cycle + background	Effective exposure dose from production cycle
		μR/h	mSv/y	Bq/m^3	mSv/y	mBq/m^3	mSv/y	mSv/y	mSv/y	mSv/y
1	2	3	4	5	6	7	8	9	10	11
Location	Background	12	0.12	3.5	0.06	2.4	0.13	0.19	0.31	
Northern Mining Department Kendyktyube	ISL well field	120	1.25	9.0	0.16	2.4	0.13	0.29	1.54	1.23
	Local IX units	240	2.5	10.56	0.19	3.08	0.17	0.36	2.86	2.55
	Pregnant solution processing units	46	0.48	4.4	0.08	18.3	0.99	1.07	1.55	1.24
Southern Mining Department	ISL well-fields	60	0.62	11.65	0.21	2.76	0.15	0.36	0.98	0.67
	Local IX units	29	0.3	30.3	0.54	1.98	0.11	0.65	0.95	0.64
	Pregnant solution processing units	99	1.03	18.9	0.34	1.84	0.1	0.44	1.47	1.16
Ketmenchi	ISL well-fields	62	0.65	4.2	0.08	3.5	0.19	0.27	0.92	0.61
	Local IX units	141	1.47	19	0.34	2.68	0.14	0.48	1.95	1.64
	Pregnant solution processing units	271	2.81	4.1	0.07	10	0.54	0.61	3.42	3.11
Mining Dept #5	ISL well-fields	93	0.97	4.7	0.08	4.17	0.23	0.31	1.28	0.97

TABLE I. (cont.)

	Pregnant solution processing units	132	1.37	5.6	0.1	4.42	0.24	0.34	1.71	1.40
Mining Dept.#5 Mine#1	ISL well-fields	71	0.74	16.6	0.3	2.49	0.13	0.43	1.17	0.86
	Local IX units	280	2.9	5.5	0.1	5.0	0.27	0.37	3.27	2.96
	Pregnant solution processing units	244	2.5	36.25	0.65	46.8	2.53	3.18	5.68	5.37
Mining Dept.#5 Mine#2	ISL well-fields	100	1.04	10.9	0.2	2.51	0.14	0.34	1.38	1.07
	Local IX Units	120	1.25	15.4	0.28	2.18	0.12	0.40	1.65	1.34
	Pregnant solution processing unit	555	5.77	20	0.36	13.3	0.72	1.08	6.85	6.54
Mining Dept.#5 Mine#3	ISL well-fields	122	1.27	5.8	0.1	5.2	0.28	0.38	1.65	1.34
	Local IX Units	126	1.31	7.8	0.14	3.01	0.16	0.30	1.61	1.30
	Pregnant solution processing unit	136	1.41	4.4	0.08	3.4	0.18	0.26	1.67	1.36
Hydrometallurgical Plant #1	Final product department	1 µSv/ hour	1.7	7.03	0.13	159.1	8.6	8.73	10.43	10.12

Chief of Dust and Gas Dosimetry Laboratory: V.Z.Petrienko
Dosimetry Engineer: E.V.Demenko

TABLE II. RESULTS OF RADIATION MONITORING OF EXPOSURE DOSE FOR PERSONNEL INVOLVED IN ISL URANIUM MINING AT NMMC FACILITIES. MEASUREMENTS TAKEN IN 1999 – 2000.

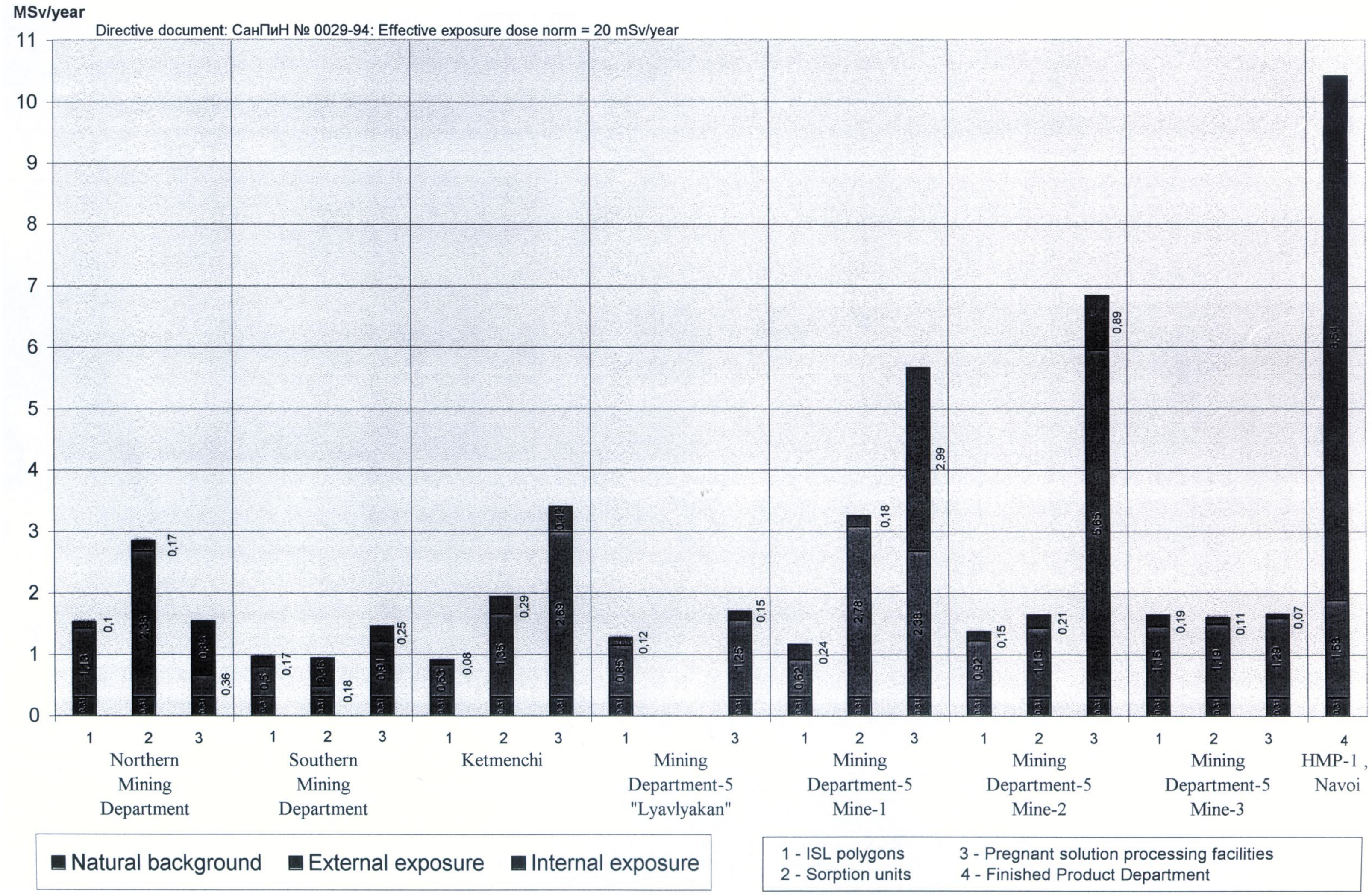

TABLE III. COMPARATIVE TECHNICAL AND ECOLOGICAL PARAMETERS FOR STRONG ACID AND WEAK ACID URANIUM LEACHING AT AITYM HORIZON ORE BODIES, UCHKUDUK DEPOSIT

No.	ISL technical and ecological parameters, underground water components	Unit	Initial concentration of underground water components (before mining)	Final concentration of components in residual solutions in stratum after completion of mining		Max. permissible concentration for portable water in Uzbekistan
				Strong sulphuric acid leaching	Weak sulphuric acid leaching	
1	2	3	4	5	6	7
1.	Cost of production	%		100	80	
2.	Consumption of sulphuric acid per 1 kg of uranium	Kg		156	6	
3.	Concentration of sulphuric acid in 1 liter of solution	g/1		10	0.1-0.2	
4.	pH value in residual solutions after completion of ISL		7.6	1.1	7.0	6-9
5.	Dry residue	Mg/1	2750	19500	3300	1000
	$Na^{+}K^{+}$	Mg/l	526	1030	620	200
	Ca^{2+}	Mg/l	132	550	220	
	Mg^{2+}	Mg/l	60	608	108	
	Fe-total	Mg/l	0.5	1560	0.8	0.3
	SO_4^{2-}	Mg/l	1400	14200	1630	400
	HCO_3^{-}	Mg/l	190	880	350	
	Cl^{-}	Mg/l	360	880	420	250

At the present time, a part of the waste depositary surface (i.e. Section # 5 with an area of 100 hectares) has been covered by a 0.5–1.0m thick layer of tailings from the gold milling circuit. The average radon flux at Section # 5 now is 0.4 Bq.m^2/sec. This is 10 times lower than the average value for the entire tailing site which has not yet been covered. In accordance with the company plan, the entire 620 hectares tailings depository will be completely covered within about 10 or 12 years. The design also provides for a top layer of local soil.

In addition, ten soil reclaiming design programs of ISL well-fields in NMMC have been planned in cooperation with specialized research centres. Three of them have already been implemented.

Since 1996, NMMC has returned 24 700 hectares of reclaimed land holdings to the landowners after conducting geological exploration and mining. This includes one thousand hectares of ISL well-fields.

Four waste disposal facilities designed for radioactive wastes resulting from decommissioning of uranium mining facilities have been constructed. Another three disposal facilities are currently under construction.

At the NMMC production facilities the average annual total external and internal irradiation exposure dose for personnel on ISL well fields, and service personnel for pregnant solution processing units, is 1.5–6 mSV. The attached Tables 1 and 2 show the calculated and actual values of average annual effective exposure does received by production personnel.

In the nearest residential areas, located 5 to 10 kilometres or more, from ISL well-fields, the effects of production cycle-related radiation have not been detected. This means that measurements of the radiation hazard factors made at these monitoring points do not noticeably deviate from background values.

Thus, it is evident that replacing conventional mining with ISL technology resulted in a great reduction in environmental impacts. This drastically changed the ecological situation in the territory affected by NMMC's uranium production cycle.

At the same time, ISL uranium mining may result in a serious ecological problem. Water pollution may result from the injection of significant quantities of acids or alkaline into the ore host aquifer. For instance, the use of leach solution containing sulphuric acid with a concentration of 10–20 gram per litre results in an increase of salinity of stratal water of 5 to 10 times as compared to background values, because of its high reactivity within the ore body contour. Such a negative impact on underground water requires development and implementation of expensive nature protective programmes after decommissioning of a production facility. For many years NMMC conducted scientific research and tests to improve the effectiveness of technology, particularly with the objective of reducing its impact on the groundwater. As a result of this work, a new geotechnical mining method providing for leaching of uranium from water saturated sandstone deposits was developed. It has been introduced into production and now prevails in NMMC. The new process uses a small amount of sulphuric acid, and water saturated with air to form a leaching solution of pH 4 to 4.5. This results in dissolving carbonate in the rock to form HCO_3. The leach solution, of pH 4 provides for relatively selective dissolution of carbonate minerals and enrichment of the solvent with bicarbonate ion following the reaction:

$$UO_2 + HCO_{3-} + O_2 \longrightarrow [UO_2\,(CO_3)_3]^{-4} + H_2O$$

The intensity of the leach process and its effectiveness are primarily determined by the amount of oxygen injected into the ore body. Tests have shown that uranium is more readily oxidized in a direct interaction of ore with gaseous oxygen, rather than in an interaction of ore with oxygen dissolved in water. For this reason the ore bed compressed air is repeatedly injected through injector wells which force out water and brings air into contact with uranium minerals. The minimal requirement for oxygen fed into the ore bed is 0.1 kg per one ton of ore. The uranium recovery rate using this 'soft' technology is as high as that of strong acid leaching. The production cost is also 17 to 20% lower than the cost of normal acid technology.

The main advantage of the method is the low environmental impact of its use. This is because the pH, total mineralization, composition and concentration of main microcomponents of the formation water during the leaching process, as well as after it has been completed, differ very little from the initial background, even within the confines of the ore body contour.

A comparison of the main technological and ecological parameters for the 'strong acid' and 'weak acid' leaching methods, as applied by the NMMC for mining the Aitym deposit, is given in Table 3. The table illustrates that weak acid leaching, as opposed strong acid leaching: does not lead to significant increases in concentrations of individual water contaminants nor does it change the water category class. Therefore, no restoration is required after the in situ leaching process has been completed.

About 50% of the uranium currently produced by NMMC is recovered using this weak acid leaching method. In the near future, the portion of uranium mined by this 'soft' technology will be increased to 75 to 80%. This will start with the commissioning of the large 'Sugraly' mine which will use this new technology.

Navoi Mining and Metallurgical Combinat is willing to familiarize any interested specialists with the ISL method using a low concentration of acid as the leaching agent.

Evaluation of the mill tailings disposal site at the Zirovski vrh uranium mine in Slovenia

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Abstract. Uranium mine Zirovski vrh in Slovenia was closed due to economic reasons. After that extensive work on decommission was done. The results of the comparison between three potential sites for mill tailings are presented. The results of the probabilistic approach to the factors of safety and confidence, seismic hazard analysis, hydrogeological models and in the economic evaluation are given. For the common evaluation they were interpreted in the way of UMTRA decision matrix. On the basis of the engineering judgemen calculations for the recent status and the status after 1000 years was preformed.

1. INTRODUCTION

Strong progress has been made in the field of peaceful and safe nuclear energy use in Europe since the end of the Second World War. As the consequence of this process, extensive research for the possibilities of nuclear energy use began in Slovenia around the year 1950. Following several years of prospecting work, high natural radioactivity was detected in the area of Zirovski vrh and soon after that the first mining works began. Development of the Zirovski vrh uranium mine ran simultaneously with the design and construction of the Krsko nuclear power plant. While the Krsko nuclear power plant still operates today at its full power, the ore extraction at the Zirovski vrh uranium mine was stopped in 1990. The omission of the extraction at the mine has been followed by extensive decommissioning works in the mine itself as well as and in its surroundings. One of the main activities was design of decommissioning of the disposals and closure of the underground mine. Immediately after the extraction process ceased, extensive sliding of the mill tailings material occurred and alternate sites for mill tailings deposition had to be considered. The methodology and results of this study are presented in the paper.

2. GENERAL SETTINGS

The Zirovski vrh uranium mine is located in the western part of Slovenia, at the distance of approximately 50 kilometres from the capital city Ljubljana (Fig. 1). It is situated in the area named Polhograjsko hribovje in the valley near the junction of two creeks that are the tributaries of the river Poljanska Sora. Geomorphologicaly the area can be described as a hilly area with steep slopes and relatively dense drainage networks where several ravines appear. The altitude difference is between 400 to 700 m a.s.l.. Water springs are very common phenomena in the valleys and ravines. The slopes are covered with dense vegetation of coniferous and deciduous trees.

The climate in the area is temperate with 1800 mm/year average rainfall and yearly real evapo-transpiration of around 550 mm. Air temperatures are between –28°C to 37°C with the yearly average of 7°C. The maximum thickness of snow cover is up to 1.8 m. The direction and speed of wind in the area depend on the relief, however, weak south-northern winds prevail. Temperature inversion occur autumns and winters at about 500 m a.s.l. in the valley where the mine entrance is located.

The uranium ore in the area was first discovered in the late fifties and the first underground investigation works began in the year 1960. The first yellow cake was produced in the processing plant in 1984. In the year 1990, the mine was closed. Altogether 3 307 000 tones of material were removed during the extraction period. The ore was represented by 633 000 tones and low-grade ore with 206 000 tones.

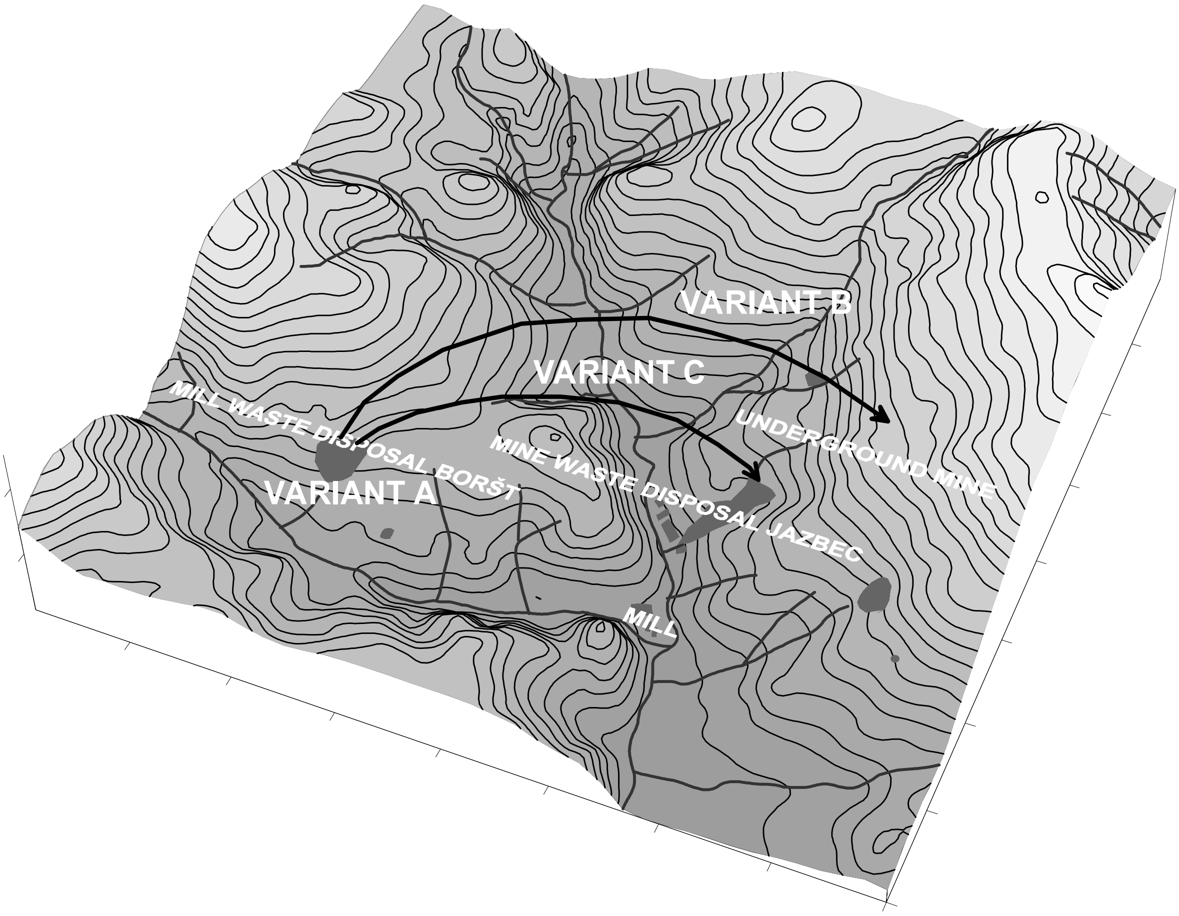

FIG. 1. Arial view on Zirovski vrh area with main characteristics of possible relocations of mill waste (area 4x4 km, sight to south).

The underground mine is perpendicular to the valley and is positioned in the hill between 430 and 610 m a.s.l. Access to the main underground works was through nearly horizontal adits positioned in the different altitudes from the valley bottom at 430 m a.s.l. to the 530 m a.s.l.. After the finishing of the exploitation works several breakdowns occurred. The influence area of this phenomenon extends to the surface above the mine. The mine is developed in the clastic groeden beds of Permian age. The ore was excavated from grey quartz sandstone and conglomerate that were deposited in the fluvial environment. In the surrounding of the mine clastic Carboniferous and Triassic rocks are also present. They are represented with various dolomites and limestones, piroclastic rocks and siltstone. The geologic structure consists of several napes thrusted from the northern direction. They are dissected by the Dinaric faults in the direction NW-SE. The ore minerals are uranium oxides in the tar and several secondary ore minerals such as uranosferit, torbernit, autunit etc. [1, 2]

During the excavation period, the mine mill tailings and mine waste were deposited in the surrounding of the mine. The mill tailings site Borst is positioned around 1.5 km from the mine entrance. It covers 4.2 ha between two ravines in the altitudes between 520 and 580 m. The total amount of 673 000 tones of tailings were deposited. Deposition of tailings began in 1983 and was ended when the mine

production stopped in 1990. The tailings consist of silty to sandy aggregate formed during the hydrometallurgical process. Chemically it is silica, gypsum and sulphate salts. In the bedrock of the tailings disposal, Triassic clay stones and piroclastic sedimentary rocks with poor geomechanical characteristics are present. The weathered zone of the rocks is relatively thick. In the year 1990, the landslide of 2.9 million cubic meters of uranium mill tailings and underlying rock occurred. The sliding was stopped by extensive drainage works with underground drainage gallery. During the construction works, a strong fault crossing the gallery was found with the evidences of past sliding. Natural conditions on the slope itself also assisted in the movement stopping.

The mine waste disposal site Jazbec covers the area in the vicinity of the mine. It consists mainly of mine waste and red precipitate from the processing plant. The deposition began in 1984 and was stopped in 1990. In the total 3 900 000 tones of mine waste was deposited between 420 and 460 m.a.s.l.. The disposal site Jazbec is positioned on rocks of various ages. Clastic rocks prevail over the carbonate ones. The area, where the Jazbec disposal site is positioned, is relatively near of water. Surface waters are drained off through underground concrete channels and plastic pipes. The later divert springs in the bedrock of the disposal site.

In the year 1990, when sliding of Borst mill tailings began, extensive studies and design of remediation works were performed. During this work, several alternatives for mill tailings redeposition were studied. Three main possible variants were established:

- Variant A: Mill tailings stays on the Borst location. The site must be improved as much as it is possible with all remediation and environmental protection measures.
- Variant B: Mill tailings and contaminated subsoil would be removed with transport to the underground openings of the abandoned mine.
- Variant C: Mill tailings and contaminated subsoil would be removed with transport onto the mine waste disposal site Jazbec.

In the each of the variants all waste sites and mine are decommissioned. All three variants have some serious drawbacks that are the consequence of geological conditions in the area:

- Variant A is problematical due to the great land sliding potential. The movements stopped with the excavation of underground dewatering tunnel could be reactivated.
- In the variant B the breakdown of roof in the mine could occur and as the consequence leaching off of the tailings material would be present.
- In the variant C the main disadvantage is great recharge area and as a consequence of this great erosion potential of the site.

3. METHODOLOGY

According to IAEA [3] recommendations the site selection should be preformed with rating matrix of Uranium Mill Tailings Remedial Action Project of United States Department of Energy [4, 5]. The UMTRA rating matrix is proposed for the site selection. In the Zirovski vrh uranium mine the sites are already present. This is the reason why the parameters of UMTRA decision matrix were slightly modified or even excluded from the analysis.

There are 35 different parameters of the UMTRA matrix divided into four different groups:

- geotechnical group (land slope, surfical materials lithology, surfical materials thickness, distance to nearest seismic risk capable fault, susceptibility to slope failures, present erosion, geomorphic stability, conflict with mineral resources, relative strength and compressibility of foundation soil or rock)
- hydrological group (well yields, background water quality, widespread ambient contamination, upgradient groundwater contamination, geologic strata where there is no existing groundwater, volumetric flux of uppermost aquifer through cross-sectional area under

disposal site, geochemical properties of aquifer and subsoil, potential for upward hydraulic gradients below a low hydraulic conductivity stratum, proximity to point of groundwater discharge, depth to groundwater in shallowest aquifer)

- environmental group (distance to the nearest point of groundwater withdrawal from potentially affected aquifer, precipitation frequency, total annual precipitation, annual pan evaporation, population density, transportation network, presence of cultural or historical sites, endangered or economically important species, scenic values, current land use, potential land use, land ownership)
- economic group (distance from existing site, distance to potential borrow sites, existing road network, roads with positive grade from mill site and tailings to disposal site)

Each parameter is ranked from 0 to 4 and weighted by factor score. For some parameters ranks are omitted. Parameter erosion in the geotechnical group presents the example of ranking. Intense gullying is ranked with 0, moderate gullying is ranked with 1, minor gullying is ranked with 2, sheet or rill wash is ranked with 3 and absence of erosion is ranked with 4. This parameter is weighted by factor score 4. The parameter well yield is the example of parameters where only two ranks are given. Well yields less than 2 m^3 is ranked by 0 and above 2 m^3 is ranked by 4. The parameter is weighted by factor score 10.

All three evaluated sites for mill tailings disposal are positioned close to each other. This is the reason why some parameters from UMTRA decision matrix are not discernible and they don't influence the final calculation of the matrix. Among them are precipitation frequency, total annual precipitation, annual pan evaporation, population density, and endangered or economically important species and land ownership.

4. RESULTS AND INTERPRETATION

According to ranking demands all the present research data should be carefully studied and incorporate in the matrix. In the present paper the most important implementations are presented.

4.1. Engineering geology

Stability of an engineering object is usually expressed with the factor of safety i.e. ratio between allowable value of some quantity to the calculated value of that quantity. For evaluation of the stability of engineering system, various methods of evaluation of safety factor are used. Calculation is carried out with several input parameters, usually with their averages that are determined in laboratories. The results of these tests and the factor of safety are distributed according to statistical distribution. The statistical measure which express ratio between mean factor of safety and its standard deviation is defined as reliability index. It describes the stability of a slope by the number of standard deviations separating the mean factor of safety. For normal distribution the relationship between reliability index (β) and probability ($p(f)$) of failure follows the equation [6]:

$$p(f) \approx 1 \times 10^{-\beta}$$

For conventional structural practice the reliability index must be greater than 3 [7]. In most cases the factor of safety that is greater than 1,5 overcome the inherent variability of the material.

For Borst and Jazbec waste sites stability analysis was done. The Borst landslide calculated safety factor is 1,3 and required safety factor that should overcome measured variability is not lower than 1,6. For the Jazbec waste site only static stability analysis were performed. For the recent status of Jazbec 1,4 safety factor was determined. In the case where the material from Borst mill tailings would be redeposit onto Jazbec waste site 1,33 safety factor was calculated. Considering the earthquake acceleration safety factor will be lowered to near 1.

4.2. Seismotectonics

Seismic hazard was studied by carefully examination of older reports and articles about the seismicity of the area. The intention of seismic hazard analysis is to predict the influence of a likelihood future earthquake with the certain magnitude on the site of interest. For this purpose we have to study surrounding seismic zones of potential seismic source and the site itself in aspect of influence of the earthquake intensity. The parameters that define seismic hazard are: magnitude of design earthquake, peak horizontal acceleration, distance of the site of the potential active fault, length of the active fault, fault characterization and visible dislocation of the ground surface as a result of a strong earthquake.

The influence of the earthquake to the site could be direct and indirect. In the case of Zirovski vrh uranium mine we verified the following consequences: land sliding, liquefaction of the mill tailings and impact to the underground excavations. In the vicinity of Zirovski vrh uranium mine there are five seismogenic zones (Ribaric, 1976, cf . Zadnik, 1992). These are:

- Ljubljana seismic zone (the magnitude 6.5, the distance 28 km)
- Idrija seismic zone (the magnitude 7, the distance 16 km),
- Villach-Dobratsch seismic zone (the magnitude between 6.5 to 7, the distance 60 km),
- Friuli seismic zone (the magnitude 6.5, the distance 80 km)
- Polhograjski dolomiti seismic zone (the magnitude 5, the distance from 10 to 15 km).

In the investigation of the neotectonics in the area of Zirovski vrh uranium mine we determined four systems of faults:

- Faults in the Dinaric (NW–SE) direction with vertical dislocation between 50–300 m and horizontal dislocation 100–3000 m. They were active in the Würm glacial and in the beginning of the Holocene,
- Faults in the cross Dinaric (NE–SW) direction are well defined. They were active in the Günz glacial,
- Faults in the Alpidic (W–E) direction. They were active in the Mindel glacial,
- Faults in the direction N–S. They are still active.

According to UMTRA decision matrix criteria designed earthquake should be considered as the earthquake with the greatest impact and with the maximum horizontal acceleration. Due to the small distance between sites the same data from Idrija seismic zone for all of three variants were used:

Distance	16 km
Maximal magnitude	7
Maximal intensity	9–10 MSK
Maximal ground acceleration	0,48 g
Design acceleration	0,27 g
Maximum amplitude	26 mm

Liquefaction potentials for sites were not treated into detail. Due to the geo-mechanical characteristics of waste and mill tailings material we assume that that the liquefaction potentials are very low. The influence of the earthquake onto underground openings in the mine was estimated according to the literature [8]. The estimated damage in the mine is smaller than on the surface.

To determine the landslide hazard of Borst the simplified pseudodynamic analysis was performed [9]. Considering the maximum likelihood earthquake the shift of 2,85 m of mill tailings mass was established. In the case where the weakening of share resistance of mill tailings material is treated the estimated shift of the deposited material is 30 m. According to the stability analysis Borst area will be stable during the institutional control. After that time, due to the share resistance reduction sliding of Borst could occur.

4.3. Hydrological characteristics

In the hydrological characterization of the sites all required parameters from UMTA matrix were evaluated. Climatic factors of the sites are nearly the same. In the contrary hydrogeological characteristics of the underlying rocks and sediments in the sites are very different and variable.

In the mill tailings Borst location bedrock is classified as very low to non-permeable rocks. The weathered zone above bedrock has hydraulic permeability between 10^{-7} to 10^{-8} m/s, clay stones and piroclastic tuffs have permeability less than 10^{-9} m/s. The hydraulic permeability of the landslide sliding plane is estimated on 10^{-5} m/s. The hydrometallurgical waste has permeability between 2×10^{-9} to 3×10^{-10} m/s. In low water conditions the outflow from underground drainage gallery was on the interval between 0.5 to 7 l/s. In the area of mill tailings two groundwater horizons are present. The first horizon is in the waste zone with intergranular porosity and the second in the bedrock of double porosity of joints and pores.

By the demand of Public Health Inspectorate after the final decommission of the Borst site average yearly Ra emission into the surface water must not be higher than 60 Bq/m^3 and total yearly emission must be lower than 50 MBq. In the year 1994 77% of ^{226}Ra and 11% of uranium from Zirovski vrh uranium mine sources was emanated from Borst site.

In the area of Jazbec waste disposal only dolomites and limestone in the bedrock are classified as aquifer. The body of ore waste is very heterogeneous and various perched groundwater horizons have been formed. The hydraulic permeability of ore waste is estimated on the interval between $2,4 \times 10^{-4}$ to 3×10^{-5} m/s. Red precipitate is very wet and with relatively low hydraulic permeability that is estimated on the interval between 10^{-7} to 10^{-8} m/s. The piping of small debris from ore waste was established during the investigation works. Due to this reason lower parts of the waste site have lower permeability. During the construction of Jazbec waste site several small creeks was covered by waste and diverted into the underground channels and drainage pipes. Nowadays some channels are damaged and broken Total discharge of water through the waste body is on the interval between 2,5 to 38 l/s. Infiltration of rainfall represents 20 %, waters from the recharge area 27%, springs on the edge of waste body 4% and 33% springs covered by the waste [10].

Waste site Jazbec contributes 6% of ^{226}Ra and 38% of uranium from Zirovski vrh uranium mine sources. Currently in average 600 mg/m^3 of $U_3O_8^-$ and 40 Bq/m^3 of Ra is released from the Jazbec area. By the demand of Public Health Inspectorate after the decommission the total yearly amount of $U_3O_8^-$ should not be higher than 100 kg and Ra emission 25 MBq.

In the mine area several sandstones with fissure porosity are classified as aquifers. The hydraulic permeability is very variable and depends on density and apertures of fractures. It is estimated on the interval between 9×10^{-3} to 1×10^{-7} m/s. Near the mine upper Triassic dolomite that is important regional aquifer is present. From the mine in average flows out 20 l/s. From the climatological data it was estimated that the recharge area of the water in the mine is 1,2 to 2,0 km^2 which is approximately the same as the ground plan of the mine openings.

The outflow from the mine contributes 11% of ^{226}Ra and 51% of uranium from Zirovski vrh uranium mine sources. Currently in average 300 mg/m3 of $U_3O_8^-$ and 60 Bq/m^3 of Ra is released from the mine openings. By the demand of Public Health Inspectorate after the sanitation works the total yearly amount of $U_3O_8^-$ should not be higher than 200 kg and Ra emission 50 MBq.

For each of the evaluated sites groundwater potential for future likelihood drinking water supply and well yield was estimated. The area of the site and all potential locations in down gradient direction were evaluated.

4.4. Economic factors

The total costs were estimated according to the available projects and other documents. The cost for each of the variant are shown below:

Variant A	13 million ECU
Variant B	28 million ECU
Variant C	17 million ECU

In all three variants the main expense is mine openings remedial measures. In the Fig. 2 the structure of the cost for all variants is represented.

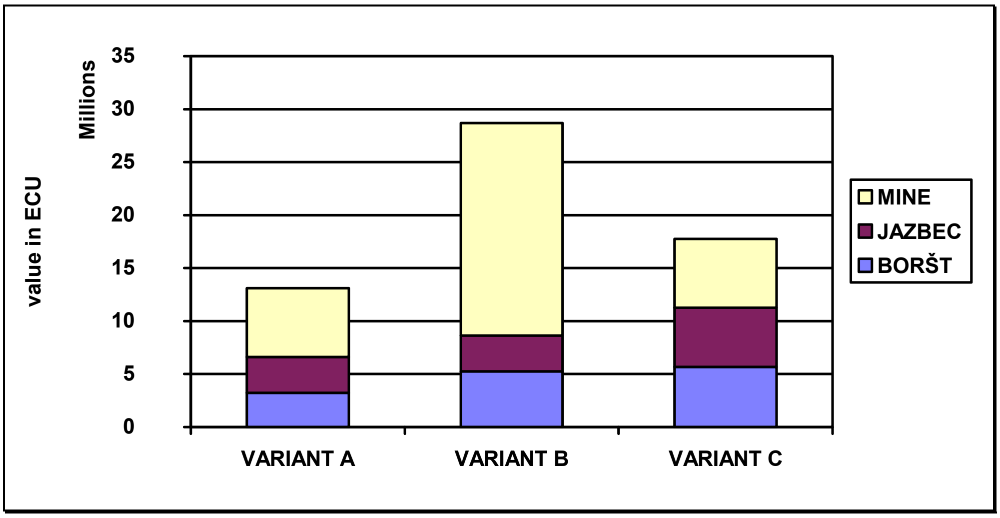

FIG. 2. Financial evaluation of variants according to available projects.

5. CALCULATION OF THE UMTRA MATRIX

For each of the variants UMTRA decision matrix were calculated. The calculations were done for the recent status and for the status after 1000 years. The results of the calculation for each site in the variants through A to C are represented.

The results of calculation for the recent status are represented in the following Table.

variant	**A**				**B**				**C**			
group	**I**	**II**	**III**	**Σ**	**I**	**II**	**III**	**Σ**	**I**	**II**	**III**	**Σ**
geotechnical	130	145	200	**475**	172	145	198	**515**	172	125	210	**507**
hydrological	12	4	12	**28**	16	4	12	**32**	16	4	12	**32**
environmental	109	109	112	**330**	107	109	112	**328**	107	109	100	**316**
economical	50	50	50	**150**	6	6	6	**18**	25	25	25	**75**
Σ	**301**	**308**	**374**	**983**	**301**	**264**	**328**	**893**	**320**	**363**	**347**	**930**

I – Borst mill tailings
II – Jazbec waste site
III – Mine

The results of calculation for the status after 1000 years are represented in the following Table.

variant	A				B				C			
group	I	II	III	Σ	I	II	III	Σ	I	II	III	Σ
geotechnical	112	82	159	**353**	146	105	159	**410**	146	99	131	**376**
hydrological	4	4	12	**20**	16	4	12	**32**	16	4	16	**32**
environmental	107	107	103	**317**	112	107	108	**327**	112	107	103	**322**
economical	12	12	12	**36**	50	50	50	**150**	31	31	31	**93**
Σ	**231**	**201**	**274**	**706**	**308**	**262**	**301**	**887**	**289**	**237**	**265**	**791**

I – Borst mill tailings
II – Jazbec waste site
III – Mine

6. CONCLUSIONS

In the re-deposition study of mill tailings disposal site of the abandoned Zirovski vrh uranium mine three variants were studied. In the variant A mill tailings stays on the present Borst location, in the variant B mill tailings and contaminated subsoil is removed to the underground openings of the abandoned mine and in the variant C mill tailings and contaminated soil is removed on to the mine waste disposal site Jazbec above the mine. With the UMTRA decision matrix all three variants were evaluated and compared.

In the Zirovski vrh uranium mine several studies about environmental impact and remediation measures were made after the closure of the mine. In our study the results of these previous studies were used in the probabilistic approach to the factors of safety and confidence, seismic hazard analysis, hydrogeological models and in the economic evaluation. These results were interpreted in the way of UMTRA decision matrix parameters.

The calculation of the UMTRA decision matrix showed that staying in the location of the present mill tailings disposal site Borst is the best solution for the present state. According to the calculations and on the basis of the engineering judgement for the future after 1000 years variant B where the relocation of the mill tailings site into the mine is assumed as the best solution.

At the present stage of the knowledge in the Zirovski vrh uranium mine the UMTRA decision matrix is additional aid in the engineering judgement for the selection of mill tailings disposal site. For the similar evaluations in the future the UMTRA matrix approach must be modified. The parameters that separate various sites according to the regional characteristics in the areas with relatively small surface similar to Zirovski vrh must be checked.

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French uranium mining sites remediation

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Abstract. Following a presentation of the COGEMA's general policy for the remediation of uranium mining sites and the regulatory requirements, the current phases of site remediation operations are described. Specific operations for underground mines, open pits, milling facilities and confining the milled residues to meet long term public health concerns are detailed and discussed in relation to the communication strategies to show and explain the actions of COGEMA. A brief review of the current remediation situation at the various French facilities is finally presented.

1. INTRODUCTION

During nearly half a centry, France produced about 73 000 tonnes of uranium. Ore deposits were numerous and the ore grades were low, varying from half a kilogramme to several kilogrammes of uranium per tonne.

More than two hundred mining sites produced 165 millions tonnes of waste rock and 52 millions tonnes of ore. Eleven mills were built, either conventional or heap leaching, leading to 22 storage sites for mill residues. COGEMA is the only manager of these sites. Only one mine is still in operation; it is scheduled to shut down next year.

2. REMEDIATION WORKS, A CONCRETE EXAMPLE OF THE ENVIRONMENTAL STRATEGY OF THE COGEMA GROUP

Environmental protection became, from the early seventies, a permanent and priority objective of the COGEMA group during all the steps of its activities. This objective does not ignor the consequences of past practices which occurred at a time when these practices derived from a lack of environmental knowledge and sensibility.

Remediation work applies to facilities left after the end of operations and include mines, mills and the storage of waste rock or milling residues.

For COGEMA, the main objectives of the remediation work are as follows:

— to ensure a perennial stability, in term of security and public health,
— to reduce as low as reasonably possible the residual impacts,
— to prevent any risk resulting from an inopportune intrusion,
— to reduce the surface area that requires rental payments on other use charges,
— to favour the opening of sites for industrial or leisure activities,
— to succeed in lansdcape reclamation in concert with local intervening parties.

3. A SPECIFIC REGULATORY FRAMEWORK

Uranium mining activities are regulated under the general juridical framework of: the «Code Minier» (Mining code), completed by the «Règlement Général des Industries Extractives» (General Regulation on Extraction Industry), with particularities resulting from the radioactivity of the materials handled. Mills and storage locations are classified as ICPE «Installations Classées pour la Protection de

l'Environnement» (Classifed Facilities for Protection of the Environment). These laws are complemented by more general regulations on Water, Air, Wastes, Noise and Landscape Protection.

Their control and supervision are ensured through additional regulations defined by the local «préfets» (prefects) with the help of services that specialize in environmental protection.

4. SITE REMEDIATION ACTIVITIES (see references [1, 2, 3, 4])

4.1. The phases of site remediation

— The first phase consists in defining the strategy best adaptated to the local site considering general objectives within the regulatory framework.

  The database necessary to define this strategy includes the following items: history of activities, waters circuits, radioactivity mapping, mapping of sampling locations, past studies together with initial topography, geology, hydrogeology and geophysics of the sites.

  This initial evaluation phase is complemented by specific complementary studies generally carried out by recognized outside experts. These studies characterize the materials, the storage areas, the potential local impact and the environment. The environmental aspect investigates the geology, hydrogeology and site geophysics, hydrology, ground stabilization and the local vegetalization. Subsequent remediaton work includes the following activities:

— A project plan is prepared to define the work required to carry out: earth moving, covering with various types of materials, compacting, site drainage water treatment, special civil works, dismantling of the installations and the disposal of products derived from the dismantling operations. The final status of the landscape is examined by computer topography simulations.

— During the working phase, any necessary adjustments are carried out.

— At the end of the remediation work, the final status includes control of monitoring of the topography, water circuits, radioactive mapping, verifying that the residual radioactivity is consistent with the local regional radioactivity and revegetation.

  These activities are complemented by an internal audit using COGEMA's quality assurance procedures.

  All of these works are carried out under the supervision of the regulatory authorities (Prefect and its services) which finally deliver an «Arrêté Préfectoral» attesting to the good quality of the work, possibly specifying future complementary work and also defining rules for future site monitoring.

— During site monitoring, regular checks are made to observe the gradual return to a natural and stable equilibrium. After a probatory period, COGEMA may ask for a reduction of the level of controls and eventually obtain permission for a definitive abandonment of the site and for its reuse for other activities by local parties. In all instances, however, the storage sites for milled ore residues storage which must remain under COGEMA's responsibility and supervision.

4.2. Underground mines, security for the public in the long term

At the end of mining operations, the priority is given to long term security for the public. Each communication with the surface is blocked to pevent any intrusion and the stopes are stabilized to

avoid caving. The proposed closure procedures are submitted to regulatory authorities and may be complemented by specific studies.

4.3. Open pits, its landscape impacts

First, the pit is filled with waste rock (several thousands or upto a million tonnes of earth may be moved) and the pit walls may be resloped with explosives for increased stability. In some cases, the pit may be transformed into a water impoundment for irrigation or other purposes.

4.4. Milling facilities

4.4.1. Dismantling and disposal of the dismantled facilities

After cleaning, the mill equipment is dismantled and sent to other identical facilities.

Two types of equipments may be considered:

(1) front end equipment, related to ore preparation (crushing, grinding…), may be cleaned and sold to the operators of other extractive industries. Before selling, this equipment is checked to confirm that it meets regulatory specifications. Also, the traceability of the equipment is ensured,

(2) back end equipment (which « saw » uranium solutions) must not be sold; it is burried within the milled ore residues. The location is carefully mapped and the disposal is supervised by regulatory authorities.

The buildings are then dismantled, concrete and other products are also burried within the milled ore residues. The grounds are cleared to the original level and rechecked for radioactivity. Covering and landscaping may complete the operations.

4.4.2. Confining the milled residues for public health

In France the milling residues are generally covered with waste rock (the Forez site, where residues are kept under waters is an exception).

The waste rock cover materials which come from the site, may be complemented with external materials, if necessary for quantity, quality or other exceptional reasons. The purposes of the cover is to:

— ensure a safe mechanical protection, resistant to erosion and to potential intrusions;
— limit the exposure to external radiation and radon emanation.

Preliminary tests are carried out to verify the efficiency of cover products. These tests include both petrographic and geotechnical examinations. Pilot units are also used to test various types of materials, compacted or not, using various cover depths and possibly combining multi-layers disposals.

Based on expert advice, the geometry of the protection dams surrounding the milled residues may be resloped and reinforced to improve the long term erosion stability of these dams.

During the course of studies on various mill tailings, it was discovered through geochemistry and petrographic analyses, that the natural leaching of radium was limited (less than 1% of the radium for stored mill tailings compared to 10% for fresh mill tailings). This can be explained by the rapid development (less than 30 years) of high surface secondary minerals such as smectite, iron oxy

hydroxides and gypsum that can trap 95% of the total radionuclides and associated heavy metals. This can be called « self confinement », which improves the chemical stability of the tailings [5, 6, 7].

4.5. Continuous monitoring

The operator must maintain as low as reasonably possible any impacts on the public and the environment; this includes preventing the dispersion of radioactive products and continuously scrutinizing these impacts through systematic and regular supervision.

This supervision is carried out by monitoring all of the transfer pathways which may be followed by uranium and its daughter products (especially radium and radon) and also by other elements such as heavy metals.

The monitoring requires frequent analyses on samples from the following sources:

— waters (rivers, underground waters, wells…),
— air (external and internal exposures, radon and dusts inhalation),
— the food chain (milk, vegetables, samples of flora and fauna…).

Water quality is a fundamental measure of environment quality. The following monitoring and control operations are used:

— on mining sites, hydrological and hydrogeological studies before and after mining operations produce a satisfactory knowledge of the water chemistry and the flow patterns. Before mine flooding, studies are carried out to predict the locations of seeps and ground water excursions that may require collection and treatment.

— at mill tailings sites, the installation of selective drainage systems allow for the separation of waters requiring treatment from those that do not; this limits the volume of water requiring treatment. Sludges resulting from water treatment are stored on site with other residues of the same nature.

For the long term, it is most important to keep a permanent record of the sites. This involves the following three fold strategy:

(1) COGEMA remains owner of the storage facilities,
(2) liabilities are listed in the licence issued at the end of remediation and registered to the « Hypothèques » (Land ownership register),
(3) a national inventory of radioactive wastes, including residues from uranium ore processing, is updated annually by ANDRA « Agence Nationale des Déchets Radioactifs » (National Agency for Radioactive wastes) [8].

5. COMMUNICATION, TO SHOW AND EXPLAIN THE ACTIONS OF COGEMA

Communication strategies are to conform with the local constraints of each site and the ongoing circumstances (shuting down period, local oppositions, etc…). COGEMA looks for a constructive dialogue with regulatory authorities, local authorities and opponents. This dialogue is achieved by participation in meetings, widespread publication of environmental survey results, site visits etc. A locally assigned COGEMA representative is in-charge of the direct contacts with local populations to hear about the concerns of all stoke holders.

Internal communication is important and is not neglected: listening to the staff, the exchange of experiences at various sites, coherence of words and acts and cohesion of various shifts, are all absolutely necessary.

6. MILLING FACILITIES WITH ONGOING OR FUTURE PLANS FOR REMEDIATION ACTIVITIES

Jouac is the only facility still operating in France. It operates through a 100% owned subsidiary of COGEMA, the « Société des Mines de Jouac ». Remediation plans are being updated, because operations will cease in mid-2001.

Remediation activities are still on going at the following facilities: Bessines (the industrial site grouping Lavaugrasse and the various Brugeaud storage sites), Lodève, St Pierre du Cantal and Bertholène.

Bessines is a complex industrial site where underground and open pit mining started in 1955; milling and heap leaching developed after 1958. Lavaugrasse (a ring dyke type impoundment) was the first mill tailings storage facility; subsequently the tailings were stored in the Le Brugeaud open pit. Both of these sites are now covered, but an opening in the cover has been kept on top of Lavaugrasse to store sludges from the water treatment plants at the mill and from mining sites in the vicinity. Remediations work is scheduled to end in December 2000.

Lodève ceased operations in 1997. The mill has been dismantled and the contaminated equipment, scrap materials and the demolition products were stored within a dedicated area atop the tailings. These tailings and the demolition products are now covered: the remediation work is scheduled to end in December 2000.

Remediation is progressing slowly at **Saint Pierre de Cantal,** because covering the last sludge decantation pond is limited to summer operations due to the presence of unconsolidated clays.

In **Bertholène**, remediation is on stand by. At this heap leaching facility, the cover material is rich in sulphides which have not been completely leached. Consequently, after resloping, installation of the final cover has been postponed in order to allow for continuation of the natural decomposition of the sulfide minerals. The water treatment plan is being kept in operation to continue the treatment and release of waters that meet regulatory limits. The sludges are filtered and trucked to Jouac for uranium recovery.

7. CONCLUSION

Following the remediation of mining sites, the chief objective of COGEMA is to support future development of the mining areas.

This can be carried out through reindustralization operations, helping with new installations or assisting local industries by reusing existing facilities such as offices or other facilities.

Open pits often occupy large surface areas in rural locations where water management is an omnipresent question. Water impoundments in these pits can be designed for irrigation purposes and the development of the aquatic fauna or for more original purposes such as fishing reserves for rare species or diving centers.

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Hydrogeological site investigation for the efficient remediation of uranium mining sites — an integrated approach

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Abstract. The currently practised remediation of former uranium mines in Eastern Germany involves the flooding of underground and open pit mines, and the stabilization of waste rock dumps and tailings ponds, e.g. by dewatering, covering, improving dams, cleaning effluents. This article presents examples demonstrating that the remediation concepts developed and implemented have failed their targets, resulting in uncontrolled flow behaviour and migration of contaminated water, leading to increased costs and additional threats to the environment. A generic series of steps for an improved remediation management with respect to financial efforts and environmental safety are proposed in terms of an integrated approach.

1. INTRODUCTION

Until 1989 Eastern Germany was an important producer of uranium. Uranium mining had gone on for three decades with a total production of 220 thousand tonnes of uranium. Various types of deposits in sedimentary and metamorphic rocks were exploited by underground and open pit mining. The end of uranium mining, which was brought about by the reunification of the two German states, was the beginning of close-down and remediation activities at several mining sites. Remediation has been done by flooding underground and open pit mines as well as by stabilising waste rock dumps and tailings ponds, e.g. by dewatering, covering, improving dams, cleaning effluents. The expected total costs of about 7 billion[1] EUR will be funded entirely by the German government.

2. GENERAL SITUATION

In order to plan the time and cost requirements for the remediation activities and to control the impact on the environment, it is necessary first to establish a prognosis on the flow (dynamics, volume) and the quality of the affected aquifers. The hydrogeological setting at the mine site is an essential factor. For most of the uranium mines in Eastern Germany the geological framework is very complex consisting mostly of lithologies which require consideration of both porous and fracture groundwater flow, sometimes in complex partially saturated conditions. In addition, the hydrostratigraphy includes units with markedly different permeabilities and hydraulic potentials, which are connected with each other to various degrees. As a consequence, the groundwater flow system at these hazardous sites is highly complex.

3. PROBLEMS AND CONSEQUENCES

In certain cases the remediation concepts developed and implemented failed their targets. The consequences are that, in spite of the significant costs already induced, concepts and measurements have to be improved at a very advanced stage of remediation, which is always a very expensive undertaking. However, if not done, one has to deal with large uncertainties in the prediction of the remediation's impact, potentially leading to severe contamination in aquifers which are in many places used for drinking water supply.

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[1] one billion=10.

3.1. Examples

The first example depicts the drawbacks of not performing a critical data review and simulation of processes before flooding a uranium mine which is to be performed in both a cost effective and an environmentally safe manner.

The second example shows that well targeted field investigations are very useful in improving conceptual hydrogeological models and are crucial for the design of suitable remediation measures.

3.1.1. Example 1: flooding of a mine

The case of a uranium mine is presented, which, after mining activities had stopped, was flooded under natural conditions. The flooding process had to be controlled, as the mine was situated at a location of high population density. Therefore, uncontrolled outflow of the flooding water at the ground surface and into aquifers used for water supply would likely cause dramatic damage.

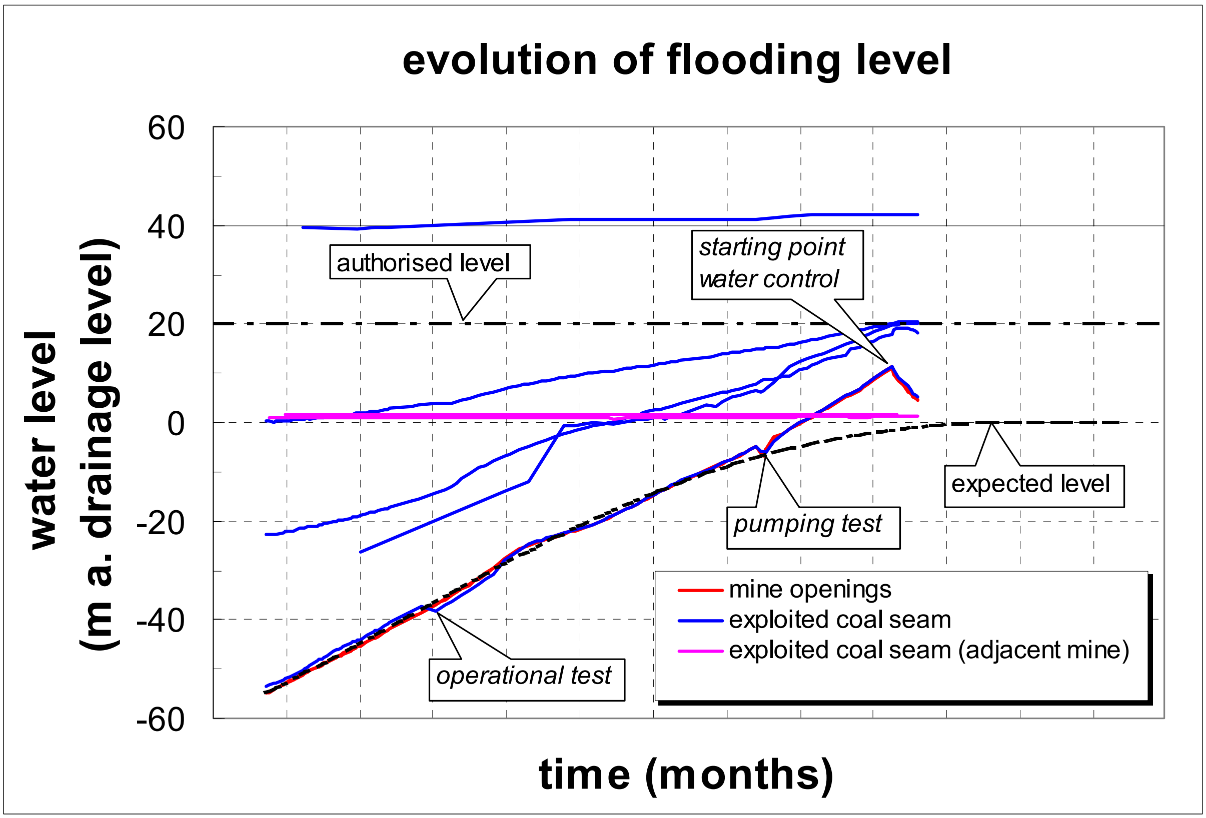
The uranium ore was embedded within a coal deposit. Large areas of the coal deposit were mined prior to the start of the uranium ore exploitation. Most of the uranium mining was concentrated therefore in the lower-most part of the deposit. As a consequence, the uranium mine is surrounded by former coal mines. Prior to the start of uranium mining, the coal mines were flooded completely and the water level was stabilized at the discharge level obtained with drainage drifts. During the uranium mining, pumping kept the mine dry but resulted in an extended hydraulic depression cone within the surrounding coal mines.

The hydraulic connection between the mines including the uranium mine was estimated to be good. It was anticipated that after pumping would have ceased (flooding), the water level would not exceed the level of the deepest drainage drift of the former coal mine. Therefore the flooding water was expected to discharge at this level, making water treatment possible at clustered collecting locations if necessary. In order to protect the environment against pollution by flooding water the maximum authorized flooding level was fixed at a level 20 m above the level of the deepest drainage drift. In order to allow for an active regulation of the flooding level (emergency case), a pump was installed in one of the shafts.

Figure 1 depicts measurements taken during the flooding process. They show that the prognosis failed completely: Neither the measured flooding water level nor the discharge location or the chemical composition of the flooding water has met the expectations. The flooding water had reached the authorized level in the mine when the water in the shaft already had exceeded the expected level by 10 meters without showing any tendency of stabilization. Therefore, it was necessary to start pumping of the flooding water in order to control the level. This “emergency” measure will have to be continued until an alternative concept is conceived and realized for a long term solution which does not necessitate an active control by man.

The failure of the prognosis has far reaching consequences. The first and most obvious one is that flooding water has to be treated which has a different chemical signature than was expected and which discharges at a different location. Based on the prognosis, an investment was made for a stationary water treatment unit. Most probably this unit will not be put into operation. Beyond the economical damage due to time delay and ill investments, a high risk for the environment exists due to the insufficient appreciation of the hydrogeological system.

This very uncomfortable situation might have been, at least partly, avoided, if the existing hydrogeological/hydrochemical data and estimates would have been carefully reviewed, analysed and possibly extended with additional measurements, and the flooding scenario studied based on various (and equivalently probable) hydrogeological models. These conceptual models might have been implemented into numerical models, the data available used for calibration of the models, and the uncertainty in the prognosis assessed with sensitivity analyses.



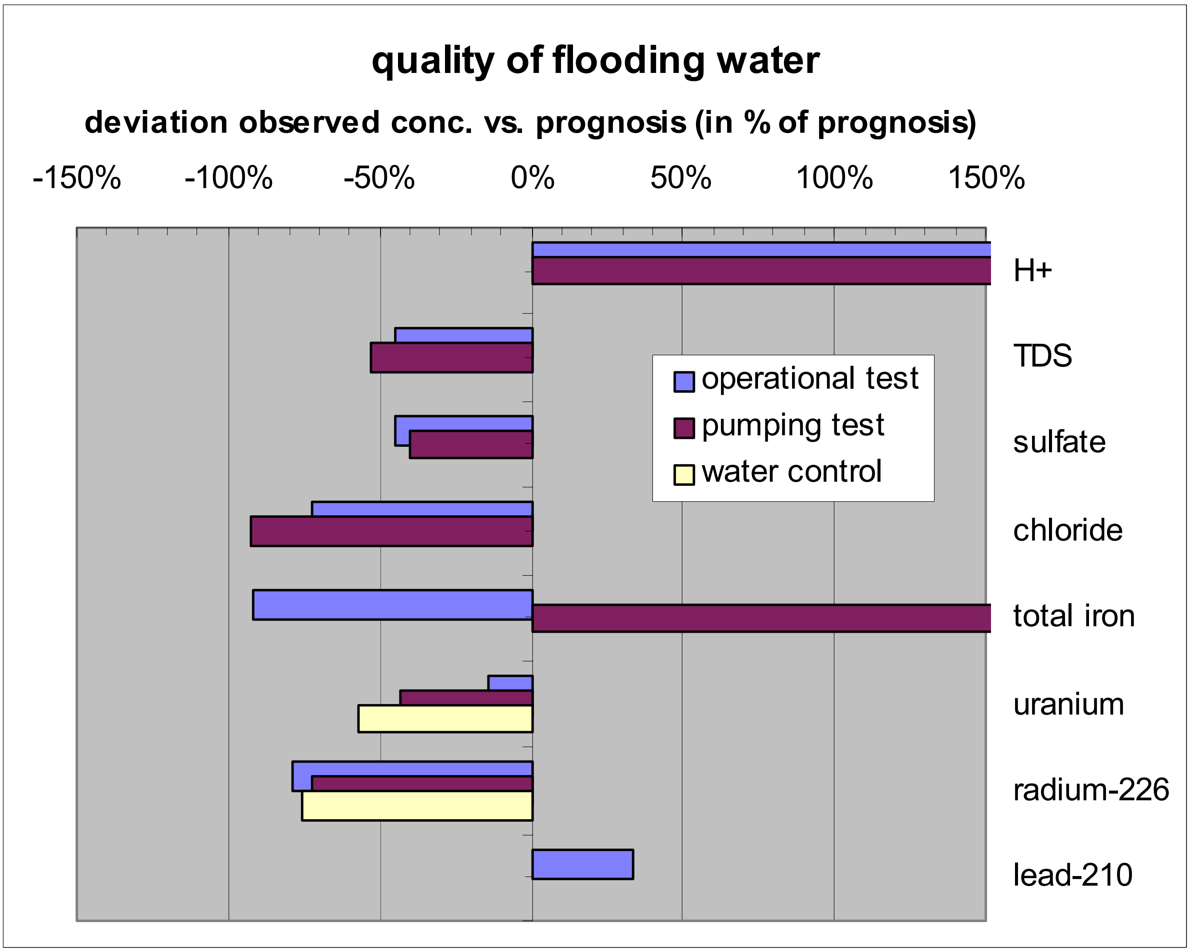


FIG. 1. Flooding of a uranium mine: Comparison of actual measurements to prognosis.

3.1.2. Example 2: remediation of a waste rock dump

Several surficial deposits of mine waste exist in the area as remnants from the period of uranium mining. One of those, mainly consisting of waste rock, is located in the immediate vicinity of a large city. In order to minimize the impact on the environment, potentially caused by the release of contaminated effluents and the exhalation of radon, the owner planned to implement a multi-layer soil cover on the dump. One important target of remediation is the protection of deep wells in the vicinity of the dump, which were used for drinking water supply at the time.

A first remediation concept was based on a strongly simplified hydrogeological model of the near field of the dump. No differentiation was made between aquifers and aquitards and the groundwater flow direction was assumed towards the nearby wells (see Fig. 2 top). This strongly simplified model was not consistent with the observations. In particular, this model does not explain why the water quality of the drinking water wells was not affected by the vicinity of the dump, although it was recognized that most of the dump effluents containing uranium and sulfate were infiltrating into the ground.

In order to check if the remediation options were suitable for reducing the impact on the environment in terms of the groundwater flow path, additional field investigations of the hydrogeological and hydrochemical conditions were conducted at the dump site, i.e.:

- measurements of flow, of concentrations of dissolved solids (esp. U and ^{226}Ra) and of contents of environmental isotopes in precipitation, surface runoff, seepage water and groundwater
- underground investigation using boreholes up to 270 m in depth and performing borehole measurements (logging, pumping tests, sampling)

This resulted in an improved conceptual model with respect to the hydrostratigraphy and the flow regime (Fig. 2 bottom) as well as a consistent water and mass balance.

One may roughly outline the hydrostratigraphy from outcrops and drilling observations. It consists of a system of two main aquifers separated by an aquiclude of several meters of thickness (Fig. 2 bottom). The discharge area of the upper aquifer concentrates in one main spring, situated besides the nearby valley. One of the recharge areas of the lower aquifer is assumed to be located in the area of surficial outcrops in the valley downstream of the dump whereas discharge occurs in the shafts of the former mine. For this reason groundwater flow in the two systems is of opposite direction. The drinking water well mentioned above is located in the well protected lower system, which explains the absence of contaminants from the dump.

4. REMEDIATION MANAGEMENT USING AN INTEGRATED APPROACH

The examples presented above demonstrate how important it is to manage efficiently the closure of old uranium mines. The proposed methodology relies on a logical, integrated approach involving the following steps (see Fig. 3):

Field investigations and data management:

- evaluation of the current situation, in particular the hydraulic and chemical data available within and outside the mine
- set up of target-oriented field investigations to obtain missing information (e.g. reference [1], [3], [10] and [11])
- sampling optimization and uncertainty assessment using geostatistical methods (e.g. reference [4])
- set up of a monitoring system for comparison of observations with model predictions
- data management and visualization: creation of a hydrogeological data base linked to Geographical Information System (e.g. reference [2]). Visualization for data verification as well as for information purposes for the public and authorities

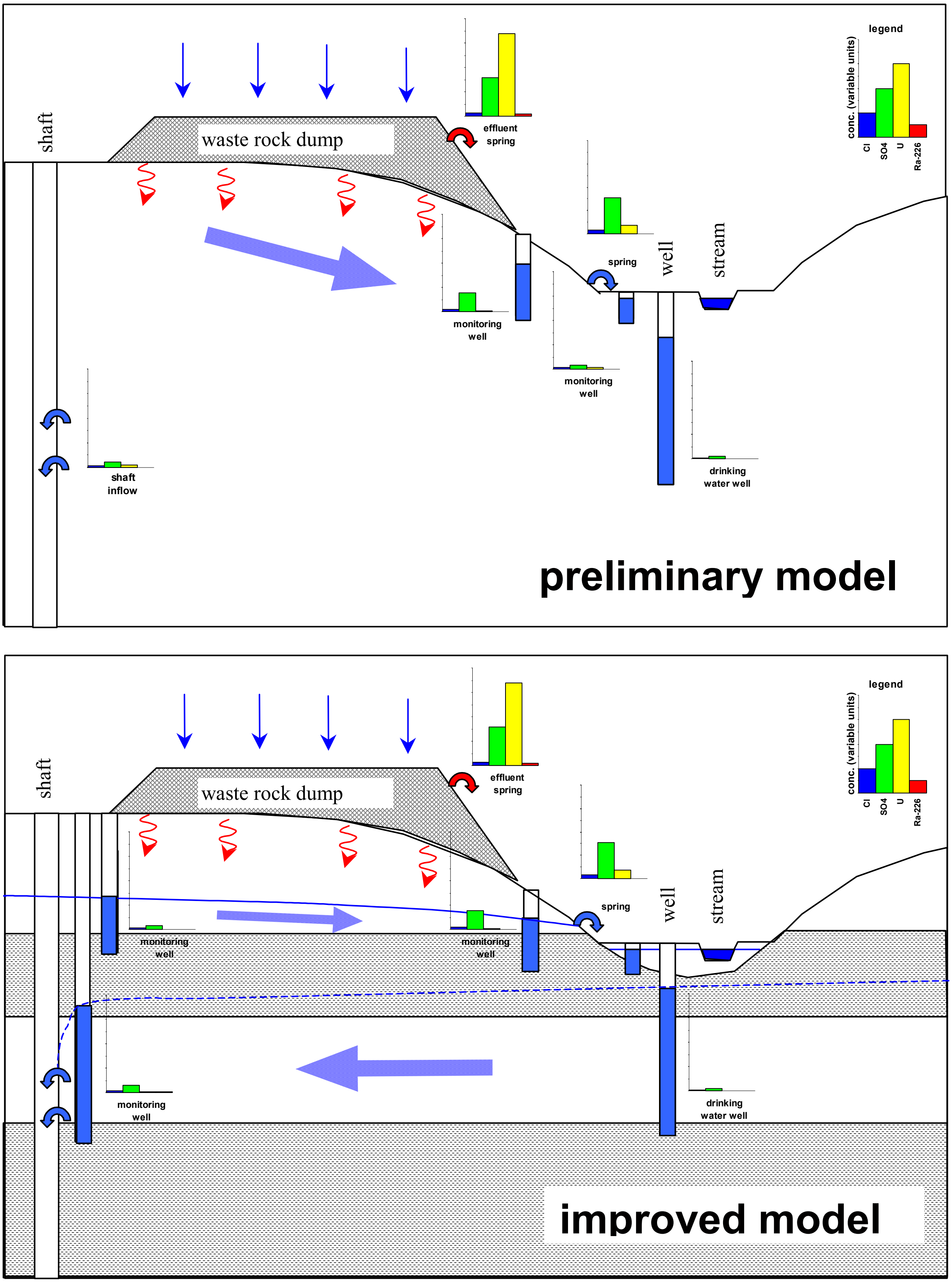


FIG. 2. Remediation of a waste rock dump: comparison of conceptual models before and after additional site investigations (schematic illustrations).

Conceptualization of the hydrogeological system:

- definition/improvement of the conceptual model of the hydrogeological system based on old/new data acquired
- determination of the hydrogeological units in terms of geometry and physical properties
- assessment of degree of heterogeneity of the hydrogeological units (e.g. reference [5])
- identification of the key physico-chemical processes involved
- determination of the boundary conditions of the hydrogeological system
- evaluation of current/historical hydrogeological impact from mining activities
- development of the remediation concept (e.g. references [7] and [8])

Quantitative assessment of hydrogeological system response with respect to remediation measures:

- implementation of hydrogeological and remediation concepts into numerical models
- discretisation of the hydrogeological structures in terms of geometry and physical properties (e.g. references [2] and [6])
- calibration of the model using measured/historic data with account of their uncertainty
- numerical simulations using alternative scenarios (related to parameter and/or different remediation measures) for reliable predictions of critical physico-chemical quantities
- interpretation by spatio-temporal visualization of modelling results (e.g. reference [6], [9], [12])

Optimum and efficient management of the environmental impact:

- application of the integrated approach as decision support tool for remediation management
- determination of optimum remediation measures based on the understanding of the functioning of the hydrogeological system.

While some of the topics listed above are usually accomplished to some extent, others such as the acquisition of target-oriented field data, the determination of the hydrogeological concept and the quantitative evaluation of the impact of remediation with numerical models are often neglected, which may induce dramatic consequences on the environment and costs at a later stage.

A programme of target-oriented **field investigations** will only be complete with boreholes used to perform appropriate in situ intermediate – large scale measurements for the hydrogeological characterization of lithological units. These include a combination of geophysical measurements (structural data) and hydraulic testing (hydraulic packer tests, pumping tests, flowmeter or fluid logging measurements, interference tests). These data and their interpretation form the essential basis for the rational design of the remediation operation.

In the following we illustrate the use of specific hydraulic testing methods through generic examples. The use of flowmeter measurements is limited to highly permeable formations. In low to medium permeability formations, a very powerful investigation method used to obtain a continuous profile of the hydraulic conductivity within a borehole is the so-called fluid-logging technique.

Figure 4 illustrates schematically the data which are obtained in a “fluid-logging” campaign in a 300 m deep borehole drilled vertically from the ground surface into a formation of medium hydraulic conductivity. The borehole is kept open during the investigation. Before logging begins, the borehole is flushed with the drilling fluid being replaced by a water-based fluid of an electrical conductivity markedly different than that of the formation fluid. The borehole is being pumped (withdrawal) while logging runs record the evolution of the electrical conductivity of the borehole fluid with time. The depth profiles of electrical conductivity are used to identify the permeable zones (see Fig. 4.) and hydraulic conductivities for these zones are derived. The results contribute to the characterization of the local hydrogeological situation with the radius of investigation reaching several meters to decameters into the formation.

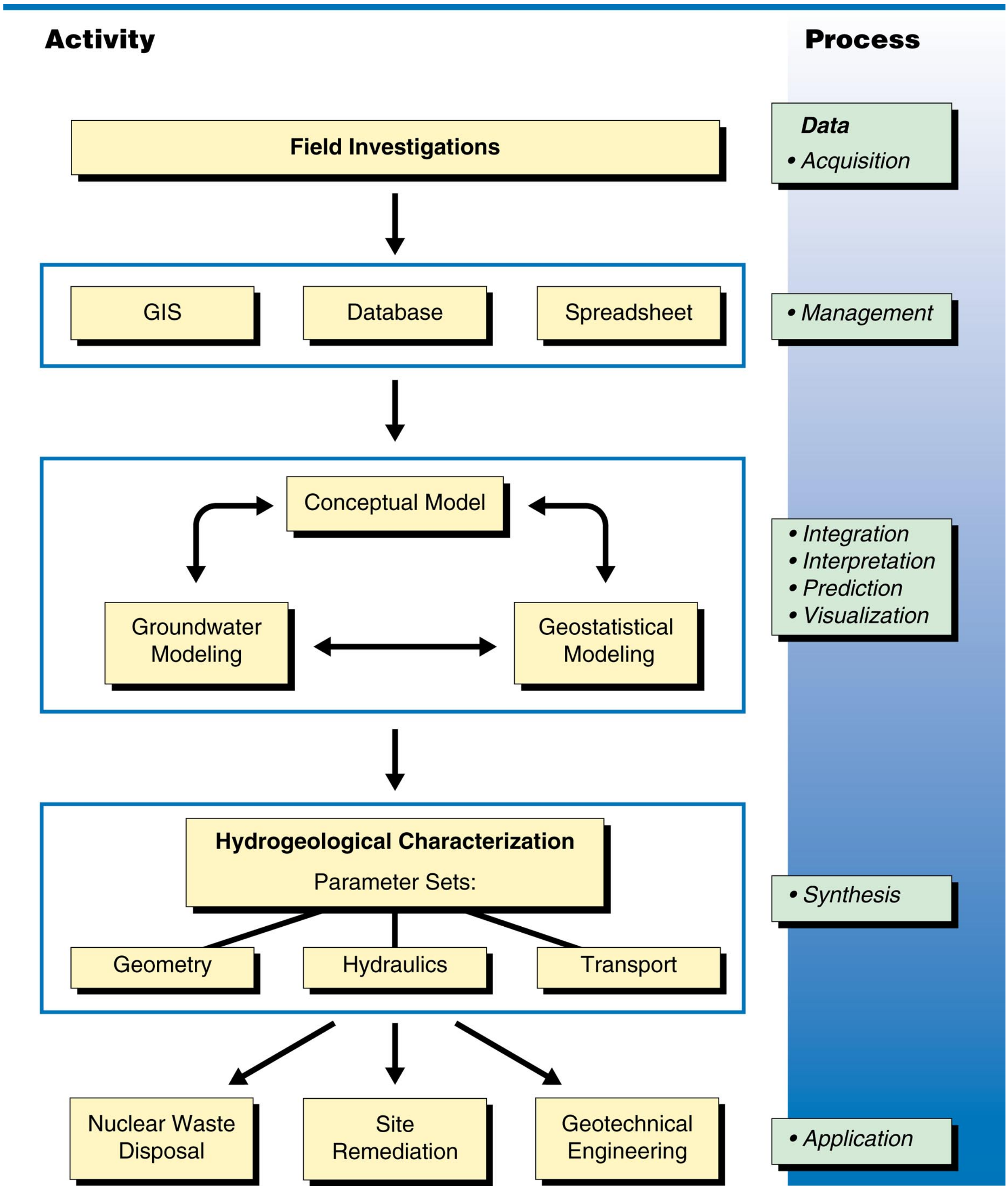


FIG. 3. Integrated approach for remediation management.

Fluid logging is generally complemented by hydraulic packer tests. These are performed in borehole sections previously determined to be of the highest permeability. A particularly valuable type of hydraulic packer tests in the vicinity of mines or rock dumps is the so-called interference test. Figure 5 schematically illustrates the concept of this type of investigation tool: A pumping test is conducted in borehole BO1 and the induced pressure variations are monitored in observation intervals in boreholes BO2 and BO3 located at a distance of several hundred meters from BO1. The pressure variations are analysed for hydraulic parameters of the rock mass at a hectometric scale (e.g. degree of connectivity of a fracture system, hydraulic diffusivity). Interference tests like this may be performed in any combination of active and passive segments in a series of two or more boreholes, or by using a configuration including an underground mine and surface boreholes.

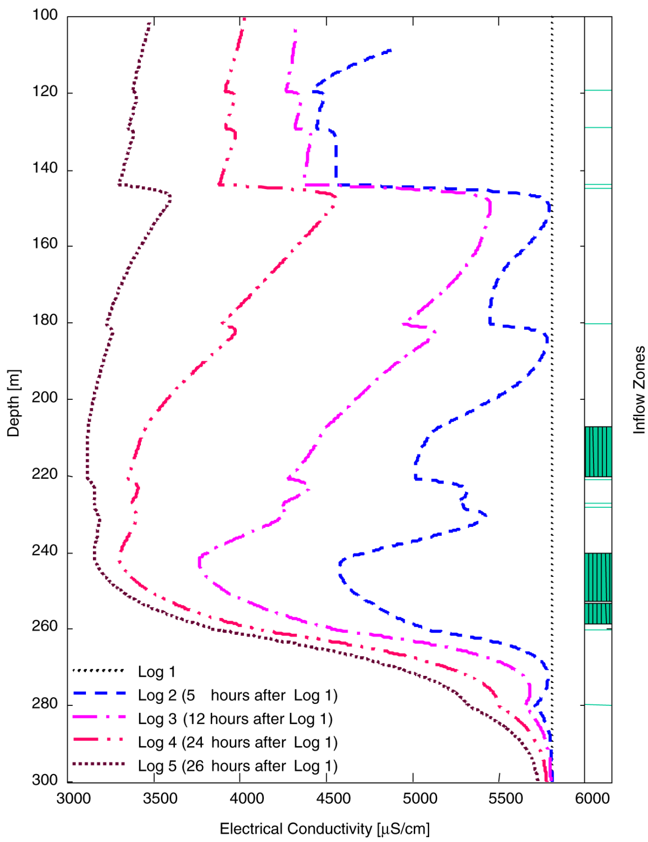


FIG. 4. Generic example of fluid-logging measurements in a borehole.

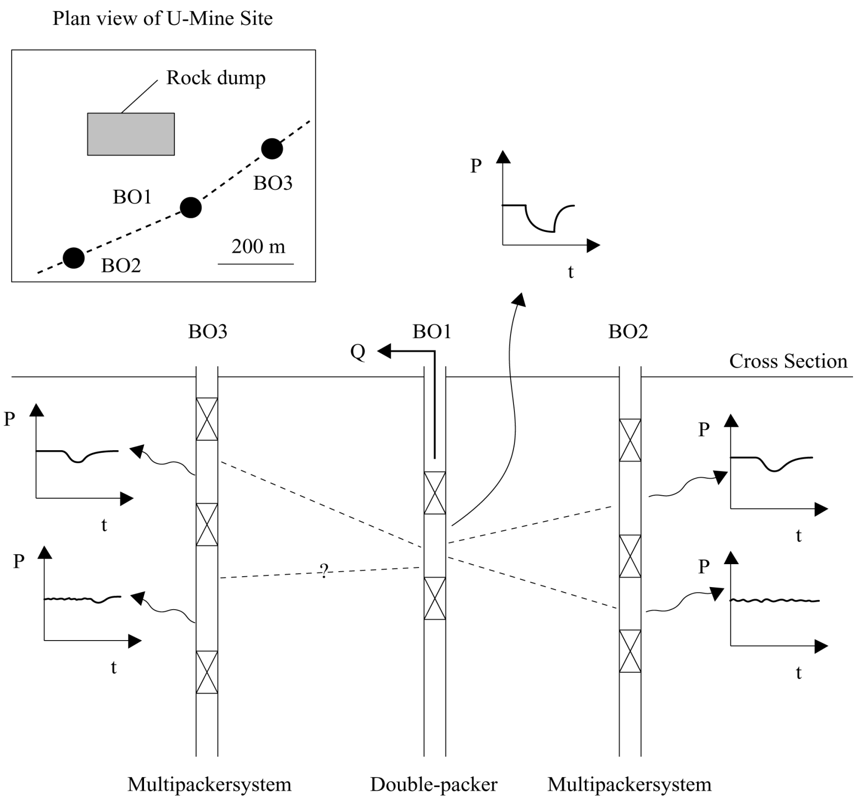


FIG. 5. Generic configuration for an interference test.

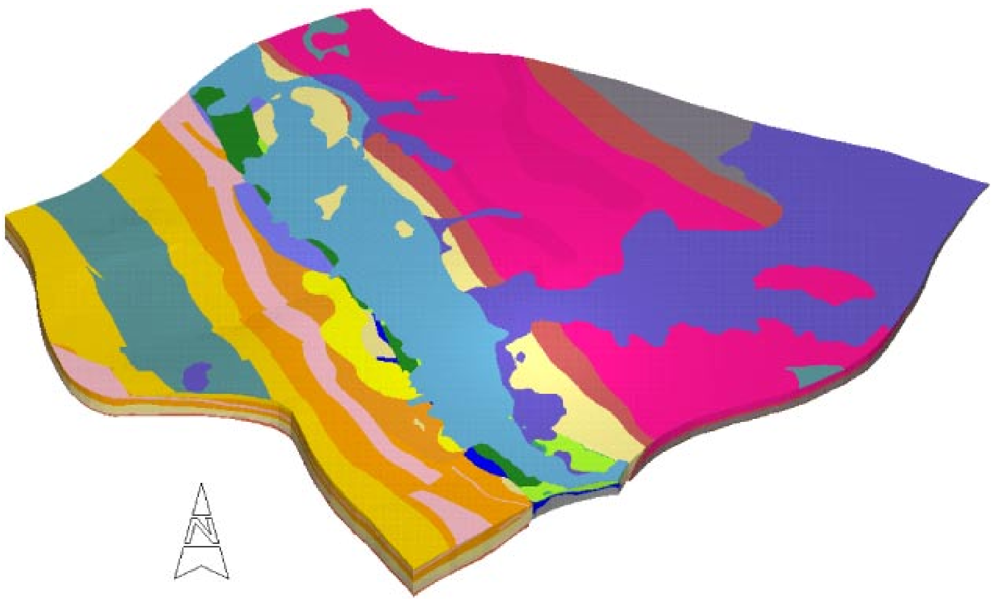


FIG. 6. 3D hydrogeological model (area covered: 60 km^2).

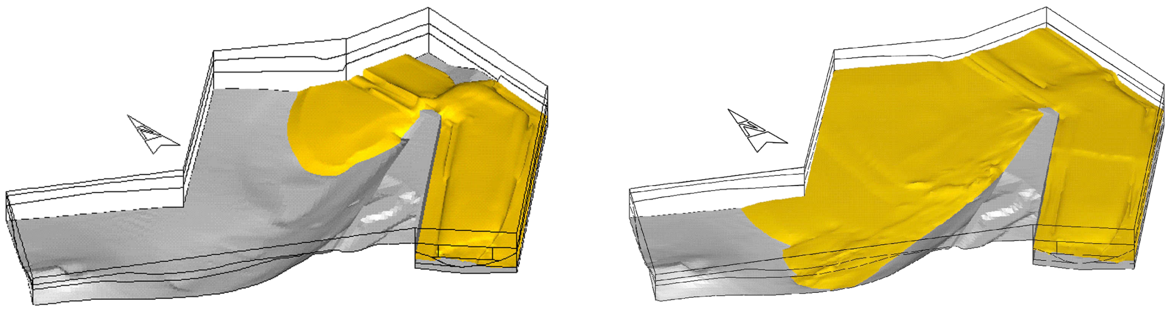


FIG. 7. Simulated distribution of contaminant in an aquifer system at different times.

In addition to investigations performed within boreholes, the flow, chemical composition and origin of all the water cycle components (precipitation, surface runoff, effluents and formation waters at specific discharge location) including their seasonal variations have to be quantified by field measurements over time of flow rates, water levels, physico-chemical parameters as well as by sampling and performing laboratory analyses of dissolved solids, radionuclides and environmental isotopes.

Based on the results of field investigations, the **conceptual model** of the hydrogeology of the mine site has to be improved in order to describe the main structures in terms of geometry and physical properties of the hydrogeological system, thereby also taking into account the key physico-chemical processes involved in a potential site contamination.

Using this system conceptualization, a quantitative evaluation of the impact of the chosen remediation concept is required. This objective is achieved with the help of **numerical models** representing the observed hydrogeological conditions, including spatial heterogeneities (in terms of geological structures; see Fig. 6 and hydraulic and transport properties) and characterising the dominant physical and chemical processes. Numerical simulations are then performed to obtain a quantitative description of the system's evolution with time in order to predict the spatial distribution of physico-chemical variables (e.g. concentration, see Fig. 7). These predictions are made for various scenarios which are related to parameter uncertainties and/or different remediation concepts.

The integrated approach – based on field investigations, system conceptualization and numerical modelling – constitutes an essential decision support tool for an efficient management of the environment in a cost effective manner when faced with the remediation of mine sites. The costs associated with such characterization and prediction studies usually do not compare within any common measure with the costs invested in the remediation itself, and in particular with the costs induced by mistakes in the planning phase.

5. CONCLUSION

Significant improvement in remediation management is required to assure a safe remediation of old U-mines. The proposed integrated approach is based on extensive developments, experience and expertise gained with the investigation programs for the disposal of radioactive wastes. In particular, the intense efforts applied in that domain resulted in the development of modern and cost effective investigation and characterization techniques which can be easily implemented for the old U-mine remediation programs. The costs induced by implementing these new techniques will be moderate for the remediation program, if planned appropriately based on comprehensive expertise. To the contrary, they will help reduce the global costs by preventing conceptual mistakes, unnecessary actions and loss of time.

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The safe management of radioactive waste from mining and milling activities

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Abstract. The IAEA is developing a Safety Guide for the management of radioactive waste from the mining and milling of uranium and thorium ores. This new Safety Guide will provide information that has been requested by Member States concerning the safe management of these wastes. The guide includes some new concepts, but they are intended to be reasonable and provide appropriate safety conditions for the workers, general public and the environment. The Regulatory Authorities of individual countries are responsible for establishing and implementing the regulatory framework through the development of appropriate rules, criteria and guidelines and establishing a licensing framework. The IAEA has issued a number of publications that provide requirements and guidance for the protection of workers, public and the environment. The overall objective and subsidiary principles developed explicitly for the management of radioactive waste should emphasize that the protection of the public from the beginning of operation to post-closure should be considered in its entity from the beginning of the design of the facility. The Safety Guide acknowledges that mining and milling wastes will contain non radiological hazards, in addition to the radiological hazards. The development of the waste management strategy is usually a complex process that aims to achieve a reasonable balance between the often conflicting goals – maximizing risk reduction versus minimizing financial expenditures. The evaluation criteria and procedures used to select the preferred option/and or development of the waste management strategy should be clearly defined and acceptable for the different parties interested in the project. This includes the public. A safety assessment should be performed to indicate how the design of the waste management facilities provides the optimum protection for the workers, public and environment using safety – type indicators.

1. GENERAL

The IAEA is in the process of developing a Safety Guide on the management of radioactive waste from the mining and milling of uranium and thorium ores. This publication has been in development for some time and will finally be sent to our Member States for review and comment within the next few months.

This Safety Guide addresses the strategies and protocols for siting, design, construction operation and closure of facilities as associated with the protection of the worker, the general public and the environment. This Guide provides guidance for facilities that are considered practices and do not necessarily relate to intervention situations. Although not specifically addresses, the guidance may be relevant to the management of wastes from the mining and milling of other ores having elevated radioactive levels in their tailings.

This new Safety Guide will replace Safety Series No. 85 "Safe Management of Wastes from the Mining and Milling of Uranium and Thorium Ores".

2. REGULATORY FRAMEWORK

Individual countries should have a national policy and implementation strategy for managing waste associated with mining and milling operations in place. Most mining and milling wastes contain non-radioactive hazardous components and these hazards must also be addressed in the overall national policy. The Regulatory Authority should consider the need for and extent of public involvement and

consultation during the regulatory process. At times this can be very painful, but it worth the investment of keeping the public informed and listening to their concerns.

The Regulatory Authority is responsible for establishing and implementing the regulatory framework through the development of appropriate rules, criteria and guidelines and establishing a licensing framework.

The operator is responsible for managing the waste in a safe manner in accordance with all safety and other regulatory requirements.

3. HEALTH AND SAFETY

The IAEA has issued a number of publicationss that provide requirements and guidance on the protection of the worker, public and the environment. The basic publication is the "International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources" commonly known as the Basic Safety Standard or BSS. The new Safety Guide restates the requirements of the BSS and provides some additional guidance specifically for mining and milling activities.

The overall objective and subsidiary principles developed explicitly for the management of radioactive waste should emphasize that the protection of the public from the beginning of operation to post-closure should be considered in its entirety from the beginning of the design of the facility. During operation the normal radiation protection requirements of the BSS apply. The facility should be designed and operated such that radiation doses to members of the public after closure remain below an annual dose constraint, determined by the Regulatory Authority, which is some fraction of the dose limit for members of the general public. The International Commission on Radiological Protection (ICRP) has recommended a value of 0.3 mSv per year.

A combination of engineering and institutional controls may be used to attain a level of radiological protection that meets the dose constraints determined by the Regulatory Authority. Regardless of the combination of these controls, there should be reasonable assurance that the controls will remain in effect for a specified period. However, it should be assumed that following this period, the institutional controls would fail. The Regulatory Authority should determine the period for which the institutional controls can be assumed to remain effective. The IAEA recommends a period of 100 to 200 years as a reasonable period. After this period, it is assumed that the waste will inevitably be subject to human intrusion, even though the engineering controls may have otherwise continued to remain effective for a longer period.

This Safety Guide acknowledges that mining and milling wastes will contain non-radiological hazards in addition to the radiological hazards. The management of these wastes should take into account both types of hazards and analyze the effect on the public and the environment. Even for radioactive contaminants, their chemical toxicity may cause unacceptable environmental impacts at concentrations well below those necessary to produce radiological effects. These impacts must be considered at the planning stage of a project and should be periodically re-assessed throughout the project life cycle.

4. WASTE MANAGEMENT STRATEGIES

The development of the waste management strategy is usually a complex process that aims to achieve a reasonable balance between two often conflicting goals, maximizing risk reduction versus minimizing financial expenditures. The process is one of optimization of protection in which the available alternatives for siting, design, construction, operation, management of waste streams and closure are evaluated and compared taking into account all associated benefits, detriments and constraints that are imposed. The characteristics of the alternatives that should be considered include:

- the radiological and non-radiological impacts on human health and the environment during the operation and in the future;
- the requirements for monitoring, maintenance and controls during operation and after closure;
- any restrictions on the future use of property or water resources;
- the financial costs of the various alternatives;
- the volumes of the various waste that need to be managed;
- the socio-economic impacts including public perception; and
- good engineering practices.

The evaluation criteria and procedures used to select the preferred options and develop the waste management strategy should be clearly defined and acceptable for the different interested parties involved with the project, including the public.

Of the different waste streams produced during the mining and milling of ores, tailings represent the greatest challenge because of the large volumes produced and its constituent of very long lived radionuclides. The preferred management option for achieving the protection goals will depend on the specific conditions at the site, the ore body characteristics, specifics of the mining and milling processes and the characteristics of the tailings themselves. The principle that undue burden should not be placed on future generations leads to the conclusion that a passive design approach for closure is preferable to one that requires significant and ongoing maintenance. Such a passive approach is generally achieved by underground disposal that may occur in excavated pits specifically for this purpose, mined-out pits or underground mine voids. It is possible that underground disposal of mine tailings at a particular site may not be feasible either due to site specific problems for which engineering solutions can not be identified, or because of prohibitive cost. In these cases, engineered surface impoundments may be the only viable option.

Other solid and liquid waste generated by the mining and milling activities need also be properly managed. While the radiological hazards associated with waste rock and mineralized waste rock are usually much lower than for tailings, the non-radiological hazards remain and are often the more important consideration in the choice of the management option. These options may include using it as backfill material in open pits and underground mines or for construction purposes on the mine site. The need to cover mineralized waste rock with inert material should be considered. The wastewater management system should be designed to minimize the volume of contaminated water. This could be achieved through the re-use of wastewater in the process circuit, use for dust suppression, and the diversion of clean water away from contaminant sources.

5. SAFETY ASSESSMENT

A safety assessment should be performed to indicate how the design of the waste management facilities provides the optimum protection for the workers, public and environment using safety-type indicators. These assessments are used in the decision making process to select options and to decide if they are optimized. The safety assessment should cover the operational, closure and post-closure phases of the project.

The scope and extent of the assessment should be commensurate with the site-specific issues that need to be addressed. The results of the initial safety assessment should be factored into the choice of the site and the design of the overall mining and milling facilities.

The steps towards deciding how to manage the waste should include:

- identifying and characterizing the site options;
- defining the criteria for human health and environmental protection;
- characterizing the waste streams;

- identifying and characterizing the waste management options including engineering controls;
- identifying and describing any institutional controls;
- identifying and describing potential institutional and engineering control failures;
- estimating the radiological and other consequences for each combination of options being considered;
- comparing the estimated doses and risks with appropriate constraints; and
- optimizing protection to arrive at the preferred management option.

6. MONITORING AND SURVEILLANCE

A monitoring and surveillance programme should be developed as early as possible and should be implemented by the operator during all stages of the life of the facility. The programme should be reviewed periodically and following major changes in waste management operations or regulatory requirements.

The goals of the programme should include:

- establishing baseline or current conditions;
- obtaining site-specific input for assessing the safety of proposed designs;
- determining whether there is compliance with regulations, discharge authorizations and procedures;
- providing data from which radiation doses to workers and members of the general public due to the waste management facilities may be assessed;
- checking the effectiveness of engineering designs;
- calibrating and validating models and verifying their predictions;
- providing data for possible revisions to discharge authorizations;
- triggering conditions for non-routine investigations/inspections;
- detecting environmental impacts; and
- verifying the physical condition and integrity of the waste management facilities.

7. SUMMARY

The new Safety Guide will provide information that has been requested by our Member States concerning the safe management of wastes from uranium and thorium mining and milling operations. There are some new concepts, but they are intended to be reasonable and provide appropriate safety conditions for the workers, general public and the environment.

Study of the post-closure provisions for managing solid tailings from the extraction and processing of uranium ores resulting from the industrial activities of the COMUF company at Mounana, Gabon

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Abstract. Between 1961 and 1999 COMUF extracted about 28 000 metric tons of uranium from the Mounana mining district. This production generated about 7.5 million tons of processing tailings that are stored in areas close to the installations. In the context of the European programme "SYSMIN", the government of the Gabonese Republic commissioned a study to specify the measures to be taken for the restoration of the Mounana mining site and the radiological monitoring to be put in place after the COMUF installations close down. The methodology applied and the restoration and monitoring work undertaken must respect the requirement for an annual added effective dose of less than 1 mSv for persons in the critical population groups.

1. INTRODUCTION

Situated on the Equator, on the Atlantic coast of Africa, GABON covers an area of 267 000 km², with forest occupying about ¾ of the territory. It is populated by 1.2 million inhabitants, i.e. about 4.3 inhabitants per km².

In 1956, a mission from the Commissariat to the French Atomic Energy discovered the first signs of uranium in the region of Mounana, on the Western edge of the Franceville basin in the Province of the High Ogoué in the South East of Gabon.

The Uranium Mining Company of Franceville, COMUF, was created in 1958. Between 1960 and 1999, COMUF extracted 7.5 million metric tons of uranium ore from the Mounana district; the average grade was 0.37 % U.

Extraction of the ore began at the Mounana open pit mine and continued from 1960 to1975. This operation was followed by the mine at Oklo, which operated from 1970 to 1985. Ore was also extracted from underground mines, first at Mounana, then at Oklo from 1977 to 1997 and at Boyindzi from 1980 to 1991.

The extraction of ore ceased in 1999 when COMUF shut down the Mikouloungou open cast mine, which was situated near Franceville, 60 km from Mounana.

From 1960 to 1982, the extracted ore supplied the original milling operations, which had an annual production of 400 to 500 metric tons of uranium. This unit was replaced in 1982 by a new plant with an annual production potential of 1500 tons of uranium.

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COMUF, which had up to 1450 employees including 200 expatriots in 1979, produced 28 000 tons of uranium from 1961 to 1999. COMUF stopped production in July 1999, because the economically extractable reserves were exhausted.

2. ENVIRONMENTAL MANAGEMENT OF THE SITES AFTER CLOSURE OF THE INSTALLATIONS

Processing of the ore extracted from COMUF's underground and open pit mines generated about 7.5 million tons of tailings. Over the years these tailings have been stored behind a dike in the valley of the Gamanboungou River, which crosses the site and also in the Mounana open cast mine and in two talwegs. These storage areas are in the immediate vicinity of the two milling operations that were brought into service in 1961 and 1982.

In 1971, the government of the Gabonese Republic commissioned a study to specify the measures to be taken for the restoration of the Mounana site. This inquiry was based on the framework of the European programme for mining development and diversification (SYSMIN) and also on perspectives for final closure of the COMUF operations. The study concerned not only the risks associated with the presence of radionuclides, but also the means and procedures required for implementation of radiological surveys after closure of the COMUF installations [1].

The study was conducted by the ALGADE Company (France), in close collaboration with the Gabonese Ministry in charge of mines and COMUF's radiation protection and environmental services.

The methodology proposed was based on the principles of justification and optimization of the radiological protection as recommended by the CIPR and the IAEA and repeated in the European directive No. 96/29 of 13 July 1999. The final objective is to achieve an effective annual dose that will exceed the natural regional background level by less than 1 mSv for the critical population groups.

This study which was accepted by the European Union and the relevant Gabonese Ministries, enabled the restoration of the Mounana site to be carried out in the following three stages:

(1) Assessment of the existing radiological environment of the installations before restoration (1997)
(2) Definition and execution of the work on the areas to be decontaminated and restored (1998–2000)
(3) Setting up radiological monitoring after closure (2000–2005)

2.1. Stage 1: Assessment of the radiological environment of the Mounana installations before restoration

This stage enabled:

— Preparing an inventory of all the areas that require restoration,
— Defining the critical groups of the public to be taken into account,
— Assessing the effective annual dose of these critical groups before restoration.

➔ **The inventory of the areas** to be restored was based on a radiological survey that used a portable scintillometer of the SPP2 type equipped with a scintillating crystal of thallium activated sodium iodide associated with a photomultiplier.

The measurements were carried out using a regular 20 m grid, and the scintillometer was carried on the belt, about 1 m from the ground. All the areas with levels higher than 500 counts per second SPP2 ($\approx 0.4\ \mu Gy.h^{-1}$) were listed.

This inventory made it possible to identify a total area of about 75 hectares that will require decontamination. The area included 60 ha of process tailings, the former open pit mine of Mounana, the valley of the Gamaboungou, the area of the confluence with the Mitembe, and the thalwegs South and North.

The critical population groups were chosen in the most realistic manner possible, taking into account the present and future environmental context and the way of life of the local populations. These choices took into account the following criteria:

- population density and its distribution over the areas concerned,
- way of life and eating patterns,
- length of time spent in the different areas concerned.

The critical groups were chosen as being representative of the individuals most exposed to sources that exist at the mining site; the groups must also have a relatively homogeneous exposure to the doses received from these sources [2, 3].

From four types of real exposure scenarios likely to be encountered, two critical groups of the public were identified, as follows:

— Critical group 1 (CG1):

People from the general public who (1) live 5860 hours per year in an environment close to the site, (2) who work 2000 hours per year in the areas of activity on the restored site, (3) who travel 500 hours per year on tracks over the site and (4) who go once a week to their plantation (400 hours a year) near the site,

— Critical group 2 (CG2):

People who (1) live in the close environment of the site (5460 h/year), (2) who work every day in the plantations (2500 h/year) near to the site and (3) those who travel every day over the site (800 h/year).

It is assumed that each person in the group inhales 0.8 m^3 of air per hour, drinks 0.6 m^3 per year of water from the distribution network and consumes 7.5 kg of fish caught downstream from the site plus 190 kg of manioc, which is the basic food of the local population. The manioc is cultivated on plantations close to the site.

It is these two critical groups who are a realistic representation of the public most likely to be exposed and who must, after restoration, receive an effective dose that exceeds the natural background by less than 1 mSv per year.

➔ **The effective dose that exceeds the natural background exposure** of the two critical groups before the restoration work was assessed from measurements supplied by a monitoring network. This network was set up to determine the pathways by which radioactivity is transferred towards the populations (air, water vectors, food chain). In 1997 this network consisted of:

— 10 fixed atmosphere testing stations that provided (1) continuous monitoring of the external exposure rates (thermoluminescent dosimeters), (2) the volumic activities of the short life daughters of radon isotopes 222 and 220 and (3) measurement of the long life alpha emitters (alpha site dosimeters) [4, 5],

— Eleven water-sampling stations that collected samples of all waters discharged from the installations and also from the different receiver watercourses. These samples were analysed monthly for the volumic activities of radium 226 and uranium,

— Three stations for sampling the drinking water of villages situated close to the environment of the mining site. Each month these samples were analysed for the volumic activities of radium 226 and uranium,

— a series of samples taken from the food chain, actually consumed by the populations (fish downstream of the site; manioc and different produce from plantations near the site) for determination of radium and uranium activities.

In order to assess the effective dose due to the sources present on the mining site, i.e. the dose that exceeds the regional natural level, the results provided by the site-monitoring network are compared with a reference station positioned in the village of Omoi. This village is situated away from the site; it is located north of the Mounana region, outside the influence of the site.

The results of the measurements carried out in 1996 and 1997 showed that radionuclide activities found in the water consumed, in the fish caught downstream from the site in the river Lekedi and in produce grown in the close environment were comparable to those found in the natural surroundings, outside the area of influence of the site (fish caught upstream from the site; produce grown in the village of Omoi). Also, the added exposure associated with the ingestion of radionuclides via the food chain is negligible in relation to that associated with external exposure due to gamma radiation and internal exposures due to the inhalation of radon, the radon daughters and the long life alpha emitters.

Table 1 below presents the estimation of the effective added dose for the two critical groups before restoration.

TABLE 1. EFFECTIVE ADDED DOSE FOR THE REFERENCE GROUPS BEFORE RESTORATION

Before restoration (01/95 → 04/97)	Pathways				Effective* Added dose in mSv
	PAE Rn222 nJ.m^{-3}	PAE Rn220 nJ.m^{-3}	LLAE mBq.m^{-3}	Gamma nGy.h^{-1}	
Reference group RG1					
Time spent in the environment	130	21	1	160	0.60 +
Work on the industrialized site	183	32	2	820	1.67 +
Travel over the Mounana site	314	31	4	810	0.39 + = **2.9**
Work in the plantations	183	32	1	360	0.15 +
Travel in the Gamaboungou valley	183	32	2	1000	0.10
Reference group RG2					
Time spent in the close environment	130	21	1	160	0.55 +
Work in the plantations	183	32	1	360	0.92 +
Travel in the Gamaboungou valley	183	32	2	1000	0.40 + = **2.3**
Travel over the Mounana quarry	314	31	4	810	0.39
Natural level					
Village of Omoï	56	22	1	140	

* The effective dose is calculated by using the conversion factors given in European directive 96/29 and in the CIPR 65 and 68 to convert the measured level to mSv values.

2.2. Stage 2: Definition and execution of the restoration work (1998–2000)

The restoration work to be undertaken must accomplish the following five objectives:

(1) To guarantee long term safety for the exposed population;
(2) To guarantee that residual impacts are as low as reasonably achievable;
(3) To ensure that the waste storage is physical stable;
(4) To determine, if necessary, the future uses of the landscaped areas;
(5) To favour integration into the surrounding landscape.

To this end, the activities implemented were as follows:

➔ Preliminary studies of the effectiveness of the containments and geotechnical constraints.

The effectiveness of the containments was examined by measuring the radon flux values and gamma proton flow rates from a series of trial plots that had different structures and cover depths.

The cover products tested were those that could be collected from areas near the installations (mining tailings: tailings outside the mining site; laterite).

➔ Site restoration work from mid 1997 to the end of 2000.

This work has made it possible to:

— Group together products to be managed, to limit as far as possible the areas likely to constitute a radiological impact for the exposed population,
— contain under water or under a solid cover, the products to be managed, taking geotechnical and radiological constraints into account.

These containments must limit the gamma dose flow rates and radon flow levels to rates that are comparable to those measured in the regional natural surroundings (80 to 150 $nGy.h^{-1}$; 0.04 to 0.1 $Bq.m^{-2}.s^{-1}$).

The most important work was:

— The construction of a new dike to supplement the existing dikes on the river Gamaboungou. The new dike, which is 200 m long with a maximum height of 11 m, was constructed using 500 000 m^3 of broken rock and laterite. This construction guarantees a minimum water depth of 1 m over the 6 ha area where the process tailings are stored in the central part of the Gamaboungou valley.

— The reshaping and containment of the Mounana open pit, which is located in the upper part of the Gamaboungou valley. A solid cover was emplaced using 500 000 m^3 of broken rock and laterite. The cover was designed to resist the heavy rains of the Mounana region. Approximately 50 ha were remediated using this technique.

In addition to these extensive undertakings, all of the areas which contain radioactive materials (process tailings, low grade ore, settlement sludge ...) were covered with at least a 0.70 m thickness of laterite.

The two milling facilities have been dismantled. The wooden components of the first mill were burned. The metallic parts and the materials were, after cleaning and radiological examination, offered to potential users or were buried in the Oklo open-cast mine, which also has a water cover. This water cover will be about 80 m deep when the open cast pit is completely filled in 2001. This

procedure will guarantee isolation of the dismantling products, without disturbing the radiological properties of the waters.

In order to integrate and blend the remediated areas into the landscape and also to reduce the effects of the equatorial rains to a minimum, a major part of the recovered areas have been replanted. This was carried out using local vegetation to guarantee the desired effects; the vegetation cover was planted by the local population using traditional techniques.

2.3. Stage 3: setting up radiological monitoring on the site

This stage, which was initiated after the restoration was completed, consisted of setting up a radiological monitoring network. Measurements taken in the air and water vectors, on the food chain and on certain bio-indicators (sediments and plants), enabled the following work to be carried out:

— inspecting the effectiveness and timelessness of the restoration work;
— assessing the effective annual dose generated by the remediated site for the identified critical groups;
— checking for compliance with all of the fixed objectives.

The monitoring network is composed of:

— Eleven fixed stations for measuring the integrated monthly alpha energy of short life daughters of radon using alpha site dosimeters. These stations were positioned as follows:

- Five stations in the inhabited areas of the environment close to the site,
- Three stations in the industrial areas of the site,
- Two stations in the tracks crossing over the restored site,
- One station in the natural surroundings outside the influence of the site.

— Twenty fixed stations for measuring the integrated monthly gamma dose flow rate using thermoluminescent dosimeters. These fixed stations were located in the following areas:

- Five in inhabited areas,
- Three in work areas,
- Eleven in crossing tracks,
- One in the natural surroundings.

— Twelve water testing stations for the measurement of radium 226 and uranium, including:

- Six stations for biannual testing of the drinking water in villages in the close environment and the natural surroundings,
- Three stations for the monthly testing of water likely to be flowing from the site towards the receiving environment,
- Three stations for the monthly testing of the receiving environment (the rivers Mitembe and Lekedi downstream from the site).

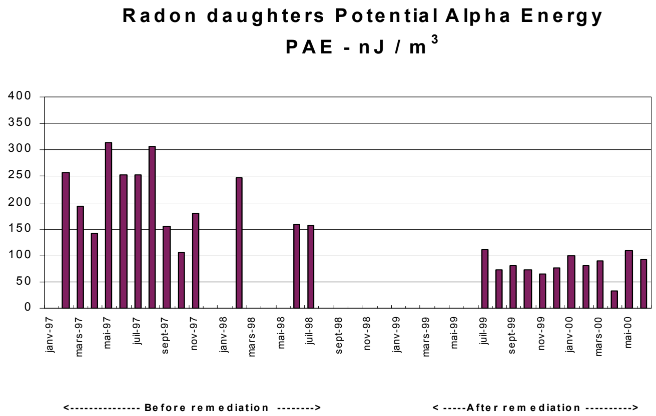
— Three stations for biennial testing of produce grown and consumed by the inhabitants, for determining the mass activities of radium 226, uranium, thorium 230 and lead 210;

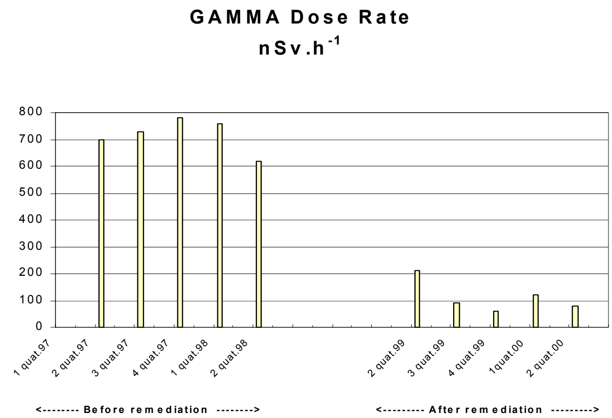
— Four stations for biennual testing of fish likely to be caught and consumed by the inhabitants, for determining mass activities of radium 226, uranium, thorium 230 and lead 210;

— Three stations for biennual testing of bio-indicators (sediments and plants), for determining the mass activities of radium 226, uranium, thorium 230 and lead 210 in the two receiver watercourses downstream from the site and also on the replanted site.

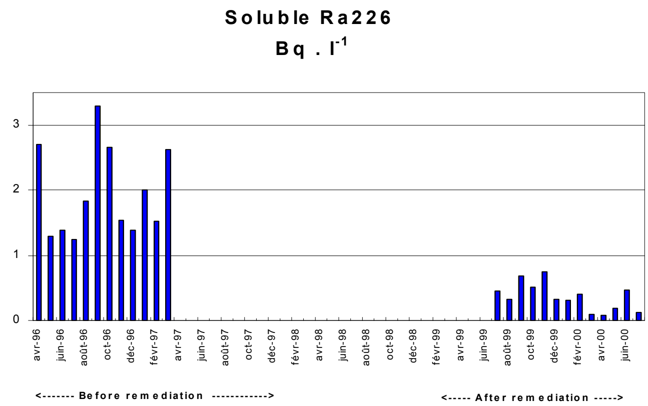
The following graphs show an example of the effectiveness of the restoration. The measurements were made at (1) the atmosphere monitoring station positioned on the Mounana quarry, (2) in an area where inhabitants pass through, and (3) at the station for testing the surface waters in the environment downstream from the site.

COMUF - MOUNANA OPEN PIT - TAILINGS STORAGE





COMUF - MITEMBE RIVER - MASSANGO VILLAGE DOWN STREAM



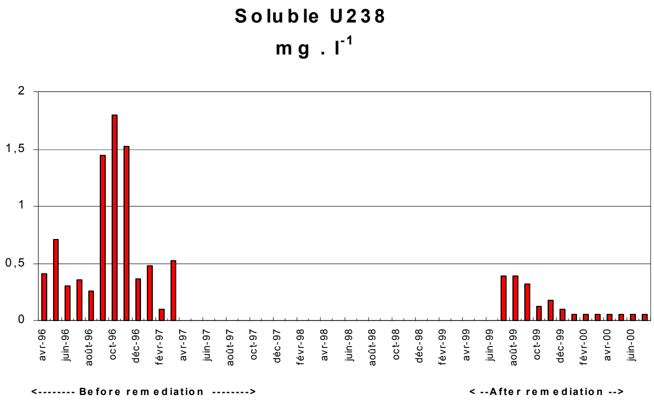


Table 2 shows that in late June 2000, after completion of all site restoration work (except for the area downstream of the Gamaboungou valley), the effective added dose for the two reference groups is close to 1 mSv, i.e. a reduction by a factor of 2 to 3 in relation to the situation before restoration (see Table 1).

The effective dose is calculated from measurement results supplied by the fixed stations during the first six months of 2000. The exposure levels associated with the ingestion of radionuclids (drinking water and food chain) remain identical to those of the natural level and do not produce any added dose.

TABLE 2. EFFECTIVE ADDED DOSE FOR THE REFERENCE GROUPS IN JUNE 2000

During restorion (01/2000 → 06/2000)	Pathways				Effective Added Dose in mSv
	PAE Rn222 nJ.m^{-3}	PAE Rn220 nJ.m^{-3}	LLAE mBq.m^{-3}	Gamma nGy.h^{-1}	
Reference group RG1					
Time spent in the environment	84	20	< 1	140	0.37 +
Work on the industrialized site	81	18	< 1	250	0.34 +
Travel over the Mounana site	84	21	< 1	100	0.02 + **= 0.97**
Work in the plantations	84	20	< 1	100	0.02 +
Travel in the Gamaboungou valley	183	32	2	1970	0.22
Reference group RG2					
Time spent in the close	84	20	< 1	140	0.35 +
environment	80	20	< 1	100	0.12 +
Work in the plantations	183	32	2	1970	0.74 + **= 1.23**
Travel in the Gamaboungou valley	84	21	< 1	100	0.02
Travel over the Mounana quarry					
Natural level					
Village of Omoï	35	18	< 1	130	

3. CONCLUSION

The restoration work at the Mounana site was undertaken in July of 1997 and was continued during each dry season for the years 1998, 1999 and 2000. By the end of June 2000, the restoration work that had been completed made it possible to achieve and effective radiation dose for the critical population groups that was only 1 mSv in excess of the natural radiation exposure. The essentially uninhabited downstream area of the Gamaboungou valley has not yet been remediated. This area is scheduled to be sealed with a laterite cover in 2001 and the watercourses channelized using layers of broken rock. It is anticipated that this restoration will limit the dose to individuals passing through the area to a gain of about 0.12 mSv for each 100 hours of exposure.

Also, by the end of 2001, the Mounana site-monitoring network which is managed by a local branch of the Ministry of Mines of Gabon, will enable an effective added dose to be calculated for the most exposed inhabitants. Projections indicate an added dose of about 0.80 mSv per year; this dose will meet the objectives that had been fixed for the redevelopment of the Mounana site.

The planned monitoring period, which will continue after final restoration of the site will confirm the timelessness of the undertaken actions.

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REGULATORY AFFAIRS

(Session 5)

D.B. CHAMBERS
Canada

The evolving regulation of uranium recovery operations in the United States of America: Innovative approaches are necessary for cost effective regulatory oversight

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Abstract. The US domestic uranium industry is at a crossroads. Historic low prices for uranium, combined with stringent and often irrational regulatory requirements, pose a very real threat to the industry's continued viability. The Nuclear Regulatory Commission has taken a number of innovative steps to reform and rationalize its regulatory programme. However, if the domestic uranium recovery industry is to remain viable, additional steps toward innovation and reform are needed, and effective implementation of reforms adopted by the Commission is essential.

1. INTRODUCTION

The past decade has seen major transformations in the uranium recovery (UR) sector around the world. Flooding of the world market with inexpensive uranium has resulted in the price of uranium at very near an all-time low. Even though the price of uranium has fallen, regulatory oversight of the UR sector has not slackened (especially in the "developed" nations) and, as a result, economic pressures on uranium producers due to the costs associated with regulatory compliance have intensified. Perhaps no uranium producers have been as significantly affected as UR operations in the United States.

In order to address the excessive regulatory burden that has been created in the US as a result of piecemeal regulatory decisions, the US Nuclear Regulatory Commission (NRC), the Federal agency charged with day-to-day regulation of nuclear materials under the Atomic Energy Act of 1954 (AEA)[1], has undertaken, at industry's urging, a strategic review of the applicable regulatory regime, with assistance and input from the regulated community and other stakeholders. The goal is to develop a more efficient, cost-effective and adequately protective regulatory programme that is not burdened by undue complexity and inconsistent interpretations.

There is no question that the governing statutes – in particular the AEA – provide NRC with the flexibility needed to fashion a more coherent, responsive and efficient regulatory regime for UR operations. It is unclear at the time of this paper's creation, however, whether NRC will take advantage of the opportunity provided by its strategic review to implement innovative and forward thinking approaches to UR regulation. Bureaucratic inertia, encouraged by vocal public opposition from anti-nuclear groups, could merely reinforce the *status quo* (i.e., an expensive and somewhat random collection of regulations, guidance and practices that hinders resolution of the complex regulatory issues confronting UR licensees). This paper suggests that new and innovative approaches can lessen the regulatory burden on the UR sector in the US, giving it the chance again to be viable in the global marketplace, without compromising protection of public health, safety or the environment.

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Moreover, as this paper suggests, the implementation of innovations and changes within and outside of the US may inure to the benefit of uranium producers and other fuel-cycle facilities around the globe.

Our analysis begins with a brief overview of the regulatory framework governing UR operations in the US. That discussion (Section II), provides a basic overview of the important regulatory requirements governing siting, operations and site closure. Section III discusses recent developments and innovative proposals in the areas of UR regulation addressed in Section II.

2. OVERVIEW OF THE REGULATION OF URANIUM RECOVERY OPERATIONS

The AEA provides NRC with jurisdiction to implement and enforce regulations for three classes of nuclear fuel cycle radioactive materials: source material, special nuclear material, and byproduct material. *Source material* is uranium and thorium that can be used to create nuclear fuel, but that has not yet been enriched and therefore, is not fissionable. *Special nuclear material* is plutonium and enriched uranium that can be used as nuclear fuel. *Byproduct material* encompasses both 11e.(1) byproduct material, which is material created from nuclear reactions, and 11e.(2) byproduct material, which consists of tailings and other wastes that are created when uranium ores are milled primarily for their source material content.

The AEA and NRC's implementing regulations generally prohibit persons from transferring, delivering, receiving, possessing, importing, or exporting any source material, special nuclear material, or byproduct material unless authorized by an NRC license. NRC is directed under the AEA to designate what constitutes "unimportant quantities" of source material for which no licenses shall be required, and NRC is authorized to exempt certain classes or quantities of special nuclear material and byproduct material or uses or users of those materials from license requirements.

With regard to the regulation of UR, the Atomic Energy Commission (AEC) (the predecessor of NRC), historically took the position that while it had jurisdiction under the AEA over uranium as source material, it was without jurisdiction to regulate uranium mining[2] and uranium mill tailings[3]. NRC continues to take the position that it does not have authority to regulate uranium mining, except *in situ leach* (ISL) mining (which will be discussed in Section III). With regard to mill tailings, Congress and NRC realized in the late 1970s that NRC's AEA authority was inadequate to address all of the complex environmental and public health issues associated with uranium mill tailings. Congress remedied this deficiency by enacting the Uranium Mill Tailings and Radiation Control Act of 1978, (UMTRCA), which amended the AEA. In UMTRCA, Congress afforded NRC broad authority to regulate all aspects of the management and disposition of uranium mill tailings and related wastes generated at NRC licensed uranium mills. Specifically, UMTRCA gave NRC jurisdiction over "11e.(2) byproduct material" which the statute defined to encompass *all* wastes, both *radioactive* and *nonradioactive (i.e., hazardous)*, resulting from the processing of uranium ore *primarily* for its source material content[4].

NRC is not the only Federal agency with responsibilities for mill tailings and related wastes under UMTRCA. The US Environmental Protection Agency (EPA) promulgates *generally applicable* standards for the protection of public health, safety, and the environment from potential radiological and *non*-radiological hazards at uranium mill tailings sites[5]. NRC implements those standards at "active" sites under Title II of UMTRCA, and the U.S. Department of Energy (DOE) implements them at "inactive" or abandoned sites under Title I of UMTRCA.[6] The standards developed by EPA for *non*-radiological hazards are required to be as protective of human health and the environment as comparable standards established under the hazardous waste law administered by EPA (the Resource Conservation and Recovery Act (RCRA)).

Finally, under the AEA, NRC lacks authority to regulate naturally occurring radioactive materials (NORM) that are not generated at AEA licensed facilities. Although these materials contain the same

naturally occurring radionuclides, they do not satisfy the *legal definitions* of *source material* or *11e.(2) byproduct material*, and therefore, they are not subject to NRC's jurisdiction. Federal and State regulators have expressed growing concern over the potential public health and environmental risks posed by NORM as it is ubiquitous in the environment and can pose similar potential hazards as source or 11e.(2) byproduct material. Various forms of NORM include naturally occurring and accelerator-produced radioactive materials (NARM) and technologically enhanced NORM (TENORM), which results from industrial activities involving petroleum, natural gas, geothermal energy, water treatment and mining[7]. Several States, including Texas and Louisiana, have promulgated regulations governing NORM; and the Conference of Radiation Control Programme Directors (CRCPD) has published Model State TENORM regulations[8].

3. RECENT REGULATORY DEVELOPMENTS AND INNOVATIONS

3.1. NRC's Adoption of A "Risk Informed" Regulatory Approach

In 1994, NRC Staff proposed [9] and in 1995, NRC established a policy – the 1995 Probabilistic Risk Assessment (PRA) Policy Statement – that requires, to the extent practicable, that probabilistic risk insights be incorporated into all nuclear regulatory activities, including UR regulation. According to NRC, PRA methods have been applied successfully in several regulatory activities and have proved to be a valuable complement to traditional deterministic engineering approaches"[10].

By way of background, NRC has generally regulated the possession and use of AEA licensed nuclear materials based on a deterministic approach. In short, deterministic approaches to regulation:

> consider a set of challenges to safety and specify how those challenges should be mitigated . . . The deterministic approach establishes requirements for use of materials and for engineering margin and quality assurance in design, manufacture, construction, and operation of nuclear facilities[11].

NRC's regulatory requirements have been intended to ensure that a licensed facility is designed, constructed and operated in a manner consistent with the AEA and without undue risk to human health, safety, and the environment. Traditionally, deterministic criteria were meant to ensure that safety systems capable of preventing and/or mitigating failures (*a.k.a.* design basis events) were utilized. Although the deterministic approach employs elements of probability, the *risk-informed* approach to regulation that is now being utilized by NRC enhances and extends the traditional deterministic approach discussed above. It does so by:

> (a) Allowing consideration of a broader set of potential challenges to safety, (b) providing a logical means for prioritizing these challenges based on likelihood and risk significance, and (c) allowing consideration of a broader set of resources to defend against these challenges[12].

A risk-informed approach considers risk insights, operating experience, and engineering judgment and allows NRC and the regulated community to focus on those areas that have been of greatest potential significance to public health and safety. Perhaps most importantly, where appropriate, a risk informed approach may be used to reduce unnecessary conservatism that results in regulatory overkill and provides negligible public health protection benefits.

3.1.1. Risk Informed, Performance Based Regulatory Approach

In addition to following a risk-informed approach to regulation, NRC has layered onto that approach the adoption of *performance-based* standards. Generally speaking, a performance based approach establishes standards of performance that must be achieved by a regulated entity, while allowing

flexibility as to the methods the entity may employ to achieve those standards. NRC has articulated four key elements to its approach to performance-based regulation:

> (1) There are measurable parameters to monitor acceptable plant and licensee performance; (2) objective performance criteria are established to assess performance; (3) there is licensee flexibility to determine how to meet established performance criteria; and (4) failure to meet a performance criterion must not result in unacceptable consequences[13].

A *risk informed, performance based* approach to regulation uses risk insights and deterministic analyses and performance history to develop parameters for monitoring the performance of a regulated entity, as well as for developing criteria for performance assessment. The use of a risk informed, performance based approach theoretically results in NRC focusing on specific areas of greatest concern as the primary means of regulatory oversight. The approach is intended to permit the licensee enhanced flexibility in complying with regulatory requirements while at the same time focusing regulator and licensee resources on those areas of greatest potential significance to human health and the environment[14].

3.2. Regulatory Developments Concerning Siting/Licensing of UR Facilities

3.2.1. 10 C.F.R. Part 2, Subpart L

Disputes concerning the siting of conventional uranium mills and ISL mines typically are governed by NRC's *informal* hearing procedures set forth in 10 C.F.R. Part 2, Subpart L[15]. The AEA requires that NRC afford "interested persons" upon request, a "hearing," in any proceeding granting suspending, revoking, or amending a license involving source, byproduct, and special nuclear materials. In 1989, NRC codified the "informal" "Subpart L" hearing process, specifying that written presentations are generally sufficient to fulfill the "hearing" requirement of the AEA, particularly where the potential public health risks as with UR operations are less significant than with reactors[16]. Under Subpart L, the Presiding Officer makes his determination based solely on a "hearing file" compiled by NRC Staff and on written presentations by the parties. At bottom, the informal Subpart L hearing is intended to elicit information and resolve issues primarily through inquiry by the Presiding Officer rather than through adversarial confrontation between the parties. Accordingly, the Presiding Officer has a great deal of discretion in controlling the manner in which the issues raised by the parties are presented and reviewed. Unfortunately, both NRC Presiding Officers and the Commission itself have allowed abuse of this process by Intervenors, who are often permitted to file multiple redundant and voluminous pleadings, resulting in substantial delays and expense, thus essentially negating the purposes and intended benefits of a streamlined *informal* Subpart L hearing procedure.

3.2.2. Environmental justice

One particular area that has received a great deal of attention with respect to the siting of uranium recovery facilities is *environmental justice (EJ)*. The National Environmental Policy Act (NEPA), creates a "broad national commitment to protecting and promoting environmental quality"[17]. NEPA is primarily a procedural statute requiring federal agencies to develop an environmental impact statement (EIS) for all major actions that "significantly affect the quality of the human environment"[18]. The principal goals of the Final Environmental Impact Statement (FEIS) are to require agencies to take a "hard look" at environmental consequences of a proposed action and, "by making relevant analysis openly available, to permit the public a role in the agency decision making process."[19] The EIS should provide a sufficient discussion of the relevant issues to enable the agency to make a reasoned decision.[20] Importantly, however, NEPA does not require agencies to select the most environmentally benign option.[21] In addition, "NEPA does not require agencies to assess every impact or effect on the environment*."*[22] *EJ* is a relatively new concept pertaining to the potential

effects of major federal actions on certain sub-populations that has recently been incorporated into the NEPA process of many agencies.

Executive Order 12898 ("EO"), *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*,[23] provides that "each Federal agency[24] shall make achieving EJ part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programmes, policies, and activities on minority populations and low-income populations[25]. The President's memorandum accompanying the EO states that "each Federal agency shall analyze the environmental effects, including human health, economic, and social effects, of Federal actions, including effects on minority communities and low-income communities, when such analysis is required by the [NEPA]"[26]. The EO goes on to state that:

> Each Federal agency shall conduct its programmes, policies, and activities that substantially affect human health or the environment, in a manner that ensures that such programmes, policies and activities do not have the effect of excluding persons (including populations) from participation in, denying persons (including populations) the benefits of, or subjecting persons (including populations) to discrimination under, such programmes, policies, and activities, because of their race, color, or national origin[27].

Finally, and most importantly, the EO states in relevant part:

> This order is intended only to improve the internal management of the executive branch and is not intended to, *nor does it create any right, benefit, or trust responsibility, substantive or procedural, enforceable at law or equity by a party against the United States, its agencies, its officers, or any person*. This order shall not be construed to create any right to judicial review involving the compliance or noncompliance of the United States, it agencies, its officers, or any other person with this order[28].

Although the EO is not generally applicable to independent regulatory agencies like the NRC, NRC has indicated that it "would endeavor to carry out the measures set forth in the Executive Order, and accompanying memorandum" in its "efforts to fulfill the requirements of [NEPA] as an integral part of NRC's licensing process." Despite the apparently clear limits on *EJ* considerations in NRC's NEPA analyses, the issue has had substantial negative impacts on the efficiency of NRC licensing actions involving siting determinations[29].

3.2.3. The Case of Hydro Resources

The most recent and noteworthy case involving the siting of a uranium mill or mining operation involves Hydro Resources, Inc.'s (HRI's) proposed ISL uranium mine near Crownpoint, New Mexico. In 1988, HRI applied to the NRC for a general license to construct and operate ISL uranium mining facilities near the town of Church Rock, New Mexico, which is primarily inhabited by native American members of the Navajo Nation[30]. After completing a Final EIS (FEIS) and a Safety Evaluation Report (January 5, 1998), NRC Staff issued a source material license to HRI permitting the company to construct and operate ISL mining facilities on an incremental basis: (i.e., well field by well field) over a twenty-year period.

Immediately after issuance of the license to HRI, the Eastern Navajo Dine´ Against Uranium Mining (ENDAUM), the Southwest Research and Information Center ("SRIC"), and others filed motions to intervene and requests for hearing raising a multitude of technical issues and challenges to the licensing process and the FEIS including *EJ*. In response to the motions, a Presiding Officer was appointed to conduct an *informal* hearing pursuant to Subpart L. The record in the case includes more than 50 000 pages of documents and more than 10 000 pages of pleadings and supporting materials.

The "informal" Subpart L hearing has been ongoing for more than two years at a cost to the licensee of more than \$500 000. The entire licensing process for HRI, including the FEIS, has totaled more than \$10 million. The *EJ* issue has yet to be resolved by the Commission even though the location of the uranium deposits, and thus the site for the ISL facility, is not under HRI's control. All of this to license the lowest risk type of facility in the entire nuclear fuel cycle.

Similarly, *EJ* played a major role in another drawn out licensing proceeding at NRC involving siting a proposed enrichment facility that led to the proposed licensee withdrawing its application. In that case, *Louisiana Energy Services, L.P.* (Claiborne Enrichment Center), CLI-98-3, 47 NRC 77, 87 (1998) ("LES"), the applicant spent more than seven years and \$34 million in what turned out to be a futile attempt to site its facility. As these examples suggest, risk-informed, performance based licensing and streamlined hearing processes may provide merely illusory benefits, particularly when disputes arise. When Staff regulators are unnecessarily conservative and Presiding Officers and the Commission lose control of the review and hearing process, even the wisest and best intentioned regulatory policies can be eviscerated.

3.3. Regulatory Developments and Innovations Concerning UR Operations

3.3.1. NRC's and EPA's Regulation of In situ *Leach Mining*

The most significant development in uranium mining and milling operations recently has been the abandonment of conventional surface and underground mining techniques in favor of ISL mining. ISL mining, which has been practiced for over three decades and currently is the primary extraction technology for commercial uranium production in the United States, provides a safe and cost-effective method of recovering uranium contained within a minable, confined aquifer system. In the ISL process, lixiviant solution, consisting of groundwater containing dissolved oxygen and carbon dioxide, is injected into the ore zone through injection wells. Uranium in the ore zone dissolves in the lixiviant, and this "pregnant" lixiviant is then drawn to the surface via a *production* well. At the surface, the pregnant lixiviant is passed through an ion exchange (IX) unit, which removes the uranium from solution. The "barren" lixiviant, which has been stripped of uranium, is then reinjected into the ore zone to complete the circuit. As NRC legal Staff has noted, ISL mining does not involve crushing or grinding of any ore, nor does it produce mill tailings; for these and other reasons, the "potential for environmental impacts due to in situ uranium mining appears to be minor"[31]. This is because, although ISL mining accomplishes the same end result as conventional mining, *i.e.,* bringing uranium to the surface for beneficiation and processing, it does so in a very different manner.

In April of 1998, the National Mining Association submitted a paper to NRC entitled *Recommendations for a Coordinated Approach to Regulating the Uranium Recovery Industry* (the "White Paper"). In this White Paper, and in subsequent correspondence with NRC, the UR industry outlined its concern that NRC's regulation of ISL wellfield activities exceeds the scope of the Commission's authority under the AEA and is redundant of existing regulatory regimes. With respect to the first point, industry noted that NRC's jurisdiction under the AEA is material-based, meaning that the Commission's authority extends only to source, special nuclear and byproduct material. Industry argued that, when the relevant statutory definitions are applied faithfully and in a manner consistent with prior NRC guidance, it becomes evident that none of the materials involved in ISL wellfield activities are subject to regulation as source, special nuclear, or byproduct material. For example, industry argued that, with respect to wellfield *production* activities, the dissolved uranium carried in pregnant lixiviant solution was unrefined and unprocessed and would not be "removed from its place in nature" until the uranium is stripped from the lixiviant in the IX unit. Under the relevant statutory and regulatory provisions, uranium ore that is unprocessed and uranium that has not been removed from its place in nature is exempt from regulation as source material[32]. Moreover, the AEA expressly provides that there *shall be* no licenses required for quantities of source material that are deemed to be unimportant (i.e., less than 0.05% uranium under NRC's current interpretation).

Wellfield production fluids prior to reaching the IX process contain “unimportant quantities” of uranium and should therefore be excluded from regulation.

Similarly, industry argued that none of the materials involved in ISL wellfield *restoration activities* fall within the purview of NRC’s jurisdiction under the AEA. For example, NRC’s regulations make clear that underground ore bodies depleted from ISL mining are not regulated as byproduct material for purposes of the AEA[33]. Similarly, the Commission had in the past taken the position that groundwater and related sludge wastes from wellfield restoration are also excluded from regulation as byproduct material, because they constitute “mining wastes” which are subject to State, not NRC, regulation[34]. Since none of the materials involved in either wellfield production or wellfield restoration is subject to NRC regulation under the AEA, industry argued, NRC has no legitimate basis upon which to exercise jurisdiction over ISL wellfield activities.

In addition to the lack of jurisdiction, industry argued to the Commission that NRC regulation of wellfield production and restoration activities is redundant and unnecessary because those same activities are regulated by the Environmental Protection Agency under the Safe Drinking Water Act (SDWA) and by the individual States, through their mining laws and delegated SDWA authority. As was pointed out to the Commission, such dual regulation leads to duplicative and sometimes conflicting regulatory requirements. At a minimum, this kind of duplicative regulation has the effect of increasing the costs and undermining the efficiencies associated with ISL mining. A more pernicious effect of dual regulation can be delayed site restoration and closure, as ISL producers struggle to reconcile disparate regulatory requirements imposed by multiple regulatory agencies.

Just recently, the Commission responded to the concerns raised by industry regarding NRC’s regulation of ISL wellfield activities, by voting on a plan to “improve the efficiency” of ISL regulation[35]. Despite this stated objective, the plan approved by the Commission appears to take a step backwards in terms of rationalizing regulation of ISL operations in the United States. Instead of acknowledging its lack of jurisdiction over wellfield materials, the Commission voted to assert an *expanded* authority over wellfield materials. In particular, NRC had in the past agreed that restoration fluids are not subject to regulation under the AEA as 11e.(2) byproduct material. However, under the plan just approved by the Commission, *all* liquid wastes produced as a result of wellfield production and restoration activities – including restoration fluids – will be considered by NRC to be 11e.(2) byproduct material and subject to the Commission’s jurisdiction. Consequently, under the plan approved by the Commission, ISL wellfield activities will continue to be subject to the inefficiencies of dual, and sometimes conflicting, State and Federal regulation (although the Commission has directed staff to engage in “discussions” with EPA and relevant states, regarding the extent to which EPA and State groundwater regulations may obviate the need for NRC regulations)[36].

3.3.2. Disposal of Non-11e.(2) Materials

A second regulatory development in the area of UR mining and milling operations involves the use of conventional mill tailings facilities for disposal of other *similar* types of wastes that do not qualify as 11e.(2) byproduct material. The potential benefits of allowing existing mill tailings disposal facilities to be used for the disposal of other similar kinds of wastes are enormous. In the United States, available disposal capacity for high volume, low activity radioactive wastes is quite limited, and this scarcity of disposal capacity is likely to continue into the foreseeable future. In part this lack of disposal capacity can be traced to the failure of past legislation (notably the Low Level Radioactive Waste Policy Act (LLRWPA)) to result in the licensing of new low level radioactive waste (LLRW) disposal facilities, as intended. Consequently, as the few remaining licensed LLRW disposal facilities close or restrict their operations, the price of commercial disposal at LLRW disposal sites has become exorbitant, particularly for high volume wastes. Consequently, sites with large volumes of low activity wastes (such as radioactively contaminated soil or debris), in particular, have not been able to dispose of those wastes at such licensed LLRW facilities. As a result, the only viable alternative for some of these sites has become on-site disposal – which necessarily results in a proliferation of disposal sites,

or in delays in decommissioning as sites wait for new disposal capacity to come on line. Both outcomes are contrary to sound environmental management principles.

Utilizing existing uranium mill tailings facilities for the disposal of other similar types of low activity radioactive wastes makes eminent good sense for a number of reasons: (i) these existing impoundments offer large amounts of *existing* disposal capacity; (ii) materials eligible for disposal at tailings facilities, such as mineral processing wastes, construction scrap, and mine water sludges are large volume, low-level wastes that are physically, chemically, and radiologically similar to 11e.(2) byproduct material and therefore would not pose any potential hazards beyond those evaluated for the 11e.(2) disposal license; and (iii) such wastes, when disposed of in a tailings impoundment, would be subject to stringent, ongoing and long-term oversight with regard to both potential radiological and *non-radiological* hazards, and this superior degree of protection would be achieved without the creation of new disposal sites. In addition, the large volume and relatively inexpensive disposal capacity provided by existing mill tailings sites would help drive down the costs of disposing of low activity wastes, thereby encouraging generators of low activity waste (such as facilities undergoing decommissioning) to dispose of their wastes promptly.

In 1995, NRC issued a regulatory policy regarding the use of mill tailings facilities for the disposal of *non*-11e.(2) waste (the "*Non*-11e.(2) Policy")[37]. This policy establishes a set of nine criteria that must be satisfied before a given waste material can be approved for disposal in a uranium mill tailings facility. A key objective of the policy is to ensure that mill tailings disposal facilities do not become subject to dual regulation as a result of commingling 11e.(2) byproduct material and *non*-11e.(2) wastes. To prevent such dual regulation the *Non*-11e.(2) Policy excludes certain types of materials from disposal in tailings facilities – notably NORM, special nuclear material, 11e.(1) byproduct material, and materials subject to regulation under other Federal statutes. In addition, the Policy imposes numerous other requirements on licensees seeking to dispose of *non*-11e.(2) wastes, such as the requirement to obtain prior approval from the DOE or the State in which the facility is located and from the appropriate Regional Low Level Waste Compact, and the requirement to obtain a waiver from NRC's regulations governing the disposal of LLRW. Although well-intentioned, as a practical matter, NRC's *Non*-11e.(2) Policy imposes so many burdensome requirements on licensees as to make it extremely difficult, if not impossible, to dispose of *non*-11e.(2) byproduct material in uranium mill tailings piles.

In its White Paper, NMA suggested a number of changes to NRC's *Non*-11e.(2) Policy in order to make the policy more accessible and thereby open the door to the benefits associated with expanded use of tailings facilities for the disposal of *non*-11e.(2) low activity wastes. For example, NMA urged NRC to develop generic risk-based criteria to be used to assess whether a particular material could be disposed of in a uranium mill tailings facility, instead of requiring case-by-case evaluation of every waste stream proposed for disposal. In addition, industry suggested that NRC expand the list of materials eligible for disposal under the policy (for example, to allow the disposal of NORM and mixed waste provided that such waste is sufficiently similar to 11e.(2) byproduct material). The White Paper also suggested that NRC explore the possibility of utilizing memoranda of understanding (MOUs) with other Federal and State regulatory authorities to eliminate concerns regarding dual or overlapping regulation of mill tailings facilities used for the disposal of *non*-11e.(2) material.

Very recently the Commission voted to retain the 1995 *Non*-11e.(2) Policy with a few modifications. Specifically, the Commission directed its Staff to pursue a generic exemption from NRC's LLRW regulations for wastes that are approved for disposal in an 11e.(2) disposal facility. In addition, the Commission directed the Staff to eliminate the exclusion of NORM wastes and wastes regulated under other Federal statutes (i.e., to allow their disposal in mill tailings facilities), provided that such materials are radiologically, physically and chemically similar to and compatible with the 11e.(2) byproduct material already present at the mill tailings facility. These modifications represent a step in the right direction with respect to simplifying the *Non*-11e.(2) Policy and making it more accessible for a wider variety of waste materials. However, even with these modifications, the numerous

requirements remaining as part of the Policy – including the requirement for prior approval by other Federal and State regulators as well as approval from the relevant interstate LLRW disposal compacts and the long term governmental custodian – still present a formidable barrier to utilizing mill tailings facilities to dispose of wastes other than 11e.(2) byproduct material. Moreover, a statement made by the Commission Chairman to the effect that licensees who take advantage of the *Non*-11e.(2) Policy must be "prepared to accept the consequences of dual regulation"[38] is inconsistent with NRC's previously-articulated goal of *avoiding* dual regulation and is likely to discourage licensees of uranium mill tailings facilities from accepting *non*-11e.(2) wastes for disposal, despite the substantial benefits associated with such a disposal option.

3.3.3. Processing Alternate Feeds

A third innovation in the area of UR operations involves the processing of *non-traditional ores* or "*alternate feeds*" in conventional uranium mills. Because these alternate feeds are often considered "wastes" by the facilities that generate them, the availability of uranium mills to process those feeds provides a unique opportunity to *recycle* those wastes in order to recover valuable uranium (and other materials) and to dispose of the residual tailings as 11e.(2) byproduct material.

Processing of "alternate feed" material is governed by NRC's August 15, 1995 "Final Position and Guidance on the Use of Uranium Mill Feed Material Other Than Natural Ores" (the "Alternate Feed Policy")[39]. Under this policy, NRC permits licensees to process alternate feed materials in uranium mills, provided that three conditions are satisfied. First, the alternate feed material must qualify as "ore". NRC has defined "ore" broadly to encompass any "natural or native matter that may be mined and treated for the extraction of any of its constituents *or any other matter from which source material is extracted in a licensed uranium or thorium mill*"[40]. This definition clearly is broad enough to encompass ores which have previously been beneficiated for uranium or other minerals, and which are outside of the initial processor's legal or technical ability to process further, provided that source material is extracted from the ore in a licensed uranium or thorium mill.

Second, in order to qualify as alternate feed, the material cannot contain a *listed* hazardous waste subject to regulation by EPA under RCRA[41]. This restriction, which is intended to avoid dual regulation by NRC and EPA (or a delegated State), does not apply to feed material that exhibits only *"characteristics"* of hazardous waste, since such material is exempt from regulation as hazardous waste under RCRA when recycled[42].

Third, the alternate feed material must be processed "*primarily* for its source-material content." Opponents of alternate feed processing have used this criterion as a basis for attacking plans to process alternate feeds for a fee, claiming that in such circumstances an alternate feed is not processed "primarily" for its source material content if fees collected to process the feed exceed the value of the uranium that is recovered. However, the Commission soundly rejected this theory in recent litigation on the issue[43]. As a result of that litigation, the Commission ordered its Staff to reconsider the tests that were employed under the Alternate Feed Policy to determine whether a feed is processed *primarily* for its source material content. Specifically, the Commission ruled that the economic viability of the uranium recovery, in and of itself, is not the determining factor in judging whether a feed is being processed "primarily" for its source material content. Basing its decision on the language of the AEA and its legislative history, the Commission indicated that if more than a negligible amount of uranium is recovered through the processing of an alternate feed in a licensed uranium mill then the mill is processing the feed *primarily* for its source material content. The Commission's decision avoids concerns about so-called "sham processing" (processing that is undertaken to change the regulatory definition of a waste stream) and allows UR mills to process a broad stream of wastes in order to recover uranium while also receiving a recycling and/or disposal fee for this processing.

As indicated, an important feature of alternate feed processing is that the tailings and other wastes that result from such processing are regulated as 11e.(2) byproduct material. This is important since

11e.(2) material is subject to stringent controls that include a 1000 year impoundment design requirement as well as perpetual monitoring and surveillance and a mandatory governmental custodian. Thus, potential long term contingent (i.e., Superfund) liability for the initial generator of the alternate feed is effectively eliminated once that feed is processed at the mill and the residual tailings/wastes disposed of in the mill tailings impoundment. At the same time, because of the fees they are allowed to charge, it is economically feasible for uranium mills to process this alternate feed at a time when conventional (natural) ores cannot be economically processed. Thus, processing alternate feeds may keep valuable milling and disposal capacity available until the price of uranium rebounds.

One firm that has employed the alternate feed guidance and has been licensed by NRC to process alternate feed materials for its uranium content is International Uranium (USA) Corporation, (IUC). IUC has processed mill tailings and other "waste materials" for their uranium content at its mill located in White Mesa, Utah. By processing alternate feed materials at its mill, IUC is able to recover substantial quantities of uranium and, in some cases, other valuable metals from materials that might otherwise be discarded as "wastes." In 1998 alone, the White Mesa Mill recovered over 600 000 pounds of uranium from alternate feedstocks. If the Commission's decision had not supported the recycling option offered by the White Mesa Mill, these alternate feedstocks would have been disposed of, the valuable mineral content of these materials would have been lost, and the mill would likely have had to shut down.

3.4. Regulatory Developments Concerning Mill Site Closure

3.4.1. The Employment of Alternate Concentration Limits

Perhaps the most significant development in the mine and mill site closure context is the employment of alternate concentration limits (ACLs) in the remediation of contaminated groundwater. Groundwater contamination, not surface stabilization, at both ISL mining sites and conventional milling sites is proving to be most costly and technically complex issue in the site closure context. In short, compliance with impracticable groundwater remediation standards (often based on tap water standards) has proven to be too costly and, in many cases, unachievable. Therefore, alternatives to strict limits are needed to permit cost-effective final site closures to occur. These alternatives are available under the applicable Federal regulations.

NRC's regulations at 10 C.F.R. Part 40, Appendix A require that groundwater protection programmes for Title II uranium mill tailings sites include the following four elements:

(1) A list of site-specific hazardous constituents;
(2) A groundwater concentration limit for each of these hazardous constituents, which must not exceed[44]
    (a) NRC-approved background concentration of constituent in the groundwater;
    (b) EPA's maximum concentration limit (MCL) for the constituent if an MCL is available and higher than the background level; or
    (c) An *Alternate Concentration Limit* approved by NRC.
(3) A compliance location where the concentration limits must be met (*i.e.,* point of compliance [POC]); and
(4) A time period during which compliance is required.

An ACL is a licensee-proposed *site-specific*, *risk-based* alternative to either the background level or the MCL that would otherwise apply to a specific groundwater contaminant. Two criteria must be satisfied for NRC to approve an ACL:[45] (1) the hazardous constituent that is the subject of the ACL must not pose a substantial present nor potential hazard to human health or the environment as long as the ACL is not exceeded;[46] **and** (2) the proposed ACL value must be *as low as is reasonably achievable* (ALARA), after considering practicable corrective actions. The ACL is based on a

concentration at the POC that over the 1000 year post-closure regulatory horizon will provide *reasonable assurance* that public health will be adequately protected.

Thus, when approved by NRC, an ACL gives the licensee flexibility to remediate contaminated groundwater to a level that provides adequate protection of public health and safety, in a manner that is reasonably achievable.

*3.4.2. Licensee-Proposed "*Alternatives*"*

ACLs are a specific example of NRC's use of regulatory flexibility that is *written into the statute* with respect to the regulation of UR site closure and the disposition of uranium mill tailings and related wastes. This statutory flexibility permits licensees to propose site-specific alternatives to the generic standards adopted by NRC or EPA, so long as those alternatives provide an equivalent degree of protection of human health and the environment. This flexibility is built into the law in Section 84 of the AEA, which provides that:

> In the case of sites at which ores are processed primarily for their source material content or which are used for the disposal of byproduct material as defined in section 11e.(2), a licensee may propose alternatives to specific requirements adopted and enforced by the Commission under this Act. Such alternative proposals may take into account local or regional conditions, including geology, topography, hydrology and meteorology. The Commission may treat such alternatives as satisfying Commission requirements if the Commission determines that such alternatives will achieve a level of stabilization and containment of the sites concerned, and a level of protection for public health, safety, and the environment . . . which is equivalent to, to the extent practicable, or more stringent than the level which would be achieved by standards and requirements adopted and enforced by the Commission for the same purpose and any final standards promulgated by the Administrator of the Environmental Protection Agency in accordance with section 275[47].

Thus, the governing statute provides NRC and the regulated community with a powerful tool that can be used to fashion site-specific standards and requirements that are protective of human health and the environment and that are more practicable or otherwise better suited to the specific circumstances facing a licensee than the generic standards and requirements that would otherwise apply. In order to avail themselves of this statutory based flexibility and to overcome regulatory inertia that inherently disfavors innovation, however, licensees must be creative and, where necessary, assertive when dealing with NRC.

4. CONCLUSIONS

In the broadest sense, NRC's regulatory focus for the UR industry seems pointed in the right direction. In particular, the Commission's strategic reexamination of its UR programme and its adoption of risk-informed, performance-based approaches to regulation hold out the promise of a more rational and efficient regulatory environment for UR licensees. However, when one looks beyond the Commission's broad policy positions and examines specific regulatory policies and positions, the Commission's record is decidedly mixed. Rational and innovative policies that are not effectively implemented, or that are even ignored in practice, are failing to yield the anticipated benefits touted by the Commission.

This is a time of great uncertainty for the US uranium recovery industry. If that industry is to remain viable, NRC must continue along the path of implementing innovative and flexible approaches to UR regulation. Licensees, too, must be prepared to think creatively and to aggressively advocate innovative approaches to the Commission.

REFERENCES

1 42 U.S.C. § 2011, *et seq.*

2 NRC, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706 (September 1980) vol. 1 at A-94.

3 See Kerr McGee v. U.S. Nuclear Regulatory Comm'n, 903 F.2d 1, 3 (D.C. Cir. 1990), where the court recognized:
As early as 1960, however, the AEC had concluded that because these mill tailings generally could not be classified as source material . . . they lay outside the AEC's statutory licensing authority and therefore beyond its regulatory reach.

4 See 57 Fed. Reg. 20,525-26 (1992).

5 42 U.S.C. §§ 7901-7942 (1998).

6 42 U.S.C. § 2021(d).

7 22 Envt'l L. Rep. (Envtl. L. Inst.) 10052.

8 See 33 LAC Chap. 14 (June 1992); 25 TAC 289.127, TCR pt. 46 (July 1993); and Suggested State Regulations for Control of Regulation, Vol. I, pt. N, "Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM), April 1999.

9 NRC SECY-94-218, Proposed Policy Statement on the Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities (1994) and NRC SECY-94-219, Proposed Agency-Wide Implementation Plan for Probabalistic Risk Assessment (1994).

10 Id.

11 Id.

12 Id.

13 Id.

14 In this regard the performance based regulatory criteria applicable to uranium mills that were developed by NRC in the 1980s were ahead of their time, reflecting the Commission's understanding that site-specific circumstances would significantly affect regulatory oversight at any given mill. See 10 C.F.R. Part 40, Appendix A.

15 10 C.F.R. §§ 2.1201-2.1263.

16 See 54 Fed. Reg. 8269 (Feb, 28, 1989). Less formal hearing processes were utilized by the NRC for nuclear material licensing proceedings prior to the adoption of Subpart L, however, the procedures were not codified in NRC's regulations. See Kerr-McGee Corp. (West Chicago Rate Earths Facility), CLI-82-2, 15 NRC 232 (1982), aff'd sub nom.

17 Louisiana Energy Services, L.P. (Claiborne Enrichment Center), CLI-98-3, 47 NRC 77, 87 (1998) ("LES"), citing, Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 348 (1989).

18 See 42 U.S.C. § 4332(2)(C).

19 LES at 87, citing Robertson, 490 US at 349-50.

20 Natural Resources Defense Council, Inc. v. Hodel, 865 F,2d 288, 294 (D.C. Cir. 1988).

21 LES at 88, citing Robertson, 490 US at 350 ("If the adverse environmental effects of the proposed action are adequately identified and evaluated, the agency is not constrained by NEPA from deciding that other values outweigh environmental costs.").

22 Metropolitan Edison Co. v. People Against Nuclear Energy, 460 U.S. 766, 772 (1983).

23 3 C.F.R. § 859 (1995),

24 For the purposes of the EO, “Federal agency” is defined as any agency on the Working Group, and such other agencies as are designated by the President of the United States, that conducts any Federal programme or activity that substantially affects human health or the environment. Independent agencies, like NRC, are requested to comply with the order pursuant to the EO. See EO at 6-604.

25 EO 12898, 59 Fed. Reg. 7629 (Feb. 16, 1994), codified at 3 C.F.R. § 859 (1995).

26 Memorandum for the Heads of All Departments and Agencies, (accompanying EO) (Feb. 11, 1994), 30 Weekly Comp. Pres. Doc. 279 (Feb. 14, 1994).

27 EO at 2-2 (emphasis added).

28 EO at 6-609; 59 Fed. Reg. at 7633

29 Letter from Ivan Selin, Commissioner NRC to President William Jefferson Clinton (March 31, 1994); see also Letter from Hugh L. Thompson, Jr. NRC Member Environmental Justice Working Group to Carol Browner, Chair, Environmental Justice IAWG (March 24, 1995); U.S. Nuclear Regulatory Commission Environmental Justice Strategy (March 1995).

30 Application for Materials License, ACN No. 8805200339, (April 13, 1988).

31 R.S. Popielak and J. Siegel, "Economic and Environmental Implications of Leakage Upon In Situ Uranium Mining," Mining Engineering 800, 804 (Aug. 1987). Moreover, the low hazard associated with the ISL technique suggests that "[t]he concept of natural ground-water quality restoration may have particular merit in uranium leaching. It is believed that, under the proper circumstances, most of the objectionable elements that have been introduced or mobilized during leaching will be removed by reprecipitation, ion exchange, adsorption, or reduction . . .." Geraghty & Miller, "Ground-Water Elements of In Situ Leach Mining of Uranium," at 76 (Aug. 1978).

32 42 U.S.C. § 2092; 10 C.F.R. § 40.13.

33 See 40 C.F.R. § 40.4.

34 See Staff Technical Position on Effluent Disposal at Uranium Recovery Facilities (April 1995) at 5; SECY-99-013 at 2.

35 Commission Voting Record on SECY-99-0013 Recommendations on Ways to Improve the Efficiency of NRC Regulation at In Situ Leach Uranium Recovery Operations (July 26, 2000).

36 The threat of dual regulation of ISL wellfield activities could be blunted if NRC were to assert that its regulatory authority over both the radiological and non-radiological components of byproduct material is exclusive, so that individual States would be preempted from superimposing their own regulatory regimes on ISL wellfield activities that are already regulated by NRC. Thus far, however, NRC has shown little inclination to assert such exclusive authority over 11e.(2) byproduct material. In the mean time, it appears that, even at the highest levels of NRC, the ramifications of overlapping jurisdiction are not appreciated. For example, the Commission’s decision to regulate ISL restoration fluids as if they were 11e.(2) byproduct material may cause ISL licensees to be in violation of their EPA Clean Water Act (CWA) permits, which prohibit the discharge of ISL production wastes.

37 60 Fed. Reg. 49,296 (Sept. 22, 1995).

38 Commissioner Comments on SECY-99-0012, Comments of Chairman Meserve (Attached to Commission Voting Record on SECY-99-0012 (July 26, 2000)) available at www.nrc.gov/NRC/COMMISSION/VOTE/1999-012vtr.html .

39 60 Fed. Reg. 49,296-7 (Sept. 22, 1995).

40 57 Fed. Reg. 20525, 20532 (1992) (emphasis added).

41 "Listed" hazardous wastes consist of a finite number of specific wastes that are listed in EPA's regulations. A listed waste should be distinguished from a "characteristic" waste, which is any solid wastes that displays one or more hazardous characteristics as defined in the regulations. See 40 C.F.R. § 261.3(a).

42 See 40 C.F.R. § 261.2(c)(3).

43 In the Matter of International Uranium (USA) Corporation, Docket No. 40-8681-MLA-4, CLI-00-01 (Feb. 10, 2000).

44 10 C.F.R. Part 40, Appendix A, Criterion 5B(5).

45 10 C.F.R. Part 40, Appendix A, Criterion 5B(6).

46 In making the present and potential hazard finding, NRC will consider the following 19 factors, which can be grouped in two categories:

(1) Those concerning potential adverse effects on groundwater quality:

(a) Physical and chemical characteristics of the waste in the licensed site, including its potential for migration;
(b) Hydrogeological characteristics of the facility and surrounding land;
(c) Quantity of groundwater and the direction and rate of groundwater flow;
(d) Proximity and withdrawal rates of groundwater users;
(e) Current and potential future uses of groundwater in the area;
(f) Existing quality of groundwater;
(g) Potential health risks posed by human exposure to waste constituents;
(h) Potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and
(i) Persistence and permanence of potential adverse effects.

(2) Those concerning potential adverse effects on hydraulically connected surface water quality:

(a) Volume and physical and chemical characteristics of waste in the licensed site;
(b) Hydrogeological characteristics of the facility and surrounding land;
(c) Quantity and quality of groundwater and the direction and rate of groundwater flow;
(d) Patterns of rainfall in the region;
(e) Proximity of the licensed site to surface waters;
(f) Current and future uses of surface waters in the area and any water quality standards established for those surface waters;
(g) Existing quality of surface water;
(h) Potential health risks posed by human exposure to waste constituents;
(I) Potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and
(j) Persistence and permanence of potential adverse effects.

All the factors listed above may not be applicable at specific sites. Where this is the case, an ACL application must specify the factors that do not apply and explain why those factors were not addressed in the application.

47 42 U.S.C. § 2114(c). Under the statute, Agreement States (States that regulate in lieu of NRC, pursuant to agreements between the State and the NRC) are provided with similar latitude to accept licensee proposed alternatives. See 42 U.S.C. § 2021(o).

Improving rehabilitation standards to meet changing community concerns: A history of uranium mine rehabilitation with particular reference to Northern Australia

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Abstract. Rehabilitation of land after mining is an issue that society has been wrestling with for at least 400 years. The issue is made even more emotive when the mineral extracted has been uranium. Over the past 50 years or so society has become ever more aware of the environment and the level of concern for proper environmental management has also increased. Today the community expects that mining in general, and uranium mining in particular, will be undertaken in an environmentally sensitive manner. As a consequence the expectations and standards for rehabilitation demanded by the community and regulators have been increasing and improving over time. Today the rehabilitation process is driven by issues of sustainable development, stakeholder involvement and consultation, inter-and intra-generational equity and a strong desire for environmental protection to be of the highest order. The paper describes this progressive improvement in rehabilitation standards using the uranium mines of northern Australia as case histories.

1. INTRODUCTION

From the very earliest times the rehabilitation of land after mining has been an issue which has attracted comment and caused much debate within the community. Agricola [1] commented that mining operations were capable of causing adverse impacts to the environment, and in trying to get the mineral industry to consider the rehabilitation issue he was, perhaps, the first advocate for the sustainable development of minerals. The nature of the mineral itself has also been a major factor in establishing the level of concern amongst the community. Whilst ferrous and base metals are often seen as relatively benign the development of radioactive mineral deposits, particularly uranium, has frequently been the cause of increased levels of community disquiet. The need for safe, effective and long lasting rehabilitation measures at former uranium mines has therefore assumed great importance in those locations where the mineral has been, or is being, exploited.

It has been noted by at least one industry observer that the minerals industry is effectively licensed by the community [2]. A mining company that has a record of poor environmental management, particularly in the area of rehabilitation, is likely to become the focus of much adverse publicity and attention when it attempts to open up a new deposit. There are several examples of new mine developments being seriously challenged, delayed and even stopped in such circumstances. Modern communications and information dissemination are now so efficient that such opposition may stretch across borders. The community has an ever increasing awareness of, and concern for, the environment. These sentiments are coupled with increasingly more stringent attitudes towards pollution abatement and prevention. As a consequence, minesite rehabilitation is required to be ever more effective, have outcomes in keeping with the desires and aspirations of the community and be acceptable to the stakeholders. This last group includes not only the nearby residents but also regulators and downstream inhabitants and even overseas customers where corporations have “green” purchasing policies. If the mineral being mined has been uranium then there are additional issues of radiation protection and long term waste management that the community and stakeholders will want to see addressed to their satisfaction. Thus the successful rehabilitation of uranium minesites has become a major issue worldwide.

2. PAST HISTORY

Throughout the world uranium has been mined in at least 25 countries [3]. The majority of this activity has taken place since 1950. In the early days environmental regulation was effectively nil, rehabilitation was not a major concern for the majority of the community and few mining companies bothered to put any effort into rehabilitation. The mining industry has been traditionally seen as a one-time user of land and the potential long term impacts of mining residues such as waste rock and tailings were not fully appreciated. Often such environmental degradation was effectively accepted by affected communities in the vicinity of mines as a consequence of mining necessary for their economic well being. Throughout the 60s there was a growing community awareness that some impacts were arising from old uranium workings and by the late seventies it was apparent that remedial actions were required in a number of locations where uranium mining or milling had taken place but the sites had been abandoned. The hazards included uranium mill tailings dispersed by wind and water, increased exposure to gamma radiation and radon from heaps of low-grade ore materials and pollution from the acid drainage generated by the weathering piles of reactive waste rock or tailings. The long lived nature of some of the pollutants was a major source of concern and communities demanded remedial action be taken.

In the USA the passage of the Uranium Mill Tailings Radiation Control Act in 1978 was followed by the establishment of the Uranium Mill Tailings Remedial Action (UMTRA) programme which expended more than US$ 1.4 billion over the next 22 years or so in remediating tailings deposits from former uranium mining and milling sites in Phase 1 of their programme. Phase 2, designed to deal with issues of remediating groundwater pollution associated with these same sites, has begun and is ongoing [4].

In Australia the former uranium mine at Rum Jungle, Northern Territory was abandoned in 1971 after about 20 years of operations, uranium was mined from 1959 to 1965. During the 1960s pollution from the site was already impacting on a local river system with ever increasing severity. By 1982 the situation had become so serious that a federal government programme was put in place to rehabilitate the site with the objective of reducing surface water pollution and public health hazards. The work cost about AUS$ 16.2 million in 1982 [5]. A further AUS$ 1.9 million was spent on the rehabilitation of an associated outlying mine, Rum Jungle Creek South, in 1990–91 [6].

The WISMUT GmbH company in Germany has been allocated a budget of over DM13 billion to cover the costs of rehabilitating the former uranium mining and milling sites in Saxony and Thuringia. Society was no longer prepared to accept the unvegetated rock heaps and increased health risks associated with the abandoned shafts and pits and the exposed waste rock dumps and tailings piles. The communities involved demanded action and a plan of remediation was formulated. Work commenced in 1991 and is likely to be spread over a period of 10 to 15 years [7].

These sums of money represent the allocation of considerable resources to the rehabilitation process, all for mines which were abandoned by their operators in a manner which, whilst legal at the time, would be considered totally unacceptable by modern society and would not meet today's standards. Modern operations are now subject to extensive environmental impact assessment procedures prior to any approval to mine being granted. These processes may take years to complete and an essential element of the documentation that has to be completed is the plan of rehabilitation, including the provision of funds to cover the cost of the work. Such funds are usually required to be provided in a form that guarantees their being available, even in the event of the company failing economically. A variety of strategies are employed by Governments to ensure that the funding is sufficient and will be available. This was not always the case and the issue of how to fund the rehabilitation of "orphan" mines, i.e. those un-rehabilitated sites that have been abandoned and for which owners can no longer be located and made to pay, is one that is troubling governments around the world.

3. REHABILITATION AND THE COMMUNITY

The level of public concern in respect of all environmental issues has increased over the past 40 years. The mining industry has been a major source of concern to many in this context. With each wave of industrial development the mining companies and the mining regulators have had to adjust to contend with changing perceptions and requirements of both governments and the community. The increase in community expectations has been marked by a series of "steps" on a steadily increasing trend towards a growing requirement that mining should not be a "one-time" user of land and that the industry will take on board the principles of sustainable development. These steps may have been associated with some form of disaster involving a minesite that has had a very significant environmental impact. Examples are the Aberfan tip slide in Wales, acid drainage from coalmines in Pennsylvania and tailings discharges in Tasmania and the Philippines. The environmental standards are changing steadily, also technology improves and so expectations change and the spiral of continuous improvement in environmental management moves ever higher.

Minesite rehabilitation is no exception to this process. In less than 50 years the community has moved from acceptance of sites being abandoned through a stage of crude landscaping with exotic, but easily grown, trees and shrubs, to ever more demanding requirements for landforms that match the local terrain, vegetation that is native and blends with the surroundings and consideration of tailings to be properly and permanently contained and final voids managed by filling with rock or water. The whole concept now is based on land not being sterilized or quarantined after mining but returning to some form of productive use. Such uses may be as biodiversity reserves or public parks or even development sites for housing and industry. For uranium mining all this is true with the additional requirement that radiological contamination must be managed so that it is no longer an issue in limiting future land use, to the greatest extent practicable. The trend is worldwide and a complete range of examples may be found in Australia.

4. URANIUM MINE REHABILITATION IN AUSTRALIA

Uranium mining only really became established in Australia after 1945 when there was a concerted effort to locate resources for use in weapons programmes. The first-generation modern uranium mines in Australia were at Rum Jungle and the South Alligator Valley in the Northern Territory and Mary Kathleen in Queensland. The next stage of development followed the surge in exploration to provide supplies for power generation projects. The major deposits of the Alligator Rivers region at Nabarlek, Ranger, Jabiluka and Koongarra were discovered, but only the first two have been fully developed. Rehabilitation was not a requirement for the first generation, but by 1980 it was a required practice although the standards and expectations of the public and regulators were not well developed. Also at this time there was a growing concern about the legacy of the earlier sites that led to some of them being rehabilitated.

A most significant change at this time was the promulgation, in 1974, of Environmental Impact Assessment legislation in Australia. Under this legislation a draft Environmental Impact Statement (EIS) was prepared for the Nabarlek uranium mine in 1977. The EIS was assessed and finalized in early 1978. The Ranger uranium mine was subject to a public inquiry, the Ranger Uranium Environmental Inquiry (RUEI) which was chaired by Mr. Justice Fox who delivered his final report in May 1977 [8]. This process fulfilled all the functions of an EIS. These processes considered the rehabilitation of these sites and resulted in a requirement for comprehensive rehabilitation plans to be put in place that had to be approved by the regulating authority. These were the first examples in Australia of uranium mines rehabilitation being considered and planned as part of the approval process prior to mine development.

The Nabarlek mine life cycle reached a significant stage in December 1995 when the rehabilitation earthworks were completed. The site had been decommissioned and revegetated in a rehabilitation

programme that reflected the growing significance of rehabilitation and environmental management in the eyes of the community. At Ranger rehabilitation has begun in areas that are no longer required for operational purposes and the rehabilitation plan is revised annually. A significant improvement from the days of "walk-away" in 1960! And even now the rehabilitation plans for the proposed mine at Jabiluka are prepared to take into account improved standards of end product and increased levels of community expectation.

5. RUM JUNGLE

The first site to be examined is Rum Jungle. After the site had been abandoned little rehabilitation was done. Pyrites in the tailings and waste rock generated acid which dissolved heavy metals, mainly copper and uranium, from the host rock. Soon the Finniss River, which runs through the site, had become significantly polluted for many kilometres downstream and there was a growing level of public concern as recreational fishing and livestock watering resources were affected. The Commonwealth Government assumed responsibility for this cleanup operation as the uranium had been mined on its behalf and the mining company was not held responsible. There was no rehabilitation bond in place for the site so the Commonwealth Government financed the rehabilitation programme. The main objective of the programme was to bring about a reduction in the volumes of polluted water leaving the site and allow the Finniss River environment to recover. At the same time, the site would be landscaped and revegetated to present a more visually pleasing aspect. There was no intention that the site should be rehabilitated to such an extent that the public could have unrestricted access, nor was any land use other than a restricted area proposed. Tailings were placed in secure containments, including a worked out pit, and grass established over the cover layer. Waste rock was encapsulated in new landforms to prevent the ingress of air and water and hence slow the production of acid. Wastewaters on site were treated with lime to raise pH and precipitate out heavy metals. The treated water was then discharged from the site with little risk of severe impact to the local river system. The grass species used were exotic and so required a relatively intensive management regime of fertilising and mowing to maintain the effectiveness of the cover. The cost of these rehabilitation measures was considerable, as is the cost of the ongoing maintenance works. Trees were not allowed to become established on the site in case their roots penetrated the clay covers which encapsulated the waste heaps, allowing air and water into the rock mass with the risk of acid production recommencing. The result is a site which is quarantined from any future use, and which requires ongoing active management.

Whilst this was acceptable at the time of rehabilitation in 1980s today's communities want former minesites to be restored to some form of productive use. This became apparent when an outlying mine at Rum Jungle Creek South was rehabilitated in the 1990s. The programme there required that the former open cut and surrounding area be rehabilitated to become a recreational lake and picnic area with unrestricted public access. The task was completed after new covers were designed and built for the waste heap and the drainage of the area was adjusted to ensure that rainwater runoff would keep the open cut full. The design also allowed for the development of a playing field adjacent to the site but this has not yet been fully established by the local community. The significant change in community expectations over a period of less than 10 years is clearly demonstrated in the widely differing ways two sites only 5 km apart have been rehabilitated.

6. SOUTH ALLIGATOR VALLEY

The South Alligator Valley uranium mines were also operating during the early 1960s and they too were simply abandoned when mining activities ceased. The sites were not rehabilitated and remained untouched until growing concern about public safety issues arose in the mid 1980s when the area was designated to be included in a National Park. In 1986 tailings were removed from the South Alligator Mill to a location outside the Park and processed to extract gold. In 1990 the Commonwealth Government undertook a programme of hazard reduction works at all the minesites, including the mill. The objectives of the programme were to reduce physical hazards at old workings, such as shafts

and adits, and to reduce radiation exposure for park visitors and traditional landowners to levels compatible with the new land use. The work was completed over two dry seasons and included revegetation of disturbed areas with native species to match the surrounding vegetation. No attempt was made to fully rehabilitate the sites. In 1996 the land was subject to a native title claim which was successful. When the land was handed back to the traditional owners it was immediately leased back to remain as a national park. However, the new lease now required that all mine sites be fully rehabilitated by 2015. The negotiations over the design of a suitable programme have taken place over a two-year period and work is scheduled to commence in 2001. A major objective of the rehabilitation is to ensure that the sites blend in with the surrounding countryside and do not require any special long term management. Again, less than 10 years after one programme of remedial action, further work is to be undertaken in response to the increase in community expectations in relation to the rehabilitation of mine sites.

7. MARY KATHLEEN

The Mary Kathleen uranium mine in Queensland operated in two phases, initially from 1958 to 1963 and again from 1976 to 1982. Very little rehabilitation work was undertaken after the first phase, as this was still the normal state of affairs at that time. However, by the time the second phase came to an end in 1982 there were expectations from both the community and regulators that such sites would be made safe. As a consequence the mining company undertook a full Environmental Impact Study and prepared a rehabilitation plan at the time of the operation's restart in 1976. Before the rehabilitation plan was implemented in 1982 it was updated to ensure that it was in accordance with the provisions of the Code of Practice for the management of radioactive waste from the mining and milling of radioactive ores that had been published in 1982 by the Commonwealth Environment Department [9]. The rehabilitation programme included the mine workings, the waste dumps, the tailings pond and the township. The main objectives of the plan were: to make all areas safe for public access in terms of radiation hazards and physical risks; all structures that could degrade or become hazards were removed; surfaces were to be made as erosion resistant as possible and revegetated with native species. The agreed final land use was to be grazing with little or no need for on-going maintenance.

The programme was completed over a period of about three years and included flooding of the mined-out pit, covering, contouring and revegetation of the major waste rock heaps, revegetation of borrow pits, removal of the processing plant and township and revegetation of those areas and secure containment of tailings in the existing above ground disposal facilities. The standards of rehabilitation were basic by today's criteria, with the heaps generally little modified in terms of trying to match the surrounding land forms, concrete slabs and building bases remain to the present and exotic flora were not removed from the township site. The construction standards set out in the Guidelines of the Code of Practice were taken into account and the regulating authorities considered that the work did comply with the necessary engineering standards during the works programme which ran from 1982 to 1985. However, whilst the landowner, a pastoralist, was apparently satisfied with the rehabilitation outcomes at the time, it is unlikely that the site would meet the expectations of a present day community or regulator. This would mainly be due to the failure to meet modern aesthetic expectations or remove all physical evidence of infrastructure combined with the presence of exotic flora.

8. NABARLEK

The most recent example of uranium mine rehabilitation in Australia is the Nabarlek site in the Northern Territory. The ore body was discovered in 1973 and its development was subjected to intense scrutiny through a Public Inquiry [8] and an EIA process [10]. The site was relatively small because the high grade and discrete nature of the ore-body allowed mining to be completed in one 143-day campaign. The ore was stockpiled and milling was spread out over a 10-year period. The site was temporarily "mothballed" for about five years whilst new reserves were sought. Eventually the

Supervising Authorities directed the mining company to rehabilitate the site with all earthworks to be completed by 31 Dec.1995 [11].

Another issue was the funding of rehabilitation. When the original agreement between the mining company and the Traditional Owners was signed it was agreed that a cash bond of AUS$ 2 million would be put aside as a surety for rehabilitation. By the time implementation of the rehabilitation programme was being seriously discussed in the late 1980s it was agreed that such a sum was no longer sufficient, also the mining company had changed hands. At that time the new owners of Nabarlek were required to cost the works proposed and provide a financial instrument that would underwrite the whole of the rehabilitation operation as planned. The outcome was a company guarantee in the sum of AUS$ 10 million.

During the pre-mining negotiations with the Aboriginal traditional owners of the land a number of agreements were reached regarding final land use and rehabilitation of the site. In particular it was agreed that whilst some items of infrastructure would be handed over to the Traditional Owners (all-weather airstrip, the accommodation camp, workshop buildings, etc), the site was generally to be landscaped to match the original contours to the greatest extent practicable and revegetated to “blend in with the surrounding vegetation”. Also, as with all post-1970 uranium mines in the Alligator Rivers Region, in accordance with the Environmental Requirements of the Commonwealth Government, all tailings were required to be returned to the mined-out pit. However, at Nabarlek, this last condition was no real imposition as the tailings had, possibly uniquely, been returned directly to the pit as the stockpiled ore was milled [12].

The criteria to be met for successful rehabilitation therefore were that the revegetation should blend with the surroundings and that the site should be safe to enable Traditional Owners to follow a traditional lifestyle of hunting and food gathering across the site, including occasional overnight camping, without limitation on access. The issue of physical safety to meet the criteria was easily addressed and completed by dismantling, decontamination and removal of the mill and much of the associated infrastructure. All residual plant and machinery items that could not be sold or satisfactorily decontaminated and all other contaminated materials, including cleaning residues, were placed in the pit above the tailings for containment on-site. The landforming was undertaken so that it was completed immediately before the anticipated onset of the rainy season, this allowed seeding to proceed at the optimum time. The seeding was completed in December 1995 and by mid-1996 there was a good vegetation cover across the site.

The major areas of interest since that time have been the radiological situation on site [13], the stability of the site in respect of erosion and the development of the vegetative cover. Whilst the radiological and erosion situations have not given any cause for concern the same cannot be said for the development of the vegetation. There is no set objective standard with which the developing plant community can be compared. An assessment by an independent expert was submitted in 1999 but has yet to be accepted by the majority of the stakeholders. In particular the issue of tree species density and abundance, absence of weed species and success of shrub species are all being questioned. The standards are now very exacting and the stakeholder community, including both regulators and landowners, is requiring that the satisfactory development of the “correct” climax vegetation association be adequately demonstrated before clearance can be given to the mining company to be released from obligations for the site. A final issue requiring resolution, to be discussed later, is the long term stewardship at Nabarlek once the mining company has been absolved of further responsibility for the site [14].

Comparison of the rehabilitation outcomes at Mary Kathleen and Nabarlek reveals how standards changed greatly in a relatively short space of time. The standards of rehabilitation proposed and accepted when Mary Kathleen re-started operations in 1976 were far less stringent than those that were applied to Nabarlek only three years later. The significant difference was that the Nabarlek EIS was drawn up in the aftermath of the RUEI and the Fox Report [8, 10]. Over the inquiry period it

became apparent that society was no longer prepared to accept mining as a one-time user of land and former sites would in future be required to be returned to some form of previously agreed land use.

9. MODERN MINESITE REHABILITATION STANDARDS

From the previous history it is clear that increasing stakeholder expectations have been the major driving force behind the improvement in minesite rehabilitation standards. Within the Alligator Rivers region there is presently one operating mine (Ranger) and one under development (Jabiluka). The rehabilitation planning at Ranger is seen by the stakeholders to be an example of best practice that stands as a potential benchmark for similar operations elsewhere in the region and the world. The five major elements are:

(1) a clear understanding of the goal and objectives of rehabilitation agreed by the stakeholders,
(2) stakeholder participation in the planning and updating processes,
(3) an approved plan for rehabilitation that is revised annually,
(4) a process which ensures that the finance for rehabilitation is completely secure, and
(5) implementation of progressive rehabilitation wherever possible.

The rehabilitation plan of the Ranger mine was set out initially in the EIS and was specifically written into the agreements between the Traditional Owners, the Government and the mining company at the time development was approved. In essence it was agreed that the final goal and objectives would be set down and agreed by the main stakeholders within a set period of time. This was finally achieved in 1990 [15]. The goal is that the project area be rehabilitated to establish an environment which reflects that existing in the surrounding country and permits the incorporation of the former site into the surrounding Kakadu National Park without detracting from the Park values. The objectives are that, to the greatest extent practicable:

(1) Revegetation should match natural species in density and abundance and form an ecosystem that would not require a management regime significantly different from the surrounding Park;
(2) Establishment of radiological conditions over the project area such that, with the minimum of access restrictions, the public dose limit will not be exceeded and the health risk to all community members will be as low as reasonably achievable;
(3) Erosion from rehabilitated areas will be limited to that characteristic of surrounding areas.

As the goal and objectives are in place the issue is how to determine that they have been achieved. For all elements, apart from the revegetation, existing standards and procedures are deemed to be satisfactory for this purpose. In the case of revegetation there has been considerable debate and many lessons have been learned from looking at examples of assessment systems in other parts of the world as well as in northern Australia, including Nabarlek. At the present time no one methodology has been agreed but the new technique of ecosystem function analysis (EFA), as developed by the scientists of the Commonwealth Scientific and Industrial Research Organisation [16] is currently being evaluated as showing the most promise. Certainly it has gained support from all major stakeholders in principle and now awaits a final decision based on the outcome of field experience in the area.

The relevance and applicability of the rehabilitation plan are assured through the annual process of updating. The mining company is required to produce an annual revision of the complete rehabilitation plan for approval by the Supervising Authorities. The major stakeholders assess this plan before the agreed version is submitted for approval, a process that may take up to two or three months. The plan has to be sufficiently detailed for stakeholders to be confident that the goal and objectives would be met should the plan be implemented during its lifetime. The detail provided must be sufficient to enable a detailed costing to be made. This provides the basis for the determining the financial guarantee required for rehabilitation. In the case of Ranger, the mining company is required to place a cash deposit in a rehabilitation trust fund by a set date each year. The size of the deposit is determined by the costs derived from the annual updated rehabilitation plan, plus any contingency

amounts as assessed independently by the major stakeholders and a quantity surveyor appointed by the Minister responsible for the *Atomic Energy Act*. In this way the burden of funding rehabilitation should not fall on the Government or the taxpayer, whatever financial or economic misfortune might befall the mining company.

The final element of the process is the application of progressive rehabilitation wherever practicable. As the mining company develops the plan and it is approved it has become apparent that some disturbed areas have been constructed to what is effectively the final landform. These areas are checked for radiological condition and, if satisfactory, are used as development sites for revegetation works. Since 1998 such areas have tended to be revegetated using what has, in effect, become the standard methodology. Results in areas that have been rehabilitated to date are very encouraging, with some trees up to 4 metres tall after only two years growth. However, the overall assessment of the success of the works has yet to be agreed as was mentioned earlier. The areas that have been revegetated in this way are also considered for exclusion from the annual rehabilitation plan's cost estimates where applicable.

The five elements of this approach to rehabilitation planning and implementation produce what the stakeholders in the Region consider to be best practice. Certainly the system is complex and subject to a great deal of verification and consultation involving stakeholders. This is why the process is considered to have such rigour and provide a benchmark for similar situations not only in Australia, but also throughout the world. The development of the process has been built on increasing stakeholder awareness of environmental issues, a community desire to see mining in the context of sustainable development and the incorporation of genuine and meaningful stakeholder consultation in the planning and implementation of rehabilitation.

The system in place at the Jabiluka project is less complex due to the relatively small amount of development undertaken to date. The company has provided a detailed rehabilitation plan, which has been assessed by stakeholders and approved by the Supervising Authorities in the same way as for the plan at Ranger. This approved plan has been costed and the company has posted a guarantee for the entire rehabilitation costs. Whenever the project moves into the next stage of development the plan will be revised. In the event that full development proceeds it is likely that the process of rehabilitation bonding to be imposed will be similar to that employed at Ranger.

10. LONG TERM STEWARDSHIP

The most significant issue that remains unresolved to the entire satisfaction of society is the question of stewardship of rehabilitated uranium mine sites. There is a real concern that the systems in place at the present may rely too much on institutional controls to remain effective in the long term. Several members of the community have a perception that former uranium mine sites can never be regarded as completely safe, no matter how involved and tightly controlled the rehabilitation process has been. Thus all rehabilitation situations now require a plan for the long term stewardship of the site or sites concerned. The major elements of stewardship are:

- Appropriate monitoring and surveillance for as long as required, in perpetuity if necessary
- Provision of maintenance as required
- Ability to undertake further remedial actions as required
- Communication and consultation with stakeholders.

Few organizations other than central governments will have the capability to provide this level of resource to manage the situation effectively and to the degree expected by the community. But it must be appreciated that even central governments may be limited in resources and so the rehabilitation programme should be designed to require the least amount of intervention. The issue of payment for the monitoring has yet to be resolved within the Alligator Rivers Region, but one possibility has been the introduction of a fee to be paid by the mining company at the time of discharge of responsibility,

most probably from the rehabilitation bond fund. Such a fee would be placed in a trust fund with interest being used to pay the basic monitoring and surveillance costs. Any additional costs for maintenance or repairs would have to be borne by Government.

Given the nature of radioactive mining wastes it is unlikely that, in the event of a major loss of containment integrity, any party other than central government would be capable of funding cleanup works. This is one reason why the placement of tailings below ground surface is required in the region. Such containments are unlikely to be breached within anything less than geological time frames. Institutions may fail but the containment should still be secure.

Finally, the programme of stewardship must include an element for consultation and information exchange with the stakeholders. Local communities must feel that they are being kept informed of the risks and hazards associated with a rehabilitated mine in their district and that they have real opportunities to contribute to decision making related to the rehabilitation process, especially in the stewardship period. The ultimate goals of stewardship must be to ensure that environmental protection is paramount and maintained at the required level. Mining should only be allowed to proceed in accord with the principle of sustainable development; and the principles of inter-generational and intra-generational equity must be respected and observed when considering options under rehabilitation plans that involve management of materials which remain potentially hazardous for very long periods of time.

11. CONCLUSIONS

Minesite rehabilitation is a subject that is quickly made highly emotive, no more so than when uranium mines are being considered. This is because the mining industry in general, and uranium mining in particular in some areas, has a long legacy of environmental degradation and scant attention to rehabilitation that causes deep seated concerns amongst affected communities. Over the past 50 years or so the environment has assumed ever greater importance in the minds and opinions of society. So much so that the mining industry has changed its attitude towards rehabilitation as a consequence of public pressure. Much of this pressure is reflected in changing regulations and laws relating to prevention of pollution and remediation of degraded areas. As these changes have come about so the mining industry has developed a growing awareness of the need to consult with stakeholders about present and future developments. In particular the exchange of information between stakeholders and proponents has reduced some of the antagonism previously experienced frequently when bringing projects to the implementation stage, as well as ensuring that rehabilitation is appreciated as a vital element in all mining projects. Standards of rehabilitation now take account of community concerns and take into account concepts such as continuous improvement and sustainable development.

The pressure for continuous improvement in rehabilitation standards has come about, and is maintained, through community pressure. At every stage of development proponents who fail to consult with their stakeholders do so at their peril and with the risk of having their programme held up or even stopped in an atmosphere of conflict. As a result most major mining projects are now proceeding with rehabilitation plans approved and in place from the first day of construction. Systems are in place to ensure funding for rehabilitation is guaranteed. And finally the principles of sustainable development and inter- and intra-generational equity are becoming established as foundations for future mining projects. As society has increased its desire for ever better levels of environmental protection, so regulators have responded, and the mining industry has acted, to meet those concerns.

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Comparative assessment of licensing processes of uranium mines in Brazil

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Abstract. Commercial operation of uranium mining and milling started in Brazil, at the Poços de Caldas Unit, State of Minas Gerais, in 1982. The Poços de Caldas Unit was licensed by the Brazilian Regulatory Body (CNEN) and its is now in the decommissioning process. In 2000, a new mining and milling installation, the Caetité Unit, located in State of Bahia, started operation. This paper will discuss how Brazilian Nuclear Energy Commission is licensing the Caetité Unit based on the lessons learned from the Poços de Caldas Unit. The objective is to draw attention to the importance of the safety assessment for a new unit, specially considering that some wrong decisions were taken for the Poços de Caldas unit. These decisions lead to less effective long term solutions to protect the environment. Notwithstanding the differences between the two units, it is of great value to use the acquired experience to avoid or minimize the short, medium and long term impacts to the environment and population in the new operation.

1. INTRODUCTION

Brazil has the sixth largest geological uranium reserves in the world, and only 30% of its national territory has been prospected. Since 1991, all systematic prospecting for uranium in Brazil has stopped. If new exploration expenditures are carried out, the geological reserves could probably double in a short time.

Brazilian Nuclear Industries (INB) is a national company responsible for all the nuclear fuel cycle activities in Brazil. INB uranium mining and milling activities started at the Poços de Caldas Unit, in the Minas Gerais State, in 1982. During the operational time, the Poços de Caldas Unit produced about 1300 tons of U_3O_8.

Since the mining and milling of uranium reserves was no longer economically feasible, the Poços de Caldas Unit shut down in 1995. During operations, tailings, by-products and about 100 000 000 tons of mine rock was generated and the mill effluents were discharged into the environment. The closure planning and remediation actions are still under development.

And drainage is the main environmental problem; this situation is enhanced by the high rainfall of the region. The acidification is generated by oxidation of pyrite present in the low-grade rock. As a result, acid solutions characterized by very low pH values and high concentrations of potential pollutants are produced. It is estimated that pyrite oxidation will occur for more than a 1000 years [1]. The long time scale involved affirms the need for permanent remedial actions. Therefore, the control measures adopted must remain effective long after mine closure and must be affordable and cost-effective. Neutralization of the acid drainage from the waste rock dumps has been an effective interim strategy to reduce the concentration levels to acceptable limits [2] but it cannot be selected as a permanent solution to the problem.

With the nuclear policy change that approved the construction of the second nuclear power plant in Brazil (Angra II), INB decided to shift its uranium production from the high-cost deposits at Caldas to lower costs reserves at Caetité, in Bahia State. This region is characterized by a very dry climate and is considered one of the most important Brazilian uraniferous provinces. Its reserves are estimated at 100 000 tons of uranium plus other associated minerals.

The Caetité Unit has received operational authorization, and production started this year. It is an industrial ore processing complex, designed to mine and mill uranium contained in about 33 ore deposits. The proposed uranium extraction process will be heap leaching. This technique has advantages such as: (i) substantial reduction in investments; (ii) lower operational costs and (iii) reduced infrastructure demand when compared to the conventional agitated leaching technique.

Regarding the environmental aspects, the absence of fine solid waste precludes the need for engineered containment structure; this minimizes potential radiological impacts. The project holds out the possibility of liquid recycling which means that liquid effluents will return to the process without discharge to the environment. Mining activities and area rehabilitation will be done simultaneously and in such a way that restoration of the environment will be completed as soon as each mine site is released.

These two contrasting case histories exemplify the INB uranium operations in Brazil. In addition to these two districts, Brazil has other known uranium deposits, and, as a whole, it is estimated that Brazil has over 300 000 tons of U_3O_8 in reserves [3].

Both units were submitted to the nuclear licensing process established by the Brazilian Regulatory Body (CNEN) that has the technical and legal competence to evaluate the environmental radiological impacts, the safety and the adequate control required for the facilities which, due to their characteristics, represent a potential risk of radiological contamination to the environment. CNEN is responsible for issuing standards and regulations related to nuclear safety and radiological protection; it also monitors and controls nuclear installations, according to the Brazilian laws, and international recommendations.

2. URANIUM EXPLORATION IN BRAZIL

Systematic prospecting for radioactive minerals in Brazil was started in 1952 by the Brazilian National Research Council. In 1955, technical co-operation agreements were signed with the government of the U.S.A for an assessment of potential uranium reserves in Brazil. In 1962, the recently created Brazilian Nuclear Energy Commission sought the collaboration of the French Comissariat À l'Énergie Atomique (CEA) to organize its Mineral Exploration Department.

An initial objective of the systematic exploration programme was evaluation of the uranium reserves associated with the zirconium ores of Poços de Caldas plateau which were known since 1948. The exploration was accelerated by the availability of funds for this work from 1970 onwards. Poços de Caldas deposits were considered to be the most promising for meeting the short term requirements of the Brazilian Nuclear Programme.

With the creation of Nuclebrás (presently INB), in 1974, the Brazilian government expanded its nuclear programme to include additional exploration, research, development and the mining of uranium deposits. The expanded exploration work identified eight areas with uranium reserves, namely: Poços de Caldas (MG), Figueira (PR), Quadrilátero Ferrífero (MG); Amorinópolis (GO); Campos Belos (GO), Itataia (CE), Lagoa Real/Caetité (BA) and Espinharas (PB). These occurrences are well documented [4]. See Table 1 for the known reserves.

TABLE I. URANIUM GEOLOGICAL RESERVES IN U_3O_8 TONS [5]

Deposits	Measured and indicated	Inferred	Total
Lagoa Real/Caetité (BA)	94 000	6 700	100 700
Itataia (CE)	91 200	51 300	142 500
Other	39 500	26 500	66 000
TOTAL	224 700	84 500	309 200

As can be seen, the Itataia deposits, which are located in the central part of the State of Ceará are the largest. These deposits account for almost 50% of the total known reserves. A radiometric aerial survey identified 273 anomalies. The uranium is associated with phosphates, an unusual type of mineralization. The U_3O_8 grade varies from 500 to 9000 ppm and the P_2O_5 grade from 12% to 37% [6]. The deposit is suitable for open pit mining; the uranium recovery from the phosphatic material is estimated to be 70%. Development of the uranium-phosphate Itataia project will depend on numerous factors including the markets for both products. In contrast to Poços de Caldas, which has been known since 1948, the Itataia deposit was only discovered in 1976, and Lagoa Real was identified in 1977.

3. REGULATORY ASPECTS

The Licensing Process of Nuclear Facilities in Brazil is controlled by the Brazilian Nuclear Energy Commission (CNEN), according the Brazilian Constitution and Federal Laws. The nuclear licensing process has as its main objectives: (i) preservation of the integrity of the installation and (ii) the protection of workers and the environment against the damage and risks associated with radiation exposure.

CNEN is the governmental regulatory authority that has the technical competence to assess environmental radiological impacts, as well as to assure that the design, construction, operation and decommissioning of nuclear installations will be carried out in accordance with established nuclear safety and radiological protection requirements, based on national and international recommendations.

The licensing process for a nuclear facility includes (1) request by the Applicant, and (2) approval by CNEN of the following statutory and legal obligations [7]:

(a) Site Approval
(b) License for Construction (Total or Partial)
(c) Authorization for Nuclear Material Use
(d) Authorization for Initial Operation
(e) Authorization for Permanent Operation
(f) Cancellation of Authorization for Operation

3.1. Site approval

The Site Approval application for the opening of the mine and/or the construction of the milling facility must contain in the annex “Site Report”, at least, information about:

(a) the characteristics of the facility design and the proposed operation;
(b) the site characterization including geography, demography, geology, geotechny, seismology, hydrology, meteorology and ecology; and
(c) the results of a Preliminary Programme of Environmental Radiological Monitoring (with data referring to a minimum period of two years).

3.2. License for construction

The License for Construction application for the mine opening and/or for the construction of the uranium ore milling facility, in the approved site, must contain in the annex “Preliminary Safety Analysis Report (PSAR)” the following information:

(a) organizational structure of the mine and/or mill facilities and updated cronogram;
(b) internal distribution of functional responsibilities;
(c) plans of the developing of the mine;
(d) preliminary project of the installation;

(e) safety measures related to physical and fire protection;
(f) occupational and environmental radiological protection measures;
(g) description of the conceptual project of the milling facility, including the processing equipment and methods, ventilation system, plants and drawings;
(h) description of all the laboratories, safety and radiation protection facilities;
(i) description of emergency and waste management systems;
(j) programmes of quality warranty;
(k) results of pilot scale tests;
(l) risk analysis for the installation;
(m) preliminary plans of personal training and
(n) preliminary decommissioning plans.

3.3. Authorization for nuclear material use

An Authorization for Nuclear Material Use will be granted upon determination that the mine or mill facility is ready to receive the nuclear material, and that the concerning conditions stated in the norms [8] were accomplished.

3.4. Authorization for Initial Operation (AIO)

The Authorization for Initial Operation of the mine and/or mill facility will be granted by CNEN when:

(a) It had been verified that the construction is substantially concluded;
(b) The evaluation of the Final Safety Analysis Report (FSAR), and of the results of the pre-operational tests had been completed and;
(c) It has verified the inclusion, in the installation, of all the supplementary safety conditions demanded by CNEN during the construction phase.

The application for AIO of the mine and/or mill facility shall include an estimate of the total operation period of the mine and/or mill facility and must contain in the annex "Final Safety Analysis Report (FSAR)" the following information:

(a) detailed description of the project, construction and operation of the facility;
(b) the design bases, including technical specifications and limits;
(c) detailed description of mining operation, crushing and grinding systems;
(d) plans related to physical and fire protection;
(e) radiation protection plans (occupational and environmental);
(f) radiation protection service description;
(g) for milling facilities, detailed description of the chemical attack system, drying, handling, packaging, storage and transport of the uranium concentrate;
(h) detailed description of the waste management system, including project plans for retaining and controlling the wastes and all effluents from the milling facility;
(i) a final emergency plan;
(j) a safety analysis for the facility as a whole;
(k) programmes of quality warranty and
(l) decommissioning plans.

3.5. Authorization for Permanent Operation (APO)

The application for Authorization for Permanent Operation of mines and/or milling facility must contain data complementary to the radiation protection plan and to the radiation protection service, or any other relevant information that had not been included during the AIO application and will be issued based the following:

(a) The Construction of the facility has been completed according the requirements established in the License for Construction and in the Authorization for Initial Operation;
(b) There is not, in any aspect, gaps concerning safety questions regarding the AIO;
(c) There is reasonable assurance that operations of a permanent nature can be conducted without risk to environment and to the health and the safety of the population;
(d) The applicant has the Authorization for Nuclear Material Use; and
(e) The applicant is technically qualified to conduct the requested authorization in accordance with the legal aspects involved.

3.6. Cancellation of authorization for operation

The application for cancellation of the Authorization for Operation shall contain the following information:

(a) probable completion date of the operating activities;
(b) preliminary plans that guarantee the safety and the health of the workers and public individuals in the phases preceding cancellation of the authorization and subsequent abandonment of the practice or installation; and
(c) report of the work performed in the mine, its current status and its future possibilities.

4. THE POÇOS DE CALDAS OPERATION

The Uranium Mining and Milling Facilities (UMMF) of Poços de Caldas is located on one of the largest alkaline intrusions in the world. The occurrence of about 70 radioactive anomalies characterize the plateau as a high natural radioactive area. The ore grade of the reserves ranged from 250 to 1250 ppm of U_3O_8.

The region has a tropical climatic. The annual average temperature is 19°C. The annual precipitation is 1700 mm, with more than 120 days of rain per year, which occurs primarily during the summer. Two hydrographic basins, Antas and Verde, cross the mine site and receive the effluents coming from the facilities. Water from both creeks are used for crop irrigation and for cattle watering.

The UMMF of Poços de Caldas began operation in 1982. The design capacity of U_3O_8 was 500 tons per year, but it never produced this amount. Between 1990 and 1992, the production was suspended because of increasing production costs and reduced demand. Production restarted in late 1993 and continued until October 1995. After two years on stand-by, the Poços de Caldas UMMF was shut down in 1997.

Milling process consisted of aggressive hot-acid leaching with sulphuric acid, liquor clarification, solvent extraction, aqueous sodium chloride reextraction and alkaline precipitation with ammonium hydroxide. After neutralization with lime, the leach residue, the solid and liquid wastes was sent to the tailings dam. The liquid effluent from the tailings dam is treated with $BaCl_2$ to precipitate the soluble Ra before release to the environment.

The mining activities have led to the formation of two main waste rock dumps (WR4 and WR8) plus an open pit. The waste rock consists of all mine material that has a soluble U_3O_8 content of less than 200 ppm which is the established mill cut off. It has been estimated that about 94.5×10^6 tons of rock were removed during mining operations [9]. Only 2% of this was ore grade material designated for physical and chemical processing in the mill. These figures give a barren/ore ratio of 50:1.

The WR4 mines produced the most significant effect on the environment because it was constructed over the Consulta river valley [10]. In perspective, it is necessary to take into account that during the seventies, the waste rock and mine drainage were not considered radiological hazards, therefore, no procedure for water treatment or planning for waste-rock disposal was implemented.

Monitoring showed that the quantity of radionuclides released to the environment from the waste rock and the mine drainage was greater than that from the chemical processing plant [11]. Pyrite oxidation was found to be the most important geochemical leaching reaction for the radionuclides. A drainage system was developed to collect and treat the effluents by neutralization with lime. Treatment of the waste rock drainage started in 1983, and this produced a significant decrease in the concentration of radionuclides in the liquid effluent. In 1985, the regulatory body required the treatment of all mining effluents.

Initially, the sludge precipitate from the neutralization process was disposed of in the tailings pond. This practice posed a serious problem for the general waste management strategy of the facilities because the tailings pond was not originally designed to receive this additional waste.

The acid-drainage problem is not restricted to the waste dumps and the mine pit. It also occurs in tailings pond where a significant amount of pyrite is present. The waste contains 2.0×10^6 tons of solid material [9]. Fernandes et al. [12] studied the geochemical processes that control the mobilization of heavy metals and radionuclides in the UMMF of Poços de Caldas tailings pond.

Since the beginning of its operation in 1982, several technical works and scientific studies have been published dealing with radiological impact assessments. The radiological impact of the waste rock piles and mine drainage on the environment was first described by Amaral et al. [11]. The potential of contamination of the aquatic environment by the tailings pond effluents was estimated by Fernandes [12].

A comprehensive environmental radiological impact assessment of the Poços de Caldas uranium operation has been carried out by Amaral [13]. This report indicates that the increase in the effective dose to a hypothetical critical group, based on conservative calculations, was on the order of 0.3 $mSvy^{-1}$. This value may be regarded as acceptable when compared to the radiation exposures limits specified for the licensing of all nuclear installations [14]. This exposure was due to adequate treatment of the chemical processing effluents, which has proved to be effective for controlling the radionuclide release to the environment. This strategy was developed during the licensing period and has been continued since the beginning of the operation. Studies investigated the contribution of radioactive and non-radioactive pollutants present in the liquid effluent to the radiation and toxicological risks of a local critical group. Data show that, in this type of facility the non-radiological impact due to chemical toxicity seems to be more important than the radiological criteria. For the non-radioactive pollutants, Mn is the principal concern regarding human health effects [15].

Interdisciplinary studies for proper decommissioning of the mines are being conducted [10]. The overall decommissioning plan should consider that the acid drainage aspect is the most important component of remedial actions decisions. The operational cost of collecting, pumping and treating acid mine drainage was estimated to be US $705 800 per year [16]. Fernandes et al. [1] pointed out that more than one thousand years will be necessary for complete oxidation of all the pyritic material in the dump and cessation of the acid drainage. This long time exceeds realistic institutional control of the facilities. Consequently, permanent remedial actions must be adopted.

Waterproof covering of waste dumps has been started, as well as the re-vegetation of the impacted areas in order to reduce the infiltration of rainwater and to help the process of rehabilitating sites to restore their environment or make them suitable for other uses.

The potential environmental impact of the tailings dam after final closure of the installation was assessed by estimating dose levels assuming the absence of remedial measures [12]. The projections included the termination of control procedures and the consequent effluent discharge to the environment without chemical treatment. The results showed that remedial actions regarding the tailings dam decommissioning would be necessary.

Both the mining company, Brazilian Nuclear Industries (INB), and the Brazilian regulatory authority maintain environmental and effluent monitoring programmes, in order to keep a strict control over the surrounding areas. The main regulatory aspects related to the decommissioning programme have been established and will be the basis for the work to be performed.

When the uranium operation terminates, the INB has proposed the use of the industrial facilities for other projects such as monazite chemical processing and rare earth production. This option would reduce the costs necessary for implantation of such units at another site.

For the above mentioned activities, INB was requested to evaluate the capacity of the tailings dam, and to establish alternatives in the case of its closure. A proposal for management of the liquid effluents arising from the waste rock and mine areas was presented. The objective is to reduce the effluent generation and, consequently, the amount of calcium diuranate (CDU) that was being added in the tailings pond. Currently, the CDU is being added in the mine pit. Evaluation of the pit for both capacity and leakage potential has shown it to be adequate for tailing disposal.

5. CAETITÉ CASE

The Uranium Mining and Milling Facilities (UMMF) of Caetité which is a property of Brazilian Nuclear Industry (INB), is located in the Southwest of the State of Bahia. The facility produces an Ammonium Diuranate (ADU) concentrate. The ore grade is about 3055 ppm (U_3O_8), and the barren/ore ratio is 6:1. An investment cost of US $40 million has been reported.

Caetité is characterized by a semi-arid climate; a predominantly rural economy; manpower of very low qualifications; and high birth and mortality rates.

The industrial complex will produce about 300 t U_3O_8/year. This amount is enough to supply the Brazilian demand. This demand includes refuelling the Angra I and II reactors, and the requirements of the Technological Programme of the Navy’s Ministry.

Initially, the ore will be mined by open pit methods. The mill uses a process similar to those of UMMF of Poços de Caldas, but the technology adopted for the extraction of the uranium is heap leaching. The process includes the following stages: crushing, heap leach extraction of uranium, solution, clarification, concentration and purification by solvent extraction and finally precipitation of an ADU uranium concentrate.

The solid heap-leach tails will be disposed with the sub-grade ore from the mine. A modular stacking method will be used to facilitate decommissioning as soon as each heap-leach unit is finished. A bottom drainage system will carry the drainage water to a storage pond. Safety personnel will monitor the drainage water from the mine and also the rainwater that falls on these areas. Based on its radiological characteristics the water will either be sent to the process or to the environment. A systematic inspection programme will detect and repair any damage that could compromise the physical integrity of the system.

Liquid effluents from the ore processing operation will be stored in a pond with a sub-aerial drainage system. Precipitates obtained from the subsequent effluent treatment will be retained. The liquid fraction will be collected through the sub-aerial drainage system and re-introduced into the process. The total volume of liquid effluent that will be generated is approximately 180 000 m^3/year, and the lime precipitation treatment will produce about 7200 t/year of solids.

The first waste disposal cell to be built will be divided into two compartments. Each compartment will be lined with a high density polyethylene sheet to assure that the system will not leak and also to acquire experience on design parameters. The planned environmental protection elements include: a system for surface drainage, waterproof covers, monitoring wells and aquifer monitoring.

A routine discharge of liquid to the external environment is not foreseen, because all the water used in the industrial processes will be recycled. However, a $BaCl_2$ treatment unit was included to provide precipitation of soluble radium when extreme conditions causes emergency discharge to the environment.

A Pre-operational Environmental Monitoring Plan and an Environmental and Effluents Monitoring Plan have been used for monitoring the region both before and during the construction and operation phases of the facilities. These plans were implemented with the objective of detecting any movement of pollutants in the air, water or solids from the facilities.

The environmental impact evaluation was developed by estimating any potential increase in the effective dose to a hypothetical critical group. These effective doses are determined by monitoring and application of dose calculation models based on the habits of the population. The effect of process uncertainties is evaluated by using conservative hypotheses, in a way to assure that the actual impact will be always smaller. Liquid effluents and atmospheric emissions compose the possible exposure pathways. Because there is a shortage of water in the area all the rain water will be impounded and the process water will be recycled. Since the liquid effluents will not be discharged to the environment, the airborne wastes represent a important exposure pathway, particularly ^{222}Rn and dust emissions caused by mine operations.

A preliminary plan for the decommissioning procedures has been prepared. This phase addresses recovery of the environment and restoring the area to its natural radiological characteristics.

The solid-waste management strategy considers decommissioning as a part of the operational stage. When each tailings pond reaches its capacity, it will be drained and decommissioned. The area will be covered by a layer of clay and soil and then re-vegetated.

Decommissioning each below grade waste dump involves the placement of an impermeable cover plus revegitation. The decommissioning will be carried out immediately after the closure of each module.

The leaching areas, after the removal of the waterproof sheets that covered the heap-leach pad will be covered with a layer of inert material that is thick enough to restore background radiation levels. The collection ponds located in this unit will be drained, filled with inert material, sealed with a waterproof cover and re-vegetated. Other industrial units, buildings, structures and equipment will be checked, monitored, decontaminated and released for alternative use if regulatory specifications are met.

The radium precipitation unit will continue operating because the mine drainage water must be treated to reduce contaminant concentrations to below the allowed limits. The precipitate product will be covered with inert material capped with a layer of organic soil and re-vegetated.

As can be seen, the licensing and development of the UMMF of Caetité has been carried out using a philosophy, where environmental management and decommissioning are part of the overall project planning. Authorization for initial operation was granted on March 2000 and INB has tested the industrial units; the objective of this programme is to obtain more precise operational parameters and to train the operational personnel.

6. FINAL REMARKS

The development and licensing process for the Caetité unit cannot be directly compared to that of the Caldas development because the relative problems involved were considerably different.

The UMMF of Poços de Caldas was the first industrial plant for uranium processing in Brazil. Therefore, it is reasonable that mistakes may have occurred during both the project development and the remedial actions for controlling environmental pollution. This may be attributed to the lack of experience in dealing with radiation protection principles at the time the mine plan was being developed.

Impact assessment studies concluded that Poços de Caldas UMMF operations were conducted within the acceptable limits of radiation exposure [17]. Although the tailings management system has been considered effective, it will be necessary to find a long term solution for the mine pit, the WRs and the tailings dump. Treatment of the drainage water must also consider toxic criteria other than the radiological criteria.

Decisions about procedures to be adopted for control and stabilization of the effluents, and the solid wastes should consider cost effectiveness. The adequacy of each procedure must take into account the environmental health impact, the cost and the risk reduction realized by its application.

At Caetité, prospecting and exploration has been carried out using a logical sequence and taking into account environmental management as part of the project. Pre-operational monitoring programmes at Caetité have been developed to demonstrate compliance with regulatory requirements whereas at Poços de Caldas the monitoring of liquid effluents did not begin until 1982, when milling operation started.

It is also necessary to call attention to important aspects of risk perception and to the potential necessity of an integrated risk assessment for licensing and control of nuclear facilities. The socio-economical aspects of the site may also be very important.

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The Canadian Nuclear Safety Commission regulatory process for decommissioning a uranium mining facility

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Abstract. The Canadian Nuclear Safety Commission (CNSC) regulates uranium mining in Canada. The CNSC regulatory process requires that a licence applicant plan for and commit to future decommissioning before irrevocable decisions are made, and throughout the life of a uranium mine. These requirements include conceptual decommissioning plans and the provision of financial assurances to ensure the availability of funds for decommissioning activities [1]. When an application for decommissioning is submitted to the CNSC, an environmental assessment is required prior to initiating the licensing process. A case study is presented for COGEMA Resources Inc. (COGEMA), who is entering the decommissioning phase with the CNSC for the Cluff Lake uranium mine. As part of the licensing process, CNSC multidisciplinary staff assesses the decommissioning plan, associated costs, and the environmental assessment. When the CNSC is satisfied that all of its requirements are met, a decommissioning licence may be issued.

1. WHO IS THE CNSC?

The CNSC, formerly the Atomic Energy Control Board, is the federal nuclear regulatory agency in Canada. The regulatory framework for the CNSC is established by the *Nuclear Safety and Control Act* (NSCA) [2], supplemented by Regulations [3], and a detailed licensing process. The CNSC's mandate is to ensure that the use of nuclear energy in Canada does not pose undue risk to health, safety, security, and the environment [4].

The CNSC is a departmental corporation that reports to the Canadian Parliament through the Minister of Natural Resources [4]. The CNSC is composed of Commission members appointed by the Governor in Council, and Commission staff. There are currently four Commission members and approximately 450 staff located in 11 different offices across Canada. The staff is a multidisciplinary team of experienced technical professionals who specialize in technical and safety-related assessment, licensing and compliance. The staff implements the policies of the Commission and makes recommendations to the Commission concerning licensing and other regulatory matters.

The Directorate of Fuel Cycle and Materials Regulation is the functional unit responsible for the regulation of uranium mining and milling, refining and fuel fabrication. The operating line is the Uranium Mines Section, which operates from a regional office located in Saskatoon, Saskatchewan [4].

2. CNSC REGULATORY SYSTEM

The NSCA allows activities within the CNSC's mandate to take place only with the permission of the Commission. These activities must comply with applicable regulations and any licence conditions imposed by the Commission. Seven sets of regulations support the *Nuclear Safety and Control Act* and contain generic requirements that apply to any nuclear facility. The *Uranium Mines and Mills Regulations* [3] contain requirements specific to uranium mining operations. A licence issued to any particular facility may contain site-specific conditions that reflect the operational activities, the work environment, and the natural environment [4]. Licence conditions have the force of law.

2.1. Regulatory control

Regulatory control is partially achieved through the licensing process. The CNSC regulates uranium mining during the entire life cycle, except for exploration, and requires separate licences for evaluation, siting and construction, operations, decommissioning and abandonment. Licence applicants are required to submit comprehensive details of the proposed design, impact assessments, and the manner in which the project is expected to safely operate. The review of these comprehensive submissions is conducted by a multidisciplinary team of specialists in the fields of geotechnical engineering, hydrogeology, geochemistry, biological sciences, transfer pathways modelling, milling, environmental impact assessment, radiation health physics, quality control and organizational management [5].

Regulatory control is also achieved through regulatory control limits. Some limits are established by the CNSC, such as radiation protection requirements, others by external regulatory authorities [6]. Regulatory compliance is monitored by surveillance, inspection, and auditing.

2.2. Overview of the CNSC licensing process

The CNSC's licensing process for the life cycle of a uranium mining operation proceeds progressively through site preparation and construction, operating, decommissioning and abandonment phases. At the very beginning of a project, the CNSC staff requires general assurances that all operational aspects of the project are feasible, including decommissioning. The information in support of the licence application is developed for each phase of the project and approved in a step-wise fashion, allowing the CNSC staff to assess and gain confidence that the licence applicant is qualified and has made adequate provision for the protection of the environment and the health and safety of persons.

2.2.1. The role of environmental assessment in the CNSC licensing process

The *Canadian Environmental Assessment Act* (CEAA) [7] sets out duties and procedures for the environmental assessment of projects involving the federal government. The CEAA is intended to ensure that federal authorities carry out their responsibilities in a co-ordinated and efficient manner, and that projects do not cause significant adverse environmental effects [8]. The CEAA specifies that the environmental assessment of a project may take the form of a screening, a Comprehensive Study, mediation or a panel review. Although the majority of projects captured by the CEAA will undergo an environmental assessment through a screening, some projects will require a more intensive environmental assessment in the form of a Comprehensive Study. Such projects tend to be large scale and, due to their nature, have the potential to result in significant environmental effects and/or to generate considerable public concern.

The CNSC is required by the CEAA and its Regulations to conduct environmental assessments before proceeding with its licensing process. Upon receipt of any uranium mine proposal, the CNSC conducts an initial environmental assessment screening of the proposed project pursuant to the CEAA and its Regulations. If the CNSC concludes that under the CEAA legislation a proposed project may proceed without further environmental review, the CNSC will proceed with the associated licence application. If satisfied, the CNSC issues a licence that may contain appropriate conditions to incorporate the assessment conclusions.

When a decommissioning plan is received, specific conditions of the CEAA require regulators to conduct a Comprehensive Study of the initiative. Upon completion of the Comprehensive Study, the Canadian Environmental Assessment Agency administers a formal public review of the study, and makes recommendations to its federal Minister on the findings. The Minister's response to these findings is forwarded to the CNSC. The CNSC cannot make any irrevocable decisions which would allow the project to proceed until the environmental assessment process is complete.

3. DECOMMISSIONING AND THE LICENSING PROCESS

Within the context of the *Uranium Mines and Mills Regulations* [3] "decommissioning" of a uranium mining facility means those actions taken by a licensee, in the interests of health, safety and the protection of the environment, to retire the facility permanently from service. The decommissioning program for any uranium mining facility is site-specific and will include activities such as dismantling of surface facilities, decontamination, reclamation activities and work performed to ensure that wastes are placed in a safe state [1].

The proponent is required by law, during all operational phases, to plan for and commit to future decommissioning and to provide sufficient information to satisfy the Commission that the facility can be decommissioned effectively. The long term objective of decommissioning is to leave the site in a state that is physically safe and provides secure, long term storage of contaminants with no unacceptable predicted future environmental impacts. This planning requirement begins during the project's early development phases with the submission of a conceptual decommissioning plan.

The proponent must maintain a financial assurance to cover anticipated future decommissioning activities in the event that the licensee is incapable of completing the decommissioning work. By Regulation, the conceptual decommissioning plan, its estimated implementation cost, and the financial assurance instrument must be reviewed each licensing term, historically every two years. Developments at a mining facility are usually dynamic, and may result in significant revisions to the decommissioning scenarios; therefore, a financial assurance review may be initiated by the CNSC or the licensee at any time because of a significant change to the facility's operation or conceptual decommissioning plan. At the end of the mine's operation, a final decommissioning plan must be submitted to the CNSC as part of the application for a decommissioning licence.

3.1. The conceptual decommissioning plan

The conceptual decommissioning plan is a general, all encompassing design for the rehabilitation and reclamation of the entire uranium mining facility and must consider all past and current activities. Conceptual decommissioning plans vary in approach, complexity, and detail depending on the site and facility operations; however, all plans must demonstrate that they are technically feasible and environmentally acceptable, and if implemented will result in an acceptable decommissioned facility [1]. The conceptual plan includes consideration of the schedule for carrying out the decommissioning activities.

Operators are encouraged to reclaim portions of their facilities as soon as possible in order to lessen the impacts of their operations, to take advantage of on-site resource capabilities to carry out the work and to allow the operators to mitigate or correct any unforeseen situations in a timely manner. The conceptual decommissioning plan provides a planned means to undertake reclamation activities during operations in a manner consistent with the long term decommissioning rationale [1].

3.2. Financial assurances for decommissioning

Once a conceptual decommissioning plan is accepted by the CNSC, the proponent is required to estimate the cost to implement the plan [1] and commit a financial assurance to protect taxpayers in the event that an operator becomes financially unable to undertake or complete the implementation of approved decommissioning plans.

Commission staff use some conservative assumptions as criteria to assess the cost estimates for implementation of a decommissioning plan. During its review of the cost assessment, the CNSC assumes that an operator is unable to carry out the activities described in the decommissioning plan, that the work will be carried out by independent contractors, managers, engineering and consulting services to be paid for out of the financial assurance fund established by the facility. Contingencies (additional costs due to overruns, unforeseen and unscheduled events) are factored into the cost

estimation. Where several options are under active consideration, the estimate is based on the most conservative option [1].

3.3. Environmental assessment and the decommissioning license application

Upon notification that a licensee is prepared to move towards final decommissioning, specific conditions of the CEAA require the CNSC to conduct or request an environmental assessment in the form of a Comprehensive Study of the final decommissioning proposal. The environmental assessment provides the proposed decommissioning approach, the associated environmental impacts and identifies any mitigative measures. The Comprehensive Study is a self-directed environmental assessment, designed to assess larger-size projects. The responsible authority must ensure that a Comprehensive Study report is prepared in accordance with the CEAA [9].

The project scope and the preferred decommissioning option(s) are assessed using a process that includes input from all stakeholders, including federal and provincial regulators; Environmental Quality Committees (EQC's) comprised of representatives from local communities; environmental interest groups; aboriginal peoples; and, companies or individuals involved in the project activity.

The study must assess the likely significance of the environmental impacts of decommissioning and permit reviewers to evaluate the accuracy of the predictions. Estimates of effect should be supported with best-available source-term data, and where applicable, the results of contaminant transport modelling. The Comprehensive Study must describe reasonable alternative means to carry out the decommissioning of each area of the facility, including the criteria used to evaluate the alternatives for the project and justification of the preferred alternatives that were proposed (such as environmental contingencies, technical complexity, cost).

Review of the environmental assessment and proposed decommissioning plan is conducted by specialist CNSC staff in consultation with other responsible federal agencies such as the Department of Fisheries and Oceans, and Environment Canada. Saskatchewan Environment and Resource Management, the provincial environmental regulatory agency, also conducts a comprehensive review as part of their licensing process for the facility. After the comprehensive review of the environmental assessment and proposed decommissioning plan, and when regulatory concerns and comments are addressed, the final decommissioning plan is developed by the licensee and submitted with the decommissioning licence application [10].

The final decommissioning plan in support of the decommissioning licence application includes specific detail on issues such as engineering, quality control and monitoring. The final decommissioning plan includes an assessment of the short and long term environmental impact of decommissioning or the decommissioned facility; post-decommissioning environmental quality criteria; a risk analysis; and, the need for institutional controls.

The case study outlined below describes a project presently undergoing a Comprehensive Study in support of future decommissioning.

4. CASE STUDY

COGEMA's Cluff Lake uranium mine is located in the western part of the Athabasca Basin, 60 kilometres south of Lake Athabasca and 25 kilometres east of the Alberta-Saskatchewan border, in northwestern Saskatchewan, Canada. Fig. 1 presents the site location. Following the conclusion of the first environmental assessment and public hearings in 1978, construction activities began in 1979; mining and milling commenced in 1980. Over the two-decade life of the operation, three environmental assessments and two public hearings were conducted. The licensee has updated the conceptual decommissioning plan four times in the recent past and the Cluff Lake Operation's financial assurance for decommissioning, as of December 1999, is $33.6 million Canadian dollars.

COGEMA submitted a project description for the Cluff Lake decommissioning project to the CNSC [9], initiating the environmental assessment process in support of a future decommissioning licence application. A screening assessment by the CNSC concluded that a Comprehensive Study under the CEAA is required for the Cluff Lake decommissioning project [10]. This detailed decommissioning plan will be reviewed by the CNSC in conjunction with the environmental assessment results; when technical concerns and comments are addressed, the final decommissioning plan will be developed by COGEMA and submitted with the decommissioning licence application [11].

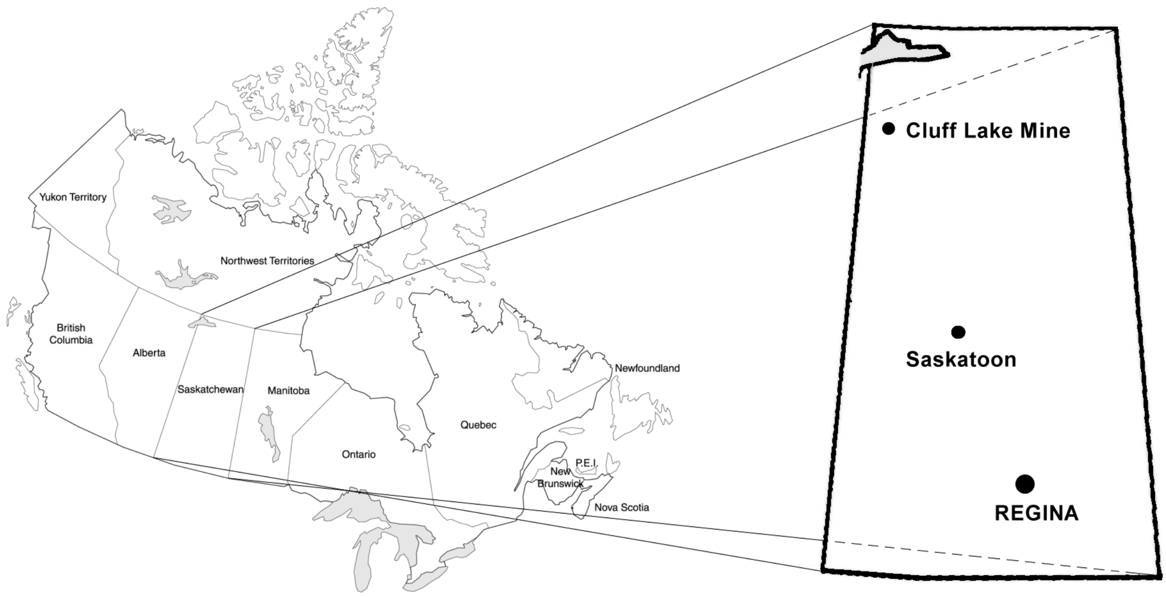

FIG. 1. COGEMA Resources Inc. – Cluff Lake Mine Location.

The Cluff Lake uranium mining facility consists of a mill complex; two underground mines; three open-pit mines; six surface waste-rock storage areas; one surface tailings management area (TMA); an effluent treatment system; and, supporting infrastructure. Fig. 2 presents a sketch of the Cluff Lake mine site. Three main components of the operation are discussed: the tailings management area (TMA), the main waste-rock piles ('DJN' and 'Claude'), and an open-pit ('D-Pit').

The Cluff Lake decommissioning project scope outlined by the CNSC to COGEMA specified the primary elements to be included in the Comprehensive Study report [12]. Decommissioning will include the closure, dismantling, site remediation, care and maintenance, and continued monitoring and surveillance of the TMA, mill complex, open-pit mines, and underground mines. Requirements also include a comprehensive description of the existing facility, including local, regional and site maps showing all key components of the facility. A well-supported assessment of the predicted environmental effects is crucial to the review process. Other information requirements include the spatial and temporal characteristics of the project, the proposed schedule of activities, revegetation programs, a description of recent and ongoing activities, proposed care and maintenance activities and any proposal for long term institutional control.

The environmental impact assessment predictions performed to date indicate that: specific water quality objectives will be met at key waterbodies immediately downstream of the site; the decommissioned site will offer a similar level of aesthetic acceptability and land use potential that existed prior to development; radiation doses are predicted to be less than regulatory limits; soil covers will meet design criteria and erosion-control measures will be in place.

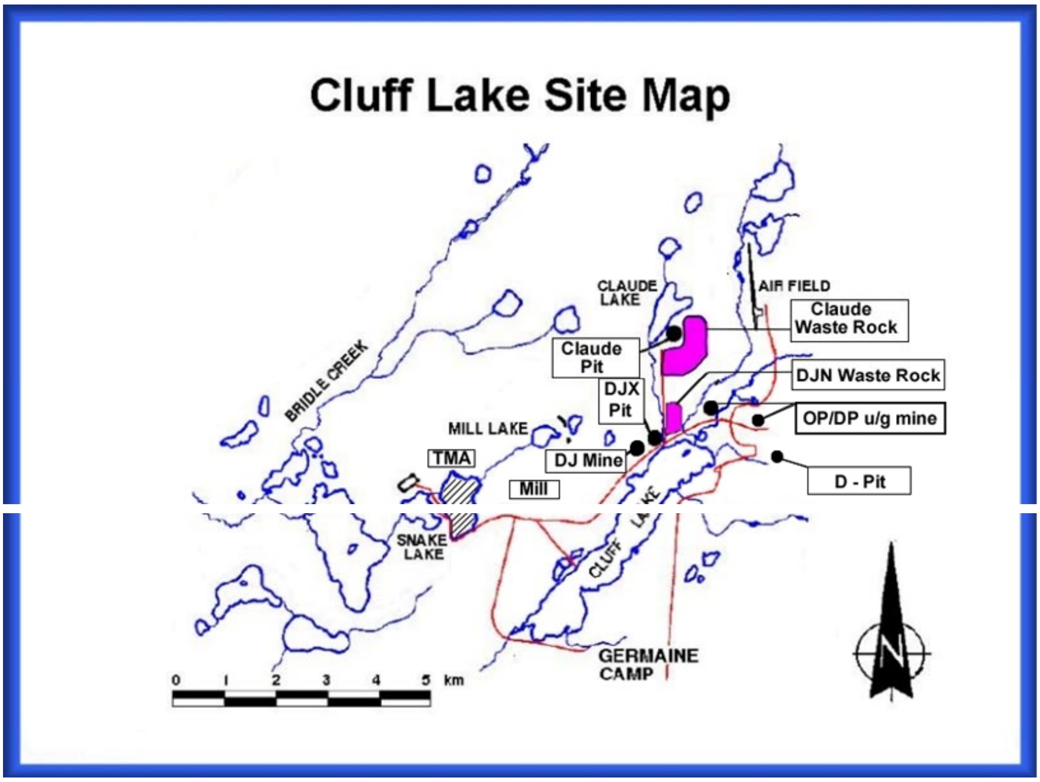

FIG. 2. COGEMA Resources Inc – Cluff Lake Mine Site Map.

4.1. The Cluff Lake Tailings Management Area (TMA)

Cluff Lake uranium mill tailings are generated from the milling, sulfuric acid leach, and lime neutralization of ores from the unconformity and fault-related mineralization of the Carswell Structure in northern Saskatchewan. The Cluff Lake TMA is an engineered surface facility, located in a groundwater discharge area. The nearest water body, Snake Lake, is located immediately southwest of the TMA. Fig. 3 presents a photo of the TMA.

The project scope for decommissioning the Cluff Lake TMA includes surface works, roads, pipelines, treatment systems; quantities and sources of construction materials (sand, gravel, rock); internal tailings drainage mechanisms; analysis of tailings consolidation and predicted settlement rates; detailed geotechnical, hydrogeological and geochemical properties of the tailings; tailings segregation, effects of ice buildup and mitigation measures; long term stability, maintenance, and intrusion resistance of TMA cover; and, existing and future monitoring systems [11]. The main design component of the TMA decommissioning plan is the proposed construction of an engineered earthen cover, using natural materials to ensure long term stability and minimize water infiltration. Computer model scenarios are extended to predict the system behaviour over the next 10 000 years [11].

4.2. Open-pit Decommissioning: 'D-Pit'

The high grade D-Pit was mined out early in the Cluff Lake Operatio's life cycle. Reclamation activities began in 1983 with recontouring of the waste rock generated from mining activities and removal of site surface facilities. The waste-rock area was covered with a layer of local glacial till overburden and revegetated. The groundwater and surface waters in the D-Pit area were monitored extensively since 1985 as part of the mine site licence requirements. The pit has had no detectable effect on the surrounding groundwater chemistry [10]. Native plant species are now invading the area. Decommissioning requirements include a well-supported assessment of the pit's long term water quality and an assessment of the potential effects of contaminant loadings to the receiving aquatic environment using pathways analysis for potential entry of contaminants into aquatic food chains.

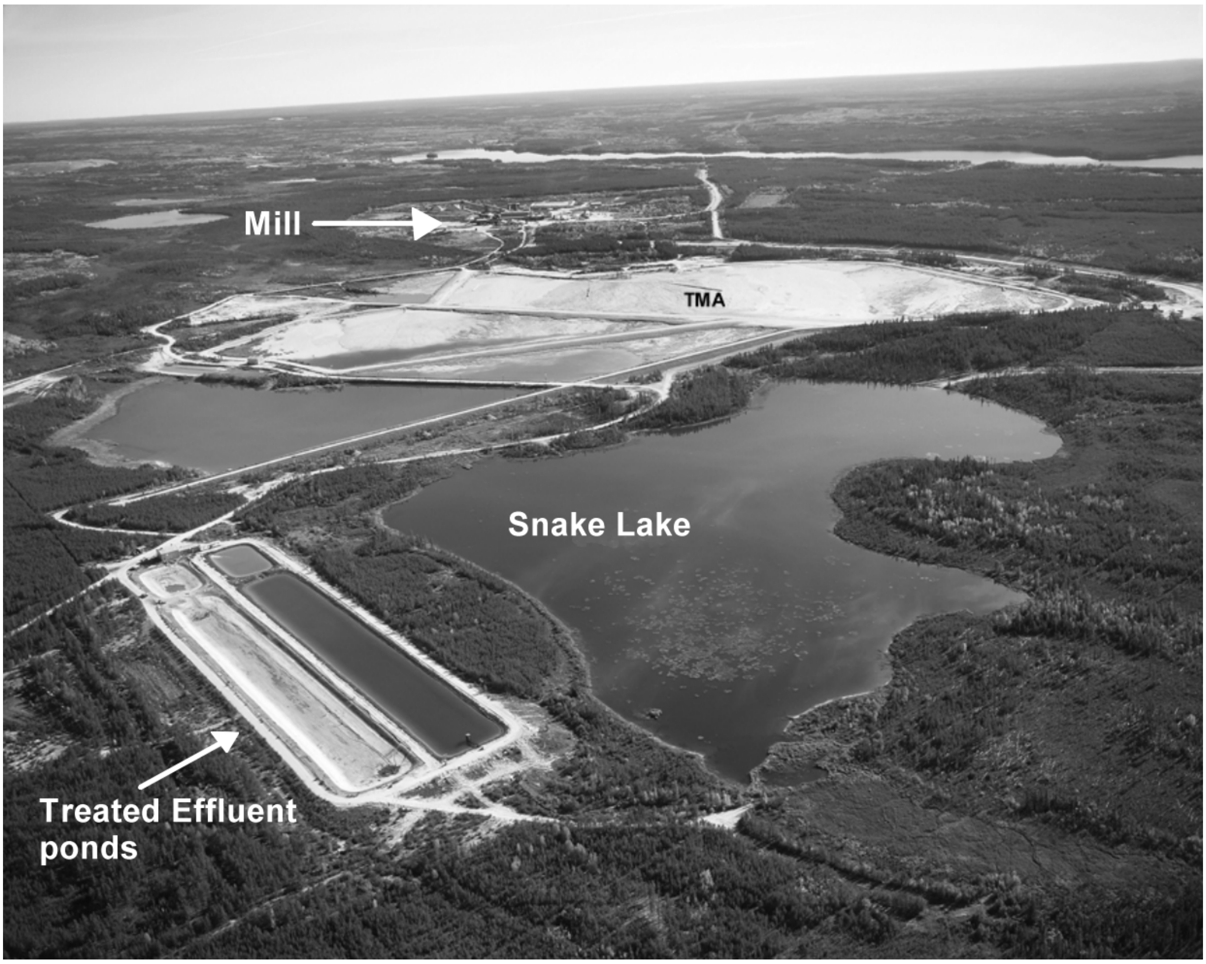

FIG. 3. COGEMA Resources Inc. – Cluff Lake Tailings Management Area (TMA).

COGEMA must assess the options of full or partial backfilling of all open-pits, including D-Pit, flooding options, predicted long term water quality, pit access, drainage patterns, and hydrologic connections to surface bodies. In addition to D-Pit, the DJX and Claude pits are planned for flooding upon closure.

A number of criteria for the final decommissioning plan are under consideration by COGEMA. Flooded pits will have no direct contact with natural watercourses; however, water quality in open-pits may exceed some water quality objectives for certain parameters in the short term.

Upcoming assessment work includes an update of the statistical data review, assessment of source-terms which may affect long term pit water quality, risk analysis of surface waterbodies connected with the pit and risk analysis of remaining in-pit flora and fauna [11].

4.3. Waste rock

The two main waste-rock piles at Cluff Lake, 'Claude' and 'DJN', contain special-waste. Special-waste is mineralized waste rock containing a high sulphur content and uranium concentrations that are uneconomical to recover. Nickel, arsenic and molybdenum concentrations are also present in sufficient concentrations to cause potential environmental concerns. The waste-rock tonnage within the Claude and DJN piles are 7.23 million tonnes and 1.62 million tonnes, respectively [10].

One of the key options under assessment by COGEMA is the installation of an engineered soil cover system for the Claude and DJN waste-rock piles [11]. The Claude waste-rock pile soil cover design

will reduce the potential for acid-rock drainage, reduce mass loading and limit the mobility of key elements such as uranium and nickel. The soil cover system, in conjunction with re-sloping to promote surface run-off will also minimize water infiltration into the waste-rock pile. The DJN waste-rock pile does not appear to have acid-generating potential; therefore, the proposed design is to level the pile and cover with a soil layer to promote revegetation. Detailed characterization of the internal physical and geochemical composition of the waste-rock piles is underway. Future work includes modelling, impact prediction, mitigation, and the development of final design options [11].

5. CONCLUDING REMARKS

The time-line for decommissioning at Cluff Lake is not finalized, because further mining and milling activities may take place into 2002. The CNSC will not move towards a decommissioning licence until the environmental assessment and Comprehensive Study is successfully completed and the detailed supporting information is assessed and accepted. In the interim, the Cluff Lake facility remains under a CNSC Operating Licence.

For further information about the CNSC, our web site is *http://www.nuclearsafety.gc.ca*. For further information about a CEAA Comprehensive Study or its process, please visit the Canadian Environmental Assessment Agency's web site at *http://www.ceaa.gc.ca*.

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Romanian regulatory framework for uranium mining and milling (present and future)

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Abstract. In Romania, all operations in the nuclear field, including uranium mining and milling, are regulated by Law no. 111/1996 (republished in 1998), regarding the safe conduct of nuclear activities. These activities can be performed only on the basis of an authorization released by the national regulatory authority, i.e. the National Commission for Nuclear Activities Control. The specific requirements which must be carried out by the owner of an operating licence for a uranium mining and milling operation are stipulated by the Republican Nuclear Safety Norms for Geological Research, Mining and Milling of Nuclear Raw Materials. These regulatory requirements have been in force since 1975. The regulatory norms include provisions that the effective dose limit for workers should not exceed 50 mSv/year and also that liquid effluents released into surface waters must have a content of natural radioactive elements that meets the standards for drinking water. The norms do not contain provisions concerning the conditions under which the mining sites and the uranium processing facilities can be shut down and decommissioned. The norms also do not contain requirements regarding either the rehabilitation of environments affected by abandoned mining and milling activities, nor criteria for the release of the rehabilitated sites for alternative uses. To implement the provisions of Council Directive 96/29 EURATOM in Romania, new Fundamental Radiological Protection Norms have been approved and will soon be published in the "Monitorul Official" (Official Gazette of Romania). One of the main provisions of these norms is the reduction of the effective dose limit for the workers to 20 mSv/year. Changes in the Republican Nuclear Safety Norms for Geological Research, Mining and Milling of Nuclear Raw Materials, are also planned; these changes will be consistent with the Fundamental Radiological Protection Norms. To cover existing gaps, the new norms for uranium mining and milling will include: (1) closure conditions for mines and processing facilities, requirements for the rehabilitation of environments affected by abandoned mining and milling activities and (2) criteria for the release of remedied facilities and materials for future use. In addition, the new Norms will contain more flexible provisions regarding the release of the liquid effluents from uranium mining and milling into surface waters. These provisions will link the permitted contents to the dose constraints and the category of the receiving water.

1. INTRODUCTION

In Romania, the mining of uranium ore started in 1953 at an important uranium deposit, located near Baita Plai in Bihor County.

The mine was worked for about 10 years; it was operated by the Romanian-Soviet society SOVROMKVARTIT. During this period geological prospecting and exploration were carried out in all the areas in the country with a geological structures favourable to uranium mineralization. This exploration discovered important uranium deposits in the Banat area, which were partially exploited by the same society. All of the high-grade ore, extracted between 1953-1963, was exported to the Soviet Union; both the low-grade ore and the mine waste rock remained at the mine site.

These activities, which had an important negative impact on the environment, developed over about 20 years because there were no specific national legislation to regulate uranium mining activities.

In 1968, a national authority was established to regulate all nuclear activities in Romania. It issued the first regulations (Law no. 61/1974), regarding the safe development of the nuclear activities. Law 61/1974 emphasized the general development procedures for the nuclear activities, it established the principles for monitoring environmental quality and it designated the state institutions that have monitoring responsibilities.

Specific regulations for the uranium mining and milling were issued in 1975, when the Republican Nuclear Safety Norms for Geological Research, Mining and Milling of Nuclear Raw Materials [4] went in force.

2. CURRENT REGULATORY FRAMEWORK

At the present time, all the nuclear practices in Romania are regulated by Law no. 111/1996 (republished in 1998) [1]. It replaced Law 61/1974. Uranium mining and milling still develops under the conditions specified by the specific norms [4] and the Republican Nuclear Safety Norms and the Republican Radiation Protection Norms [7] which went in force in 1975 and 1976 respectively.

The main provisions include the following:

- effective dose limit for the workers exposed to radiation is 50 mSv/year;
- effective dose limit for the general public is 5 mSv/year;
- there are no limits provided for apprentices and students;
- the maximum admissible limit in the air for the equivalent equilibrium concentration of ^{222}Rn (for professionally exposed people) is $0.3 \cdot 10^{-10}$ Ci/dm^3 (1.1 Bq/dm^3);
- the maximum admissible limit in the air for ^{222}Rn, for the general population is $0.03 \cdot 10^{-10}$ Ci/dm^3 (0.11 Bq/dm^3); this limit includes the decay products of ^{222}Rn;
- liquid effluents released by the mining and milling facilities are considered radioactive waste if their natural radioactive elements content exceeds 10 times the admissible limits for drinking water;
- the discharge of effluents which contain natural radioactive elements into lakes or streams is prohibited if the concentrations exceed admissible limits for drinking water.

Table 1 shows a comparison of the admissible concentration limits for natural radionuclides in liquid effluents that can be released into streams in Romania, Germany, the U.S.A. and countries that have adopted the International Commission on Radiological Protection (ICRP) specifications. These data are consistent with PHARE ZZ 9725 ("Underground Mine Rehabilitation Ciudanovita Romania" by Dames & Moore) [5]. Table 2 lists the permissible radionuclide concentrations for drinking water, and Table 3 shows a comparison of the concentration limits for radionuclide elements in air.

TABLE I. EFFLUENT RELEASE LIMITS FOR RADIONUCLIDES

Country	U nat. (mg/l)	Th-230 Bq/l	Ra-226 Bq/l	Po-210 Bq/l
Romania	0.021 (L)	0.04 (L)	0.088 (L)	0.136 (L)
Germany	2.0 (L)	n.a.	0.3 (L)	n.a.
USA	2.0-4.0 (L)	n.a.	0.185 (L)	

L – maximum admissible limit
n.a. – this value was not available and/or it is not known whether it exist in the legislation

TABLE II. CONCENTRATIONS LIMITS FOR RADIONUCLIDES IN DRINKING WATER

Country	U nat (mg/l)	Th-230 Bq/l	Ra-226 Bq/l	Pb-210 Bq/l	Po-210 Bq/l
Romania	0.021 (L)	0.04 (L)	0.088 (L)	0.025 (L)	0.136 (L)
Germany	0.28 (L)	n.a.	0.7 (L)	n.a.	n.a.
USA	0.015 (L)	n.a.	0.185 (L)	n.a.	n.a.
ICRP	n.a.	n.a.	0.37 (L)	n.a.	n.a.

L – maximum admissible limit
n.a. – this value was not available and/or it is not known whether it exist in the legislation

TABLE III. CONCENTRATIONS LIMITS FOR RADIOACTIVE ELEMENTS IN AIR

Country	Rn-222 Bq (m^3)	U nat (Bq/m^3)	Th nat (Bq/m^3)	Ra-226 (Bq/m^3)	Specific Activity of Radioactive Contaminated Dust, (Bq/m^3)
Romania					
Occup.	3700 1110 (RN daughter)	2.2	1.11	1.11	n.l.
Public	111	0.07	0.03	0.111	n.l.
Australia					
Occup.	1221 (Rn daughter)	5.31	11.48	n.a.	n.a.
Public	n.a.	0.18	0.36	n.a.	n.a.
ICRP					
Occup.	1000	n.a.	n.a.	n.a.	n.a.
Public	400	n.a.	n.a.	n.a.	n.a.

L – maximum admissible limit; R – recommendation
n.l. – this value does not exist in the legislation
n.a. – this value was not available and/or it is not known whether it exists in the legislation.

As illustrated in Table 1 the current provisions in Romanian legislation are extremely stringent for the natural radioactive element content of liquid effluents from uranium mining and milling that are released into surface water. The severity of the conditions for the release of the liquid effluents into the environment is due to the fact that the specific norms [4], state as follows: "do not release into open pools or water flows the effluents which contain natural radioactive elements in concentrations higher than the maximum admissible concentrations for the drinking water", but do not specify the values. It is obvious, however, that the norms refer to the maximum admitted concentrations for the drinking water, in force in 1975, when the specific norm [4] was issued. Meanwhile the admissible limits for the drinking water have been significantly reduced. The current norms are 30 times lower, but the link between these norms and the limits for release of the liquid effluents from uranium mining and milling into the environment is still in force. It should also be noted that the current legislation does not address the difference between the requirements for the drinking water and the permissible radioactive element content for other categories of water such as streams or lakes.

Norms [4] define the characteristics that the liquid effluents from the uranium mining and milling must have in order to be considered radioactive waste. These norms follow the drinking water specifications that existed when the Norms were issued. To be considered as radioactive waste, the concentrations must be 10 times the admissible limit for drinking water, and if below these limits the effluents can be released into a public sewerage system. This provision, however, is not applicable in Romania, because the uranium mining and milling operations are located in isolated areas, which have no access to public sewerage systems.

For the drinking water, the admissible limits for the natural uranium and ^{226}Ra are comparable to those in countries with more flexible legislation and important uranium mining and milling activities.

It is obvious that these regulatory provisions concerning the admissible limits for liquid effluents released from the uranium mining and milling cannot be achieved with the current technical equipment in Romania. These limits result from their linkage to the standards for drinking water,

which currently have changed considerably since 1975, when the norms issued. Actually, the accomplishment of these criteria is not economically and socially justified. It would be useful if the new Republican Safety Norms for Mining and Milling of Nuclear Raw Materials adopted more flexible admissible limits for the liquid effluent discharge from these activities.

Another characteristic of the Romanian legislation is the total absence of provisions for the rehabilitation of areas contaminated with radioactive waste from existing or past mining and milling of radioactive ores.

The rehabilitation of these areas is important for Romania because the area covered with uranium mining and milling residues is larger than 1000 ha and is located in nine counties. Over 6 million m^3 of mine waste is stored in about 150 dumps a significant portion of these dumps is made up of rock containing 0.008-0.05% U.

The uranium milling operations have produced about 6 million tons solid radioactive waste with a total activity of about 110 GBq; these wastes are stored in tailing pounds.

Abandoned and operational mines discharge about 10 000 m^3/day of mine water containing up to 3 mg U/l and 0.2 Bq Ra/l. Most liquid effluents are treated before being discharged into the environment. After treatment, their average content is 0.2 mg U/l.

This milling facilities produce an effluent flow of 4000-5000 m^3/day that contains up to 7 mg U/l and 0.5 Bq Ra/l.

Since important quantities of radioactive waste are produced from both current and abandoned radioactive mining activities, the new Norms for radioactive ore mining and milling must provide, updated rehabilitation requirements for the abandoned areas contaminated with uranium mining residues.

3. MAIN CHANGES AND ADDITIONS WHICH ARE TO BE MADE TO THE ROMANIAN REGULATORY FRAMEWORK FOR REGULATION OF URANIUM MINING AND MILLING

The new Fundamental Radiological Protection Norms [2] have been approved and will become effective in September 2000, after being published in the “Monitorul Oficial” (Official Gazette of Romania).

The Norms must comply with the requirements of the Council Directive 96/29 EURATOM [3] and must provide elementary safety standards for the health protection of both workers and the general public against the dangers arising from ionizing radiation.

According to the draft norms, the dose limits are modified as follows:

(a) for radiation workers
  - (i) the limit for effective dose will be 20 mSv/year;
  - (ii) the limits for equivalent dose for the eye lens, skin, hands, forearms, feet and ankles will be as specified in the Council Directive [3].

(b) for apprentices and students, as well as for the members of the general public, the dose limits will be as specified in the Council Directive [3].

The only major change is that the effective dose for radiation workers is more restrictive, because there is no possibility to spread this limit over five years.

The National Commission for Nuclear Activities Control in Romania considers that it will not be difficult to comply with the new limits except at some uranium mining activities, in which the mean

effective does for the most exposed workers is 45 mSv/year. Even when the closure of old mines is taken into account, the mean effective does for the most exposed workers in operating mines remains at 35-40 mSv/year. If mine ventilation is improved, this exposure could be reduced towards 30 mSv/year. Further reduction would result if the present conservative dose-assessment procedures are modified. Finally, if additional actions are required to comply with the 20 mSv/year dose limit, the rotation of workers between posts with different exposure rates will be implemented.

The above actions will require about 3-4 years for full implementation. During this period, even though the new norms will become fully applicable one year after being issued, the regulatory authority will treat the mining activity of the most exposed workers as a situation that justifies special authorized exposures. The reason of this waver, which is permitted by the draft norms [3] is that the Romanian mining activity is considered hard work and the miners retire earlier. Therefore, the life time dose for the most exposed worker will be significantly lower than the dose for a normal European radiation worker. Even taking into account that the doses are received at younger ages, the expected reduction in life expectancy will be less than that anticipated by the Council Directive [3].

Regarding the closure of uranium mines, the interpretation of the regulatory authorities is that the decommissioning activity shall be carried out as a component of the overall mining operation. Therefore, the provisions of the nuclear law and regulatory norms are applicable.

The requirements that must be fulfilled by the owner of authorization for mining or milling are stipulated by the nuclear safety norms for mining and milling [4]. The norms have to be updated, in order to be consistent with the fundamental radiological protection norms [2].

According to these norms [2], a proposal for the derived emission limits must be initiated by the holder of license and approved by the regulatory authority. These limits must ensure full compliance with the dose constraints for members of the public. For example, for the closure of a mine, the regulatory authority plans to impose a constraint of 0.2 mSv/year (or less if the collective dose is too high) for each individual within the critical group. Similar constraints are applicable for the operation of mines. This constraint is based on the 10^{-5}/year standard for an increased frequency of cancer for an individual. These constraints, which are based on a probabilistic risk assessment can be released under some conditions for liquid releases. Currently these releases linked to the standard for drinking water, which is a very rigorous requirement, because the receiving water is generally of lower quality. The requirements for the maximum permissible radioactivity in drinking water remain valid for this category of water. The standards for other categories of water must include standards for radioactivity. Therefore, the emission limits mentioned above must take into account the requirements for both the dose constraint and the observance of the limits established by the standards for the various categories of the receiving waters.

The new norms for uranium mining and milling will specify the radiological protection principles required for the use or release of contaminated areas, buildings, sites or dumps from uranium facilities. This approach will cover the gap in current legislation regarding these activities. The standards and procedures will follow the Recommendations of the German Commission on Radiological Protection [6].

The new norms for uranium mining and milling will recognize the difference between abandoned mines and those closing or to be closed in the near future.

Therefore, to consider the rehabilitation of the uranium mining sites after closure as an intervention only those mines abandoned in the past will be accepted. This procedure follows the provisions of the established norms regarding past practices.

For abandoned mining sites, which have long-lasting exposures resulting from past operations the intervention will be based on dose limits or constraints but on the optimization of radiation protection.

When the radiation source, the exposure pathway and exposed individuals are still present at an abandoned site, the radiological protection norms for intervention must be applied. A single remediation procedure will be justified only if the advantages exceed the disadvantages associated with that procedure. Optimization of the intervention will consist of adopting those measures that produce the maximum benefit at the lowest cost. This remedy must take into account both the economic, social and social economic aspects. Also, the measures must consider the potential environmental consequences from sources other than radionuclides. When remediating abandoned sites, the dosage levels for unrestricted use will be used in order to minimize the individual radiation exposure.

Due to both the magnitude of the consequences of uranium mining and milling and the limited availability of financial resources, the remedial action must not be taken until the question of future use has been decided. A decision might include, for example, use as an industrial site or park, which can be achieved even with the "null-option" that requires no particular remediation measures. All options must be considered including cleaning procedures which will provide alternative measures for each potential use.

Generally, at abandoned mine sites, an effective dose level of 1 mSv/year will be required before unrestricted use of contaminated areas, building, and dumps is approved. This dose will be in addition to the natural background exposure. These remediation criteria follow those recommended in the USA [GILB 85] and Canada [SENE 87]. For unrestricted use of the soil, an average level of 0.2 Bq/g will be used for radionuclides from the ^{238}U series, which includes ^{226}Ra.

The new norms for uranium mining and milling will provide detailed procedures and requirements on how to determine the degree of contamination (depths and areas for measurements, the density of the measurements, the maximum admissible values etc.).

In the case of the mines which are closing, the remediation activity will be designated as decommissioning rather than intervention, and the norms will require a supplementary dose limit of 0.2 mSv/year or even lower if the collective dose is too high.

For the unrestricted use of the reusable equipment and devices a limit of 0.05 Bq/cm^2 total alpha activity will be established.

The new norms for uranium mining and milling will define the radiological release requirements for individual sites, materials and facilities as follows:

- Radiological protection principles concerning the release of scrap from closed uranium mining operations;
- Radiological protection principles concerning the release for industrial use of areas contaminated by uranium mining (the dumps and the tailings pounds are excluded);
- Radiological protection principles concerning the use for forest and agricultural purposes and as public gardens (parks) and residential areas of areas contaminated by uranium mining (the dumps and the tilling pounds are excluded);
- Radiological protection principles concerning the safeguarding and use of mine dumps;
- Radiological protection principles concerning the release of buildings for future commercial or industrial use and the disposal of building debris from uranium mining and milling;
- Radiological protection principles concerning the release for general use of reusable equipment and installations from uranium mining.

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Regulation of uranium mining in the Northern Territory

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Abstract. In Australia, uranium and other 'prescribed substances', including thorium, and any element having an atomic number greater than 92, are the property of the Commonwealth under the Atomic Energy Act 1953. However, the regulation of mining in Australia is managed by the States. The Uranium Mining Environment Control Act, was passed by the NT in 1978 and this remains the primary legislation through which uranium mining is regulated. Under working arrangements with the Commonwealth, the NT carries out regulatory activities including monitoring, evaluation and surveillance, in respect of each of the operating mines. The monitoring is overseen, validated and its continuing relevance audited by the Commonwealth Office of the Supervising Scientist and the Northern Land Council representing the local traditional owners. Environment Impact Assessment is co-ordinated jointly by the Commonwealth and the NT and has recently been concluded for the Jabiluka Project. Delays in final approval on this project are occasioned by social concerns expressed by some of the traditional indigenous owners and anti-nuclear protestors. Although Jabiluka is not in a World Heritage area, the concerns have resulted in intervention by the World Heritage Commission. This has required the Company and the Government to modify the way they handle the approval process. This paper analyses the development of the regulatory system which evolved to ensure best practice environmental, occupational health and safety management on the NT uranium mines.

1. INTRODUCTION

The mining of uranium in the Northern Territory (NT) has been the subject of much debate and controversy since uranium ore was first discovered at Rum Jungle in 1949.

The effects of uranium mining on the NT have been enormously beneficial in economic and social terms, spurring regional development initially at Batchelor and Pine Creek and more recently in the uranium province at Jabiru. There has also been a significant flow-on effect elsewhere in the NT economy. An opportunity now exists to expand on this economic base and develop the considerable known additional resources.

Since the opening of the first uranium mines, the NT has taken a leading role in the development of occupational health and safety standards for miners as well as environment protection and rehabilitation practices. Extensive monitoring of the Nabarlek and Ranger Mines by numerous bodies has not identified any significant impact on the environment or threat to human health that can be attributed to uranium mining. This fact illustrates the effectiveness of the regulatory processes administered by the NT Government.

2. HISTORY OF URANIUM MINING IN THE NORTHERN TERRITORY

2.1. Background

The major known uranium deposits in the NT are all located within the Alligator Rivers Region (ARR), which covers about 22 500 square kilometres in the north-east portion of the Pine Creek Geosyncline. This region also contains the 20 000 square kilometre Kakadu National Park which surrounds but does not include the Ranger, Koongarra and Jabiluka deposits (Fig. 1).

Uranium was located at Rum Jungle in 1949 at a time when the mineral was eagerly sought on the world market primarily for the development of nuclear power and weapons technology. The initial discovery led to a uranium rush throughout the Territory with occurrences being identified in the South Alligator, Westmoreland, Adelaide River and Tennant Creek Regions. The discovery between 1969 and 1971 of the Nabarlek, Ranger, Jabiluka and Koongarra deposits reactivated interest in the

NT with much of the enthusiasm being subsequently lost due to adverse Commonwealth Government policy. In 1971 the Commonwealth Government imposed a freeze on exploration and development of the Alligator Rivers Region deposits to enable a regional development and orderly resource exploitation policy to be established. There has been negligible exploration done since that time and the resource exploitation is limited at the moment to a single mine, Ranger.

The origins of the Northern Territory regulatory regime began with the Ranger Uranium Environmental Inquiry (RUEI) in July 1975. It was required to report to the Government on probable environmental consequences of mining the Ranger deposits, and also to make recommendations as to what should be done. Following the production of a very detailed Environmental Impact Statement (EIS) by Ranger, public hearings began in September 1975 and evidence was received from 303 witnesses. The first report released in October 1976 found that the objections to the mining and sale of uranium based on perceived risk of nuclear war were not such as to justify a decision not to develop Australian uranium mines provided the activities were properly regulated and controlled. The second report was released in May 1977 and dealt with the environmental aspects of the Ranger project.

The review and recommendations of a second RUEI formed the basis of the Commonwealth Government's decision to allow the project to proceed. The Environmental Requirements (ERs) originating from the review were attached to a Section 41 Authority to Mine under the Atomic Energy Act 1953 and a Section 44 Agreement with the NLC under the Aboriginal Land Rights (NT) Act 1976.

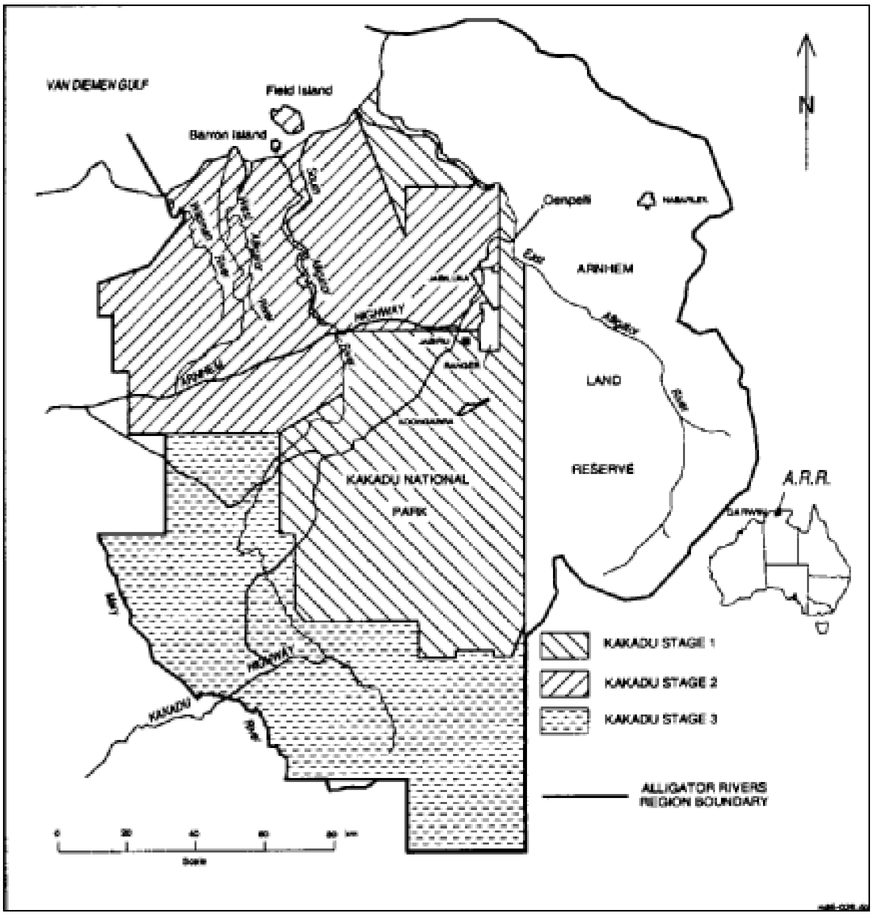

FIG. 1. Map of the Alligator Rivers Region showing Kakadu National Park and uranium mine leases.

In 1978, the NT was granted self-government and immediately passed the necessary legislation to enable the proposed new mines at Ranger and Nabarlek to proceed including the Uranium Mining (Environment Control) Act 1979 (UMEC). The ER's were subsumed within NT legislation as a schedule of UMEC. Under a Memorandum of Understanding with the Commonwealth, the new mines were to be regulated using the provisions of the new NT legislation. The Commonwealth retained a "watchdog" in the form of the Office of the Supervising Scientist (OSS) to overview the process and to conduct research through the Environment Protection (Alligator Rivers Region) Act 1978.

Mining of the Nabarlek deposit commenced in May 1979 and mining was completed in 128 days. The milling operation was completed in 1988. Approximately 14 000 tonnes of uranium oxide were recovered at an average ore grade of 2.3%. The total value of sales from this mine alone was about 1 billion dollars.

Ranger is located about 260 kilometres east of Darwin and within the ARR. Ranger commenced mining in 1980 with reserves of around 120 000 tonnes uranium in two orebodies, known as Ranger #1 and Ranger #3. The Ranger mine, and directly linked activities, accounted for no less than 7% of the whole of the NT's economic activity over the 11 years between 1981–82 and 1991–92. By June 1992 a total of $304 million (in 1991–92 money terms) had been paid to Aboriginal groups from the Ranger project [1]. This underlies the importance, from a cashflow perspective, of uranium mining to indigenous peoples.

3. LEGISLATION

Both Commonwealth and NT legislation are applied to uranium mining projects in the ARR. The powers of government used in the Northern Territory are not necessarily applicable anywhere else in Australia. The NT administers its responsibilities principally through UMEC using the Department of Mines and Energy (DME) as a “one stop shop”.

3.1. Principal Commonwealth Legislation

3.1.1. Environment Protection (Impact of Proposals) Act 1974

This Act empowered the Commonwealth Government to inquire into the effect that a proposed operation might have on the environment and to make recommendations concerning the environmental conditions to which approvals and authorizations for a project should be subject. The Act has been replaced by the Environmental Protection and Biodiversity Conservation Act 1999.

3.1.2. Environmental Protection and Biodiversity Conservation Act 1999

This Act provides for protection of the environment, especially those aspects of the environment that are matters of national environmental significance and to promote the conservation of biodiversity and ecologically sustainable development through conservation and ecologically sustainable use of natural resources. Requirements for environmental approvals relate to matters of national environmental significance; activities on a declared World Heritage property or a declared Ramsar wetland; impact on listed threatened species and communities or listed migratory species and nuclear actions. These issues all coincide in the uranium province.

3.1.3. Atomic Energy Act 1953–1966

This Act empowers the Commonwealth Government to authorize the mining and milling of uranium ores subject to such conditions as it deems necessary. Part III of the Act refers to the Ranger project and allows for the Minister to Authorize mining for prescribed substances, on behalf of, or in association with the Commonwealth.

3.1.4. Environment Protection (Alligator Rivers Region) Act 1978

This Act established a 'Supervising Scientist' who has the power to:

- Carry out research and collect information relevant to the protection of the environment;
- Develop and/or advise on the development of standards and practices for the protection of and restoration of the environment;
- Co-ordinate and supervise the implementation of environmental protection requirements imposed by other legislation and
- Advise the Commonwealth Government about any of the above matters.

3.1.5. Environment Protection (Nuclear Codes) Act 1978

This Act gives the Commonwealth Government the power to produce "Codes of Practice", in association with the States/Territories and to make regulations to ensure that these codes are observed.

Three codes have been produced:

- Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores 1987;
- Code of Practice for the Safe Transport of Radioactive Substances 1982;
- Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores 1982.

The Act was repealed in 1998 and replaced by the Australian Radiation Protection and Nuclear Safety Act.

3.1.6. Aboriginal Land Rights (NT) Act 1976

The Act provides for the granting of traditional Aboriginal land in the Northern Territory for the benefit of Aboriginals, and for other purposes. It essentially prohibits an operator from seeking minerals or mining on Aboriginal land until he has concluded an agreement with the land council concerning those things related to the mining operation which may affect Aborigines.

3.1.7. The Environment Protection (NT Supreme Court) Act 1978

This Act gives the NT Supreme Court the power to make orders, at the suit of either the Commonwealth or Territory Parks and Wildlife organizations or the Northern Land Council (NLC), with respect to any relevant legislation which is pertinent to the protection of the environment in those parts of the Alligator Rivers Region in which they have a legitimate interest.

3.2. Principal NT Legislation

3.2.1. Uranium Mining (Environment Control) Act 1979

This is the prime Act for the day-to-day regulation of the uranium mining industry in the NT. The key to its operation is the requirement that "the owner or manager of a mine shall not construct or use any works, processes or equipment with respect to mining except with and in accordance with conditions of an authorization".

Authorizations under the Act, and any conditions attached to them, can be altered or revoked at any time but must be consistent with any conditions imposed under the Control of Waters Act and the Soil Conservation and Land Utilization Act.

The Act further stipulates that when issuing an authorization, primary consideration must be given to:

- Terms contained in any agreement between the mining company and the NLC, and
- The conditions attached to the relevant mining lease. In the case of Ranger and Nabarlek these are ERs attached as schedules to the Act. When exercising any power conferred on him by the Act, the Minister shall have primary regard to these ERs.

The ERs cover such areas as:

- Ensuring the numbers and qualifications of environmental protection staff are adequate
- Control of water such that radioactive materials should not be removed or allowed to escape from site except under approved conditions
- Atmospheric pollution control
- "Best practicable" technology (BPT) must be used
- Waste rock dump design and final rehabilitation programmes have to be submitted for approval
- Methods of blasting are to be approved and all blast levels monitored
- Vegetation and landscape protection
- A continuous monitoring programme to include measurements in relation to biota, water, sediments and air within the project area includes both personnel and environmental monitoring
- The company is to provide research programmes as directed by the government.

3.2.2. Environmental Assessment Act 1982

This Act provides for the assessment of the environmental effects of development proposals and for the protection of the environment.

3.2.3. Mine Management Act 1990 and Regulations

All mines in the NT are subject to the provisions of the Mine Management Act (MMA). All aspects of mining activity are covered including the environment, health and safety, engineering principles and mining practice to Australian Standards and Codes of Practice. This Act is now under review.

4. REGULATION OF NT URANIUM MINES AND PHILOSOPHY OF COMPLIANCE

Regulation of uranium mining and milling is effected principally through the MMA and UMEC.

The "philosophy of compliance", agreed between the NT, the Commonwealth and the mining companies, provides for the companies to comply with specified operating requirements, including a comprehensive monitoring regime, and to demonstrate their compliance through a reporting programme. This monitoring in turn is overseen, validated and its continuing relevance and adequacy audited by the DME in consultation with the OSS and relevant NT authorities.

4.1. Technical, Advisory and Supervisory Committees

In addition to the extensive monitoring programmes conducted by the companies and the DME, numerous committees assess and revise BPT and resolve technical issues on environmental matters and proposals for each uranium mine.

4.1.1. Alligator Rivers Region Advisory and Technical Committees

A Co-ordinating Committee for the ARR was replaced by an Advisory Committee (ARRAC) and a Technical Committee ARRTC) by amendment of the Commonwealth's Environmental Protection (Alligator Rivers Region) Act in 1994.

ARRAC is a forum for information exchange between the mining companies, government authorities of the NT and the Commonwealth, and environmental, Aboriginal and community groups. ARRTC examines the research needs of the region, recommends research programmes, and examines methods for the efficient co-ordination and integration of research.

4.1.2. Minesite Technical Committees

Minesite Technical Committee (MTC) meetings are chaired by the NT with committee members representing DME, OSS, the NLC and the respective mining company. Other parties with specialized contributions to make may be invited to attend specific meetings.

4.1.3. Ranger Water Management Working Group

Ranger Water Management Working Group meetings are chaired by Energy Resources of Australia (ERA) and are convened as required to review proposals for water management. ERA, OSS, NLC and DME are represented on the committee.

4.1.4. NT Legislative Assembly Sessional Committee on the Environment

The Sessional Committee on the Environment meets on an ad-hoc basis to gather information with which to advise the Legislative Assembly. The Committee conducted a major review in 1992 [2] and a one-day inquiry in 1996 into the environmental impact of uranium mining and milling in Australia and the effectiveness of environmental protection measures. The last review undertaken by the Committee was in 1999.

4.2. Monitoring programmes

Aquatic pathways are the most likely conveyors of any pollution from mine sites in the tropics (in which all the NT's uranium mines are situated) and downstream aquatic ecosystems and local communities are the major potential casualties. A primary emphasis of environmental monitoring has been to ensure the protection of aquatic ecosystems. Although environmental protection from water pollution is best provided by engineering controls, physico-chemical monitoring by ERA and DME of both underground and surface waters, plays a major role in detecting problems.

4.3. Water release

The Ranger Uranium Environmental Inquiry (Fox Report) [3] (p 89) stated that “The possibility that contaminated water from the mine site might cause environmental damage downstream was one of the main arguments advanced against the proposal”. Nevertheless, less than 10% of the report addressed the issue of water management. Evidence put before the second RUEI, which it admitted contained inaccuracies and inconsistency, and its resulting recommendations, can now fruitfully be analysed with the benefit of hindsight.

The construction of dams to retain accumulated runoff water from around the mine site was not considered to be good engineering or environmental practice by the original mine designers and they proposed a system of silt-traps on undisturbed catchments, which overflow naturally, together with controlled release of water which ran off potentially contaminated catchments. Specific recommendations were included in the ERs as to how such controlled releases should be managed. This strategy was essentially supported in a review of Best Practice for Water Management undertaken by the Supervising Authorities in 1986. Despite this, the only releases which have taken place from the Ranger site have been from uncontaminated catchments.

Receiving water standards were developed for Magela Creek using information from ecotoxological studies, accepted water quality guidelines and in some instances from a statistical analysis of the

natural waters. A biological monitoring programme was established, using protocols developed by the OSS, to ensure the safety of the downstream ecosystem from any release from the mine.

Surplus runoff from the ore stockpiles and process plant areas is dispersed by wetland filtration and land irrigation which, together with natural evaporation have generally been sufficient to ensure that there has been little accumulation of water passed from one year to the next.

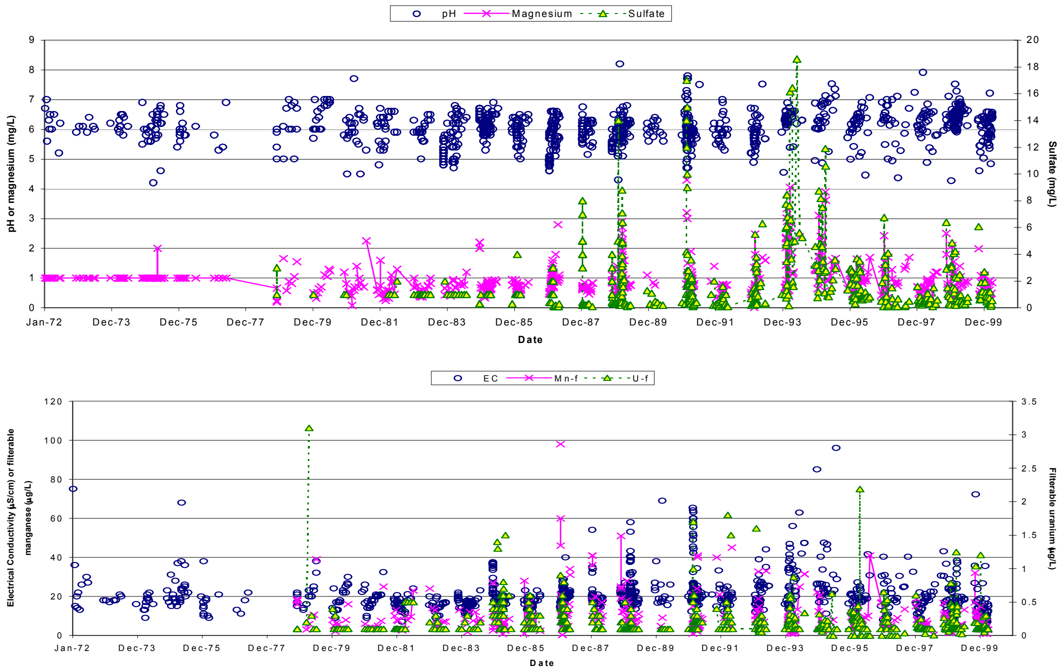

FIG.2. Water quality over time downstream of Ranger Uranium Mine.

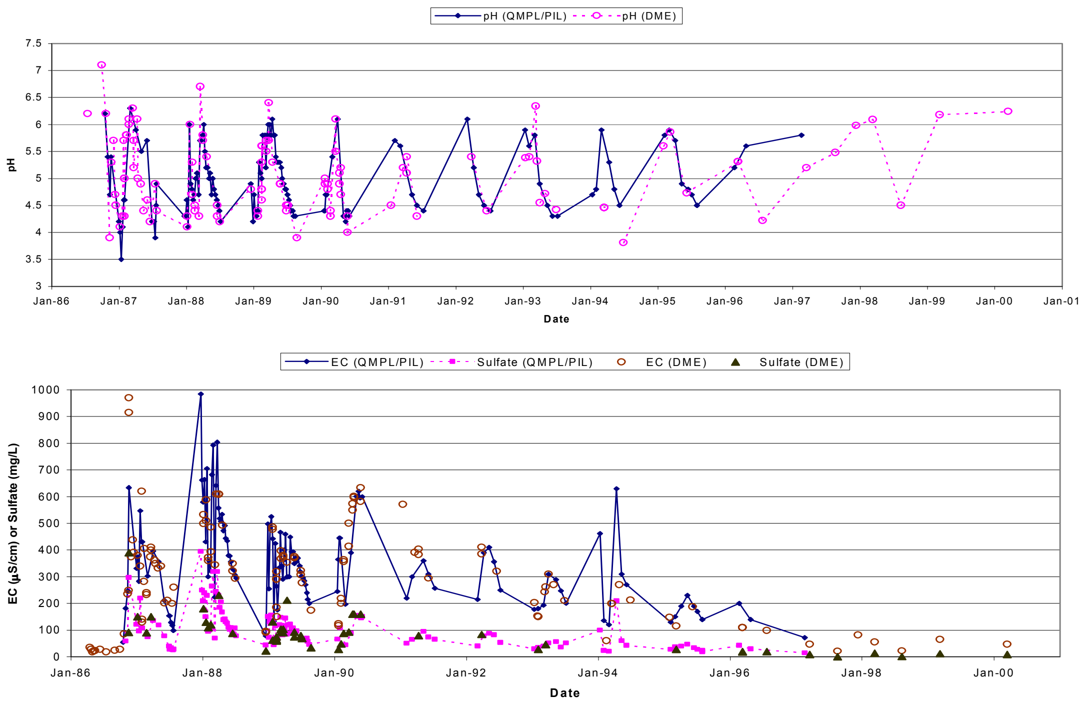

FIG. 3. Conductivity, sulfate and pH in Kadjirrikamarnda Creek, downstream of the former Nabarlek Uranium mine.

Site waters at Nabarlek were never released directly into the local creek system and evaporation was the main means of water reduction. Heavy rainfall in 1984 and 1985 meant large volumes of water were being stored and land application was introduced to disperse the excess water. The groundwater which was affected by the land application was intensively monitored and results to date show a decline in the solute levels is occurring over time.

5. IMPACT OF URANIUM MINING AND EFFECTIVENESS OF MONITORING

There has been no significant impact from uranium mines in the NT on downstream surface water quality (Figs. 2 and 3). All potential contaminants show little or no upward trends with time, and are below suggested criteria in Water Quality Standards manuals [4, 5]. Billabongs on the Ranger site itself show some impact, most particularly Djalkmarra Billabong.

Land application of minesite derived waters has been of concern at Ranger with respect to the impact of such a practice on the ground and surface water catchments. Water first passes through a constructed wetland filter or is irrigated before entering a billabong. Wetland sediments very effectively attenuate uranium, so that uranium concentrations in the billabongs have remained low. Data from land application at the former Nabarlek Uranium mine have shown that groundwater catchments recover quickly.

DME monitoring programmes and their efficiency have been extensively reviewed and continue to be reviewed periodically. The mining company monitoring has also been extensive and precise and thus the database on uranium mines in the ARR clearly shows trends in impact over time.

5.1. Public perception of uranium mining and environmental protection

In 1986, the Milton Committee investigated Ranger's water management system after a blatant dramatization in the media via elements of the environment movement. A constant misreporting of events, particularly by the Australian Broadcasting Corporation (ABC), has continued relentlessly often regurgitating previously incorrectly reported information.

Little coverage was given of the high level of scientific agreement between the OSS, DME and the mining companies on technical matters. Disagreements, mainly on procedural matters, which are highlighted in the overview of the OSS reports or from NGO press releases, tend to be covered in detail. When this information is taken without qualification, the media reports erroneously lead one to the conclusion that the ARR is in grave danger of destruction.

The misreporting has led to a view of the Australian public that the Ranger uranium mine causes damage to, or at least poses a threat to Kakadu National Park and there are clearly those who capitalize on this view.

Allowing that there may be some difference of opinion on details, those scientists and others charged with the responsibility of assessing the environmental performance of the mine have not found any evidence of environmental detriment to Kakadu National Park resulting from the past 20 years of operations at Ranger. Scientists have also not been able to quantify any realistic threat to Kakadu National Park from the operations. The Northern Territory Government and OSS Annual Reports have expressed general satisfaction with the level of environmental protection being achieved.

Clearly a huge credibility gap exists. It is therefore important to examine and understand why the difference between the general public's concern and the lack of quantifiable evidence to support that concern has arisen. To do so it is necessary to follow the path of information from the mine to the general public and investigate whether appropriate standards of professionalism are being employed in its transmission. If the misinformation results from a deliberate programme then it would also be instructive to understand why.

One reason for confusion may have arisen because both the media and the environmental movement see uranium mining as an issue of social/political conflict and the topic is newsworthy for that reason. The Ranger mine has all of the necessary ingredients for a good story – aboriginal issues, the nuclear debate, health and safety matters, Commonwealth/NT relations, industrial relations and of course environmental impact. All of the above have been addressed in the past by media-inspired public inquiries or significant reviews and all have shown that the Ranger mine is neither unusual nor performing badly for an operation of its type.

5.2. Occupational health and safety of mine workers

The occupational health and safety of workers in recent NT uranium mines has been extensively managed and studied. The record of the industry is excellent.

In 1987 Ranger held a 4-Star Health and Safety Management System Award from the National Safety Council of Australia. The mine achieved the maximum 5-Star rating in 1993, the only mine in Australia to have achieved this rating.

Ranger has participated in an initiative whereby the mining industry has adopted responsible self-regulation in relation to lost time injury frequency rates. Each mine develops its own specific safety framework while the role of the DME is to approve practices and provide guidance where necessary. By its performance in reducing the lost time injury frequency rate, the industry has proved the value of this approach. The DME conducts regular system and performance audits on the Ranger mine and a culture of safety and continuing improvement has developed on the mine.

5.3. Radiological considerations

Of the potential worker hazards on uranium minesites, radiation is the issue which is the most thoroughly researched, best understood and for which the best quantitative tools exist for modelling. The current maximum permissible dose (in addition to background) to radiation workers is 50 milliSievert per year and 20 mSv/year over five years.

The average background dose to people in the Jabiru region is about 2 to 3 mSv/year. Background doses vary dramatically due to frequent occurrences of uranium mineralization on or near the ground surface. The Australian public is exposed to an average background dose of 2 mSv/year, which is quite low by international standards.

The average dose (above background) to the most exposed workers at Ranger during the last five years was 6, 4.6, 5, 4.1 and 4.8 mSv/year respectively. About two-thirds of the dose is caused by radioactive dust, the remainder coming from external gamma radiation and radon daughters.

5.4. Radioactive dust management

Monitoring at Ranger has shown that by far the largest component of dose arises from radioactive dust. Dust reduction techniques have been devised, such as regular haul road watering and strict housekeeping in the mill, which reduce dust levels and reduce radiation doses.

At present, all radiological reports received from the mine are analysed and, where necessary, discussed with ERA. On some occasions, specific recommendations concerning radiological matters are made to ERA.

5.5. Impacts on communities adjacent to mines or mill sites

The current maximum permissible dose (in addition to background) to the general public is 1 mSv/year.

For communities near the Ranger Mine, detailed studies on radiological impact have shown that the mine is producing only a marginal increase in dose to the general public of about one tenth of a millisievert per year which is similar to a single diagnostic chest X ray.

6. SUMMARY

The value of potential uranium projects in terms of regional development, Aboriginal development and general wealth creation in the NT is huge. Uranium mining has been and can be conducted in the NT in a manner which is safe and environmentally sound. This paper demonstrates that:

- uranium mining in the NT is now conducted under environmental controls which are among the strictest in the world.
- the industry has a high level of commitment to the health and safety of those involved in, and affected by, the process of uranium mining and milling.
- the environmental controls and the commitment to the health and safety of those involved in, and affected by, uranium mining have resulted in minimal detriment and substantial benefits.
- history reveals the NT experience in meeting the challenges associated with uranium mining and in adapting to technical and social change so as to make the best use of available resources and assure environmental protection and quality of life for present and future residents.
- The Government is a leader in applying the multiple land use concept. The Government's record in facilitating Aboriginal involvement in resource development, in park management and, most particularly, in environmental protection, is second to none.
- the NT Government views uranium mining as an effective tool in ongoing regional development of the NT.

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POSTER SESSION

Natural radiation at the Cerro Solo U-Mo deposit (Argentina)

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This paper presents results of work done to establish baseline levels of natural radiation in the vicinity of the Cerro Solo U-Mo deposit, prior to proposed uranium mining activities. This was accomplished through a number of Comisión Nacional de Energía Atómica (CNEA) and International Atomic Energy Agency (IAEA) supported activities, including reprocessing and back-calibration of 1978–79 airborne gamma ray spectrometry data (1) and acquisition of new ground gamma ray spectrometry data.

The Cerro Solo U-Mo deposit is located in Chubut province in the southern Patagonia region of Argentina at 43º 20’ south latitude and 68º 45’ west longitude, at 630 metres above sea level. The deposit occurs as conformable layers and lenses within Cretaceous sandstone and conglomerate of Los Adobes Formation (Chubut Group). These units represent a high-energy fluvial system. The mineralized horizons occur between 60 and 120 metres below surface. Cretaceous tuffs of Cerro Barcino Formation (Chubut Group) and Jurassic andesitic rocks of the Lonco Trapial formation complement the main local geology. Regionally, a thin soil horizon is developed from the underlying bedrock.

In 1978–79 the CNEA collected, under contract, approximately 100,000 line kilometres of multi-parameter (gamma ray spectrometry and total field magnetic) airborne geophysical data (1) between $42^o – 47^o$ S and 67^o $30^/$–70^oW. The survey was flown at a line spacing of 1 kilometre with a gamma ray detector volume of 48 litres. Stacked profiles and contour line maps were produced from the corrected counts for potassium, uranium and thorium. In cooperation with the IAEA and the Geological Survey of Canada (GSC) the original archive data from this survey was reprocessed and back-calibrated (2) to produce a corrected digital archive to be used for ongoing and future geological mapping, mineral exploration and environmental radiation monitoring. To support regional interpretation of the airborne geophysical data, ground gamma ray spectrometry was conducted at selected sites. These follow-up investigations established the radioactive element characteristics of the main lithologies present in the study area.

For both the airborne and ground gamma ray spectrometry data, the natural exposure rate is computed from the following equation assuming equilibrium conditions (3):

exposure rate (μR/h) = 1.52 K% + 0.63 eU ppm + 0.31 eTh ppm

Figure 1 shows the distribution of total natural radiation expressed as exposure rate in μR/h combined with the digital terrain model for the area around the Cerro Solo U-Mo deposit. Exposure rate levels range from 0 μR/h over water to 16 μR/h associated with rhyolites of the Marifil formation. Considering a 4km by 4km area around the deposit, the average exposure rate value computed from the archived line data is 7.41 μR/h. Table I summarizes the airborne gamma ray spectrometry data for the area around the Cerro Solo deposit. The results of the ground gamma ray spectrometry investigations are presented in Table II.

TABLE I. SUMMARY STATISTICS FROM AIRBORNE DATA OVER A 16 KM^2 AREA SURROUNDING THE CERRO SOLO DEPOSIT.

	n	range	mean	std. dev.
K %	889	0.38 - 5.23	2.24	0.67
eU ppm	881	0.26 - 92.93	2.07	5.52
eTh ppm	884	0.16 – 21.25	9.61	3.27
Exposure μR/h	876	2.97 – 39.95	7.41	2.26

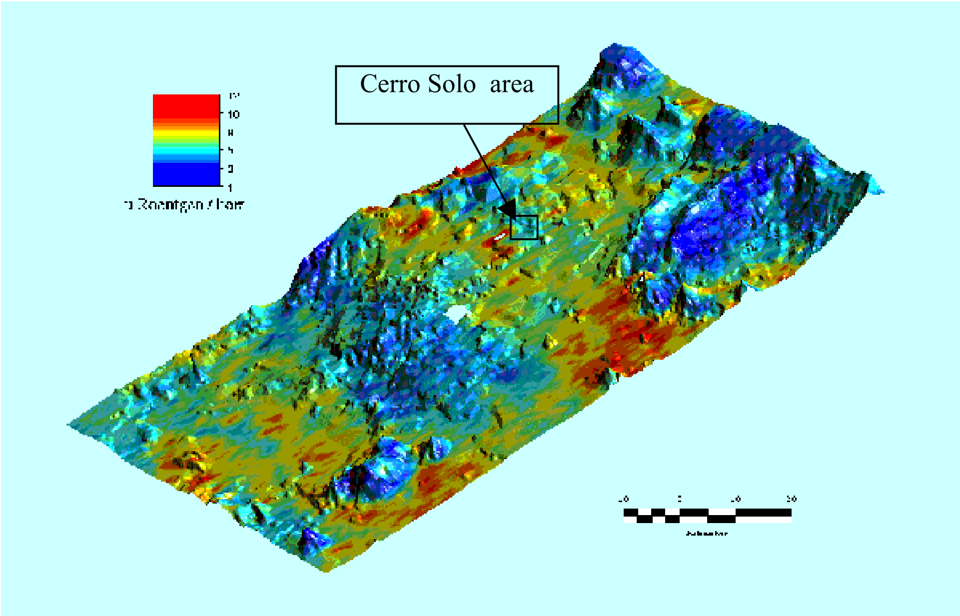

Figure 1. Regional exposure rate map.

TABLE II. AVERAGE RADIOACTIVE ELEMENT AND EXPOSURE RATE VALUES FOR SELECTED LITHOLOGIES, DETERMINED USING GROUND GAMMA RAY SPECTROMETRY.

Rock Type (n)	Exposure Rate (μR/h)	K% (%)	eU (ppm)	eTh (ppm)
andesite (3)	5.36	2.3	0.8	4.4
rhyolite (4)	14.30	4.8	2.9	17.0
sandstone (2)	12.29	4.0	3.9	12.2
tuff (4)	4.80	0.5	4.0	4.7
area soil (7)	5.42	0.8	2.7	8.1
Cerro Solo cover (5)	7.12	2.2	2.1	4.4

The concentrations of radioactive elements derived by ground gamma ray spectrometry compare closely with the corresponding airborne levels. For example, cover material around the deposit has an average ground exposure rate of 7.12 μR/h. This is similar to levels derived from the airborne data (7.41 μR/h). The average ground exposure rate for rhyolites of the Marifil formation is 14.3 μR/h, which also compares closely with the computed airborne value of 16 μR/h.

In support of environmental radiation monitoring associated with proposed uranium extraction, these results demonstrate that the regional airborne gamma ray spectrometry data can be used to establish pre-mining, baseline radioactive element levels.

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Sustainability of new uranium mining projects in Argentina

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Abstract. The regulatory framework issued in the 1994-1995 period, connected mining activities in Argentina with international good environmental practices. Agreements between National Government and Provinces allow the application of the regulations, while Act N° 24.585, the milestone about the matter, establishes the steps for the approval of the Report of Environmental Impact, on successive stages of the project. Specifically for uranium mining and milling, the assessment of the radiological protection aspects of the planned activities is assigned to the Nuclear Regulatory Authority.

The National Atomic Energy Commission is at present carrying out two uranium mining projects, that involve the Sierra Pintada and Cerro Solo deposits. The goal of them is restart uranium production in the country in the medium term, by lowing the gap between indigenous and market uranium prices.

The first one consists in updating the feasibility study of the, at present inactive, Sierra Pintada Production Center (Mendoza Province). Studies for improving the mining and treatment methods are performed in the project, co-ordinately with the investigation and forecast of mining waste and processing tailings management. Besides, the procedures will be determined taking into account the methodology to be applied when getting the closure stage, about the existing waste and tailings.

Development of the Sierra de Pichiñán District, Chubut Province (U-Mo), is the objective of the second project. It is remarkable that about Cerro Solo, the main ore deposit belonging to this area, at the prefeasibility stage, CNEA is currently encouraging private investment through a bidding process. Environmental studies are an important aspect of the activities carried out and planned in the area.

As a conclusion, with regard uranium mining and milling activities in Argentina, the regulations and environmental technical-scientifical knowledge are becoming friendly with the sustainable practice.

Phytoextraction of low level U-contaminated soil

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The nuclear fuel cycle may be a source of environmental contamination. Uranium exploitation produces large quantities of wastes but also accidental spills at nuclear fuel production, reprocessing or waste treatment plants have led to soil contamination with uranium. U-contaminated soil is generally excavated, packaged and removed which is a costly enterprise. Soil washing has also shown promising in removing U from contaminated soil, but results in the generation of liquid wastes and the deterioration of soil properties. In contrast, phytoextraction, the use of plants to remove contaminants from polluted soil, allows for in situ treatment and does not generate liquid wastes. Furthermore, the contaminated site is covered by plants during phytoextraction and wind and water erosion will be reduced.

The phytoextraction potential depends on the amount of radionuclides extracted and the biomass produced. Hyper-accumulating plants often have a low biomass production. Moreover, uranium soil-to-plant transfer factors (TF: ratio of U concentration in dry plant tissue to concentration in soil) rarely exceed a value of 0.1 gg^{-1}. With a TF of 0.1 gg^{-1} and a biomass yield of 15t dry weigh ha^{-1} only 0.1% of the soil uranium will be annually immobilised in the plant biomass. These figures clearly show that the phytoextraction option is not a feasible remediation option, unless the uranium bioavailability could be drastically increased. It was shown that citric acid addition to highly contaminated U contaminated soil increased the U-accumulation of *Brassica juncea* 1000-fold [1].

The objective of present paper is to find out if low level U contaminated soil can be phytoextracted in order to achieve proposed release limits.

1. MATERIALS AND METHODS

The U-contaminated sandy soil was collected from spot contamination at a nuclear fuel processing site. A portion of the soil was already washed with bicarbonate in order to extract part of the uranium. The total α activity is 1.61 Bq g^{-1} for the control soil and 0.47 Bq g^{-1} for the bicarbonate treated soil. The ^{238}U levels are 0.0317 and 0.069 Bq g^{-1}, respectively. The proposed exemption limit for release level is 0.3 Bq g^{-1}.

Perennial ryegrass and Indian mustard were selected for phytoextraction since they generally show the highest TFS. For each of the plants, six 1-L pots were filled with control and bicarbonate treated soil. Seven days before the harvesting date, citric acid (25 mmol kg^{-1} soil) was applied to three of the six pots. All plant samples were oven-dried (70°C), dry weight (DW) was recorded and ^{238}U content determined.

2. RESULTS

Biomass production was significantly lower on the bicarbonate tread soil. Treatment of the control soil with citric acid resulted in a significant yield decrease of 22% and 15% for mustard and ryegrass respectively. Yield decrease was not significant following citric acid treatment of the bicarbonate soil (Fig.1A). Dry weight production in t per ha can be calculated from the dry weight per pot, culture time (1 month for ryegrass, 1.5 months for mustard) and an effective growing season of 6 months.

The TF on the control soil was 0.012 g g^{-1} for mustard and 0.073 for ryegrass. On the bicarbonate treated soil TFs are about a factor 15 higher. Though the citric acid addition decreased biomass production, it increased the U-transfer to the plants up to 1000 fold. The increase in TF is higher for the control soil than for the bicarbonate treated soil. The highest TF were observed for mustard with a TF of 7.64 g g^{-1} on the control soil and 6.27 g g^{-1} on the bicarbonate treated soil. For ryegrass TFs were 2.77 and 5.10 g g^{-1} respectively.

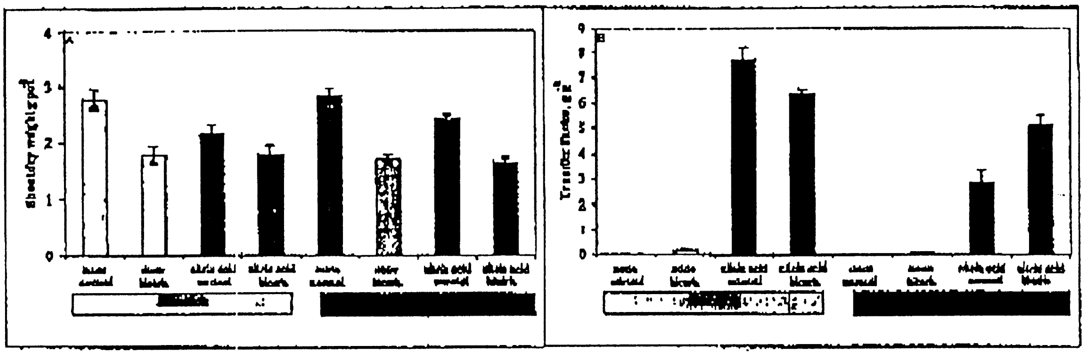

FIG. 1: Dry weight production (A) and ^{238}U transfer factors (B) for ryegrass and mustard grown on control and bicarbonate treated soil, with or without amendment of citric acid.

3. DISCUSSION AND CONCLUSIONS

With biomass production (t ha^{-1}), the extraction percentage can be calculated. The figures in Table 1 clearly show that it is impossible to phytoextract a substantial fraction of the soil U without citric acid amendment. Following citric acid addition up to 4.6% of the soil U can be extracted annually. Given the low total alpha activity of the bicarbonate treated soil (0.45 Bq g^{-1}), we only need a 66% reduction in soil U to attain the release limit of 0.3 Bq g^{-1}. With an annual extraction of 3.5 or 4.7% it would take about 11 or 9 years to attain this reduction. For the control soil a 5-fold reduction in contamination level is needed, requiring more than 30 years.

TABLE 1: PERCENTAGE U ANNUALLY PHYTOEXTRACTED BY MUSTARD AND RYEGRASS

Soil	**Citric acid**	**Mustard**	**Ryegrass**
Control	No.	0.009	0.007
Control	**Yes**	**4.624**	**2.810**
Bicarbarbonate treated	No	0.102	0.052
Bicarbarbonate treated	**Yes**	**3.095**	**3.477**

Citric acid treatment of U contaminated soils, potentially makes phytoextraction of these soils a feasible remediation option, which is not the case for unammended soils. Important uncertainties remain however, e.g. growth potential after repeated citric acid application to soil, U uptake by more adults plants etc. Furthermore, the phytoextraction approach involves costs at different stages (crop establishment, harvest, treatment of contaminated biomass) and this for the total period required for the phytoextraction. These costs should be carefully calculated and compared with the cost of other remedial options.

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Radiological characterization on the industry of phosphate in Brazil with emphasis on the ITATAIA project

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The Brazilian resources of phosphatic rocks represented by its 15 principal deposits, are roughly of 3.84 billion tons, containing about 430 million tons Of P_20_5, 698,888 tons Of U_30_8 and 1,421,000 tons of $Tb0_2$ and a concentration radioactive average of ***3,600Bq/Kg***.

The annual production of phosphatic rocks is approximately 21 million tons correspondent to an annual activity of the order of ***$2x10^{14}$Bq*** of the which 85% are from alkaline rocks that contain thorium and uranium in their composition and they answer for an accumulated activity distributed in the several products industrialized along the last 30 years is about ***$6x10^{15}$Bq*** and in the same period, they were produced about 40 million tons of gypsum, corresponding to an activity of **$5,3x10^{13}$Bq**, owed the contribution of the ^{226}Ra and ^{228}Ra mainly.

In the quality of comparison, the mine of uranium of Poços de Caldas produced in all your useful life about 1,123 tons of U_30_8 equivalent to an activity of ***$4.1x10^{13}$Bq***.

The mine and milling activities cause ecological risk that are translated by alterations in the ecosystem and that happens during the implantation phases, operation and decommissioning of the enterprise. In the specific case of the industry of phosphate, it should be considered the impacts still caused by the presence of radionuclides of the series of the ^{238}U and ^{232}Th, that will be present in the several segments of the industrial process, affecting direct or indirectly the ecosystem. The natural leaching of the present radioactive elements in the ore is a particularly important process, mainly for the performance of the sulfuric acid present in the process with the liberation of liquid and gaseous effluents and also due to the mobilization processes that happen eventually in the departures; in the storage ore; in the open pit; in the waste basin and in the stock piles of gypsum.

The uranium, thorium and radium associated with the fertilizers phosphated during its application, pollute the soil, the water and the air, being this industrial segment one of the largest responsible for the contamination of the environment. About 90% of the phosphate products obtained in the Brazilian industry is for production of phosphate fertilizers, destined to the application in the agriculture and it is considered that, approximately 21 million hectares of its soils receive annually a radioactive concentration of the order of ***400KBq/ha,*** of which about 10% can be assimilated by the vegetables, entering in the alimentary chain and causing radiological risk to the human bodies.

The ITATAIA Project as planned by Industrias Nucleares do Brasil S/A-INB, it is the only in national terms, that has as objective the production of phosphoric acid and uranium in the form of diuranate of ammonium (yellow cake).

The ore reserves that will be mined is equivalent to 80 million metric tons, containing about, 9 million tons of P_20_5 and 80 thousand tons of U_30_8.

The ITATAIA deposit is one of the biggest in the world and consequently the soils of the area are configured as natural radioactive sources, exposing the antropic, biotop and physical environment to the production of liquid and gaseous effluents and radioactive dust. In the last years the ITATAIA Project was object of several studies in the scale pilot, seeking to obtaining of radiometric parameters,

so that the impacts that can happen during the implantation of the industrial enterprise and the measures necessary to minimize for the radiological protection can be appraised.

The measures of doses obtained in the research phase presents value of 2.4mSv/y until a maximum of 31,4mSv/y. The exposure rate measured in a radius from 20km of the deposit, ranges from ***20µR/h*** to the ***40µR/h*** and maximum of ***500µR/h*** and of ***1,600µR/h*** inside of the research galleries. The levels of radon measured in the galleries reach values of up to ***2.3WL,*** falling at normal levels with ventilation only forced reaching values of the order of ***0.3WL***. As samples of waters of the research galleries they present concentrations of the order of ***7.4Bq/l*** and the concentration alpha measured in the superficial and underground waters they locate below ***0.37Bq/l***. The soils present concentrations of ***1,439Bq/kg.*** The measures of concentrations alpha and beta in the ashes of the vegetables of the proximities of the deposit the concentrations presents value of ***1.4Bq/g*** and ***10.5Bq/g*** respectively.

About 964.200 tons of ore, containing 17% of P_20_5, 1384ppm Of U_30_8 and 140ppm of TbO_2, will be sent to the mill annually. The ore will be attack with sulfuric acid, with the objective to produce 150.000t/y of phosphoric acid and 700t/y of U_30_8, with a final recovery of approximately 52,5%.

In the industrial process about 47,5% of the radionuclides of the series of the uranium and thorium will accumulate in the waste rocks products mainly in the fine fraction below 400 mesh and that correspond to an annual loss of approximately 634 tons of uranium and of its descendants, generating an activity of approximately, ***$22x10^{13}$Bq,*** should demand measured to minimize, for the protection of the environment, the critical points of the project and allowing the radioprotection to the worker and the local population. Besides, the production of phosphoric acid should generate about 500.000 tons of gypsum demanding special cares of storage, in view of the high radioactivity concentration in this product, could reach values of up to ***11.65KBq/kg,*** due to presence of the ^{226}Ra ^{228}Ra in your composition. It is considered an exposure rate for the piles of gypsum of the order of ***220µR/h*** and a flow of radon of approximately ***110Bq/l.***

Below are presented in the quality of comparison, some of the principal radiological parameters of several products of the industry of phosphate of Florida and of the 'industrial Project of ITATAIA.

Factor	Florida	ITATAIA
Grade of U_30_8 in the ore	160ppm	1384ppm
Grade of $Th0_2$, in the ore	10ppm	140ppm
Radioactive Concentration in the Ore	1.56KBq/kg	13.73KBq/kg
Radioactive Concentration in the Phosphoric	1.86KBq/kg	16.31KBq/kg
Radioactive Concentration in the Gypsum	1.33KBq/kg	11.65KBq/kg
Exposure Rate in the Ore	86µR/h	752µR/h
Exposure Rate in the Gypsum	30µR/h	220µR/h
Absorbed Dose in the Ore	478nGy/h	4,164nGy/h
Absorbed Dose in the Gypsum	165nGy/h	1.210nGy/h

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Radiation protection optimization in the CAETITE industrial complex

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Abstract. This paper presents, briefly, the radiation protection aspects of process, project and operation of the Caetite Industrial Complex, CIC.

Planing priorities were to minimize Environmental Radiological Impact and Occupational Radiological Risk - Based on previous experiences, the process and the project were optimized, in order to minimize environmental impact and allow simultaneous natural environment restoration and operation. Technical, practical and economical advantages became evident during all project fazes, from the initial project development to the conclusion of all decommissioning steps.

Planing, conducts. adequate working methods and workers training, together, turned out to be the most efficient way for occupational radiological risk reduction. This efficiency was proved during operational tests and initial operation of the Complex.

Radiation Protection optimization is achieved by worker's responsibility, turning safety corrections interference less frequents, rising consequently, minimizing environmental impact.

Evaluation of radon release from uranium mill tailings in Eleshnitca, Bulgaria

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Rn-222 emanation coefficients and Rn-222 soil-gas concentrations have been determined for uranium mill tailings in Eleshnitca, in order to estimate the Rn-222 exhalation and the contribution of this source to the total outdoors Rn-222 concentrations in the valley.

The region has been a center of uranium mining and milling industries from 1956 to 1996. The processing plant and the mill tailings are situated very near to the living area. The highest risk in this region is due to Rn-222 and Rn-222 progeny inhalation. The exposure due only to outdoor sources of Rn-222 was found to be 0.9 WLM per annum [1] and the gamma background was 2–3 times the average for the country.

The Rn-222 emanation coefficients for tailings have been measured and the effect of size fractions, moisture and disaggregation was studied.

The emanation coefficients vary with the size fractions.

A great rise in emanation coefficients has been occurred for the samples with higher moisture content. The emanation coefficients for water-saturated tailings were slightly higher then those for dry materials.

The soil-gas concentrations measured in depth 1m by a method of Lucas cell [2] are shown in Fig.1. They vary from 0,59 to 12 MBq m^{-3}. Highest values were obtained for the wet zone of the tailings. The high values of Rn-222 concentration were also observed at the borders of the site where the finer fractions have been deposited.

This results are in good agreement with laboratory measured Rn-222 emanation coefficients as a function of grain size and moisture content of the samples.

The Rn-222 and gamma dose mapping has been done on the basis of the results obtained for Rn-222 soil-gas concentration and gamma dose on the surface of the tailings.

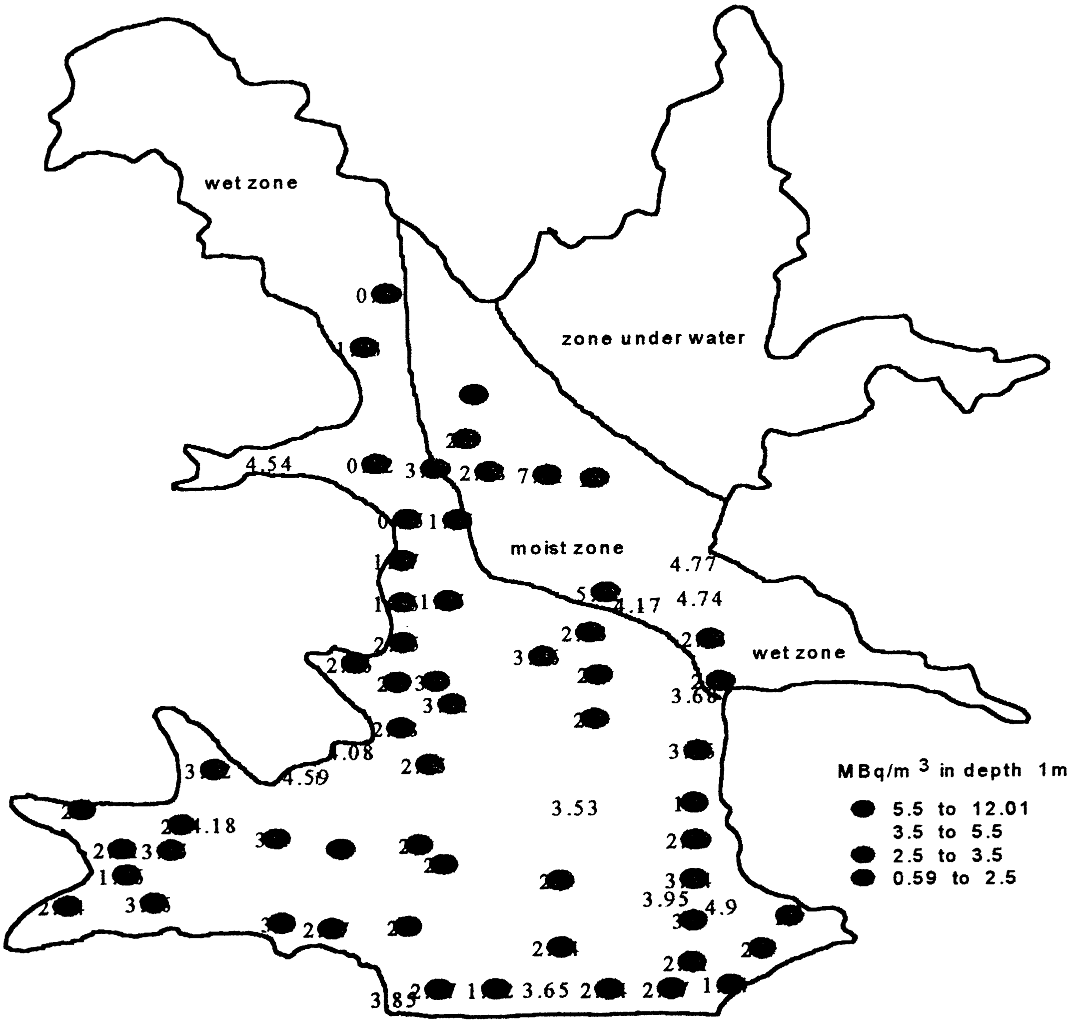

FIG.1. Rn-222 soil-gas concentration map on the Eleshnitca uranium mill tailings.

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Control of remediation of uranium deposit Stráž with use of numerical modelling approach

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The chemical mining of uranium on the deposit Stráž has caused large contamination of groundwater of cretaceous collectors in Stráž block of Northbohemian cretaceous table. The low cenomanian aquifer where the uranium deposit is placed is mainly afflicted. In the cenomanian collector there is now more than 4.8 mil. t dissolved solids mainly SO_4^{2-}, Al, Fe, NH_4^+ etc. The total salinity reaches up to 80 g/l. The upper laying turonian collector is drinking water reservoir for larger region. Its contamination is weaker than in cenomanian collector.

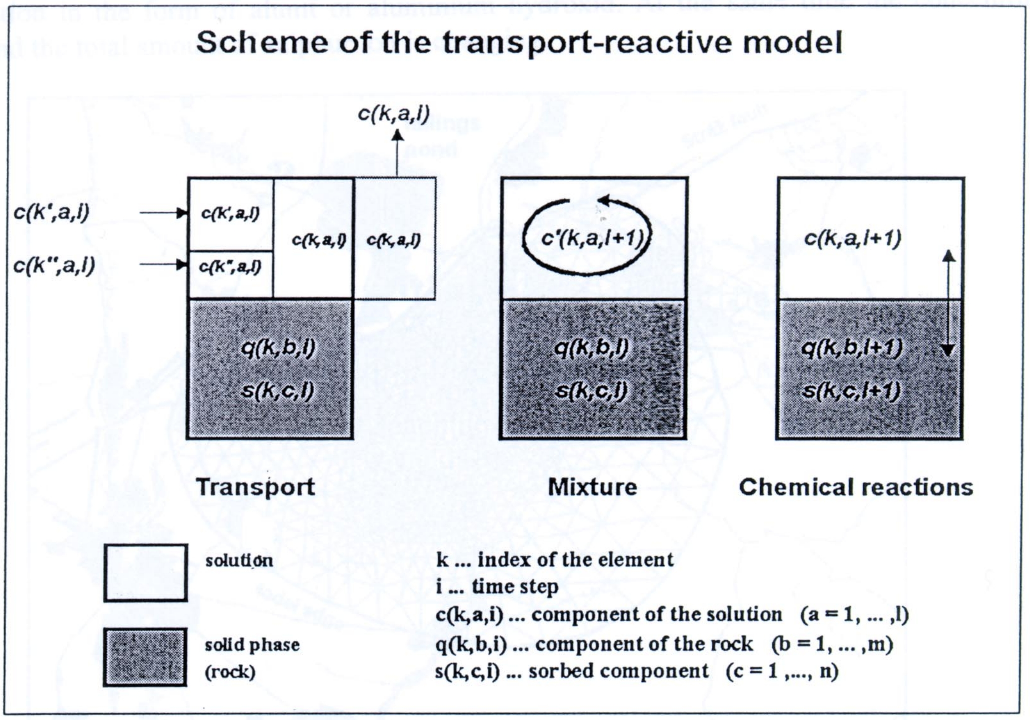

Fig.1: Scheme of the transport-reactive model

Use of complex 3D Transport – Reaction Model can be divided into two separate parts. First modelling step is a quantification of overflow between individual mesh elements calculated out of calibrated mixed-hybrid flow model. Two different types of mathematical models are used to accomplish the task:

- Flow model based on a primary formulation of finite element method, which calculates spatial distribution of piezometric head and flow velocity vectors in selected points of area considered (finite element mesh nodes). This model exactly describes hydraulic situation in area studied.
- Flow model based on mixed-hybrid formulation of finite element method. This model strictly complies with exact water balance at inter-element faces.

In the second part transport-reaction model based on finite volume method is used for calculations using pre-calculated advective velocity field in the area considered.

The finite-element mesh covering about 40 km^2 consists of about 16 000 spatial elements. In the leaching fields area the length of the triangular edge is 100 – 150 meters, vertically the horizon is split into 9 – 13 layers. The geological boundary-lines were constructed from a database containing information about almost 10 thousand wells. Permeability parameters are defined on the bases of hydrogeological model calculations (calibration) and their vertical distribution is defined more precisely using the GTIS (Geotechnological Information System) data. The initial conditions (the concentrations of contaminants in solution) in the leaching field area are defined from the monitoring wells.

Chemical processes are solved by two different methods. A decay of caolinit caused by the sulphuric acid is solved using the thermodynamic-kinetic model. This model was developed from the balanced thermodynamical model for solutions and rocks of the Stráž deposit. The thermodynamic system of the balanced model consists of 18 main components of solution, 32 minerals, 110 chemical reactions between the solution components and 44 reactions between minerals and the solution. The main components of the solution can occur in 184 different forms. In the first stage the kinetic model was reduced to 5 components and 11 equations. The model solves a leaching of Al from the rock and its precipitation in the form of alunit or aluminium hydroxid. At the same time the concentration of H_2SO_4 and the total amount of sulphur ion is changing.

To decide the strategy of abstraction pumping, it is necessary to have an overlaying model describing an operation of the devices on the surface, evaluating the costs of remediation and calculating the contaminants removing.

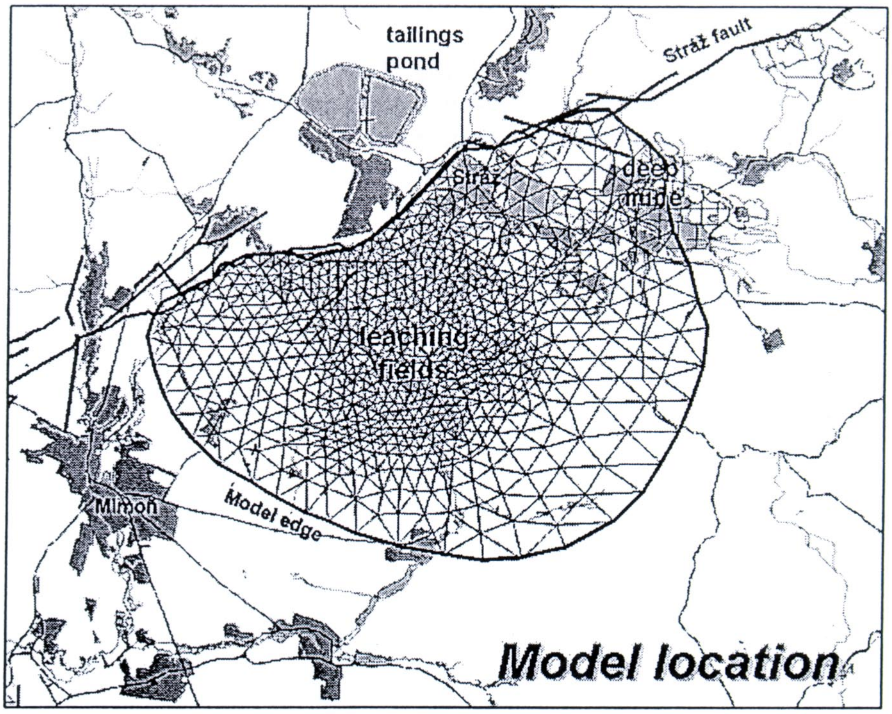

Fig. 2: Finite-element mesh and its location

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Numerical modelling of ISL process in Stráž uranium deposit

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The pilot plant experiments were realised in 1967 and afterwards the rapid progress of this mining method followed in parallel with research works and the gradual solution of the technical and technological problems. A great number of the original technological and technical devices for the proper production and the following remediation of the affected area have been developed during the years. Vast experience has been gained in the methods of optimisation of the mining process and control of underground hydraulics over large area (designing and operation of hydraulic barriers, pumping centres, etc).

In the deposit Stráž there are very difficult conditions for ISL. Part of the deposit is composed of badly leachable hydrozirkonium ores, part of well leachable ores occurring in even worse permeable rocks. Owing to these conditions it has been necessary to use the acid leaching with the high batches of sulphuric acid. An effective time for the process in some parts of the deposit has been more then 20 years. Under these conditions it has been impossible to optimise an exploitation without mathematical models.

A fairly detailed model description of the deposit is necessary for successful modelling. The model has to contain information about the permeability of different layers of a geological profile, information about rock composition, about the types of ores, and distribution of the ores in the geological profile. Chemical reactions of the leaching process are usually slower then the global flow of the solutions in the Stráž deposit. The leaching process is heavily depended on the acidity of the leaching solution in the case of some ores. The kinetic functions enable to model both main reactions, uranium leaching and the reaction of acid with the rock, under continually changing conditions in the orebody.

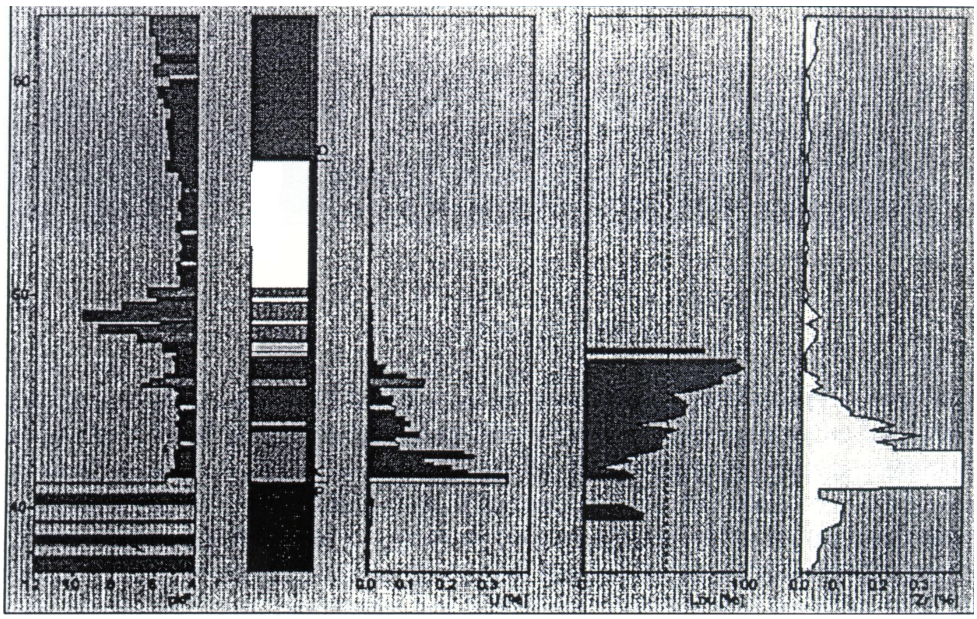

Fig. 1. Example of well assessment.

TECHNOLOGICAL WELL

The lab tests and core well technological assessment methodics were worked out for the modelling needs, the mineable reserves estimation and the mining schedule selection purposes. The lower ore-bearing profile part is sampled in steps (10cm). The capping non-bearing parts of the elder wells were not sampled at all. The new ones were sampled at 0.5–2 m. Besides chemical analysis, standard tests of the sulphuric acid consumption are performed for each sample and leachability standard tests for each sample with the ore-bearing balance. The lab assessment of the filtration coefficients kxy, kz was performed for 5–10% of the samples and the values for the rest were counted acc. to the regression coherence with the Al and Ti content for the area given.

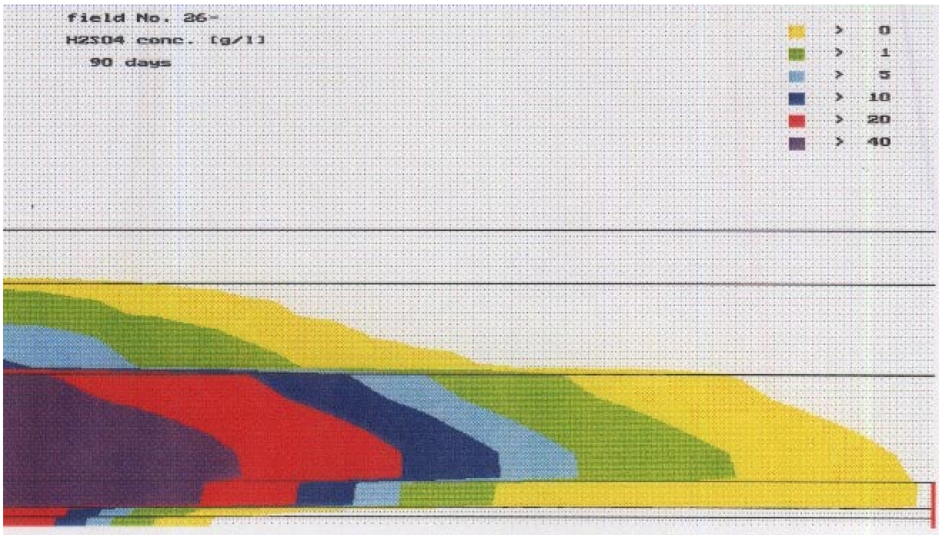

FIG. 2. Example of model results.

Each sample is then subjoined to one of the 23 technological types. Classification is performed acc. to the position on the geological profile, the permeability, the metal volume and the leachability. All of the data is summarized in the data basis system GTIS. This system performs an automatic well interpretation proposal based on the input data. The interpretator will use these results and will perform the interpretation based on the comparison with neighbour wells. At the same time some mistakes, which are either going out from the geological documentation subjective character or they appeared during the primary data processing, are found and corrected and the areas with the core loss are completed.

KINETIC FUNCTIONS SETTINGS

The area assessment begins with creating geotechnological cuts along the core well lines. The interpretation is performed in the interactive graphic mode. Eventual issues coming out of the geological documentation subjective substance are treated during this definitive interpretation. Also other experiences from the parts not directly contained in the databases — e. g. small tectonics with the shifts amount to several meters are used. Separate samples are put together creating higher group levels, usually lithotechnological segments and layers. A sample mixture is then taken (with the proportional representation acc. to the thickness in separate layers) for long term lab test purposes.

The test objective is to gain a kinetic description of the 2 main reactions: sulphuric acid consumption and uranium leaching. The homogenized sample mixture is divided into several columns through which differently composed solutions go (the content of the acid, oxidants and other salts eventually) and sometimes at different temperatures too. The liquid phase analyses are performed at the kinetic points 1, 3, 10, 100, 300 and 1000 days.

3–8 samples and 3–6 solutions are evaluated for separate areas. The mathematical formula of kinetic functions will be derived from these curves. It is possible to use the kinetic functions of the sooner examined analogic rock and ore types for the preliminary evaluation and the clue is the micro test data file. The quantity of results enables the transfer of lab results achieved on the crushed rock into real underground conditions.

NUMERICAL MODELLING APPROACH

3D transport — reactive model based on the finite elements and finite volumes method was developed to model the ISL process. This model is used for the well network optimisation and for the frame leaching schedule definition for the area. This model uses six-sided final elements with 20 nodes in corners and in the middle of the element which enable the triquadratic pressure interpolation. The filtration velocity is derived from the pressure derivations. We estimate the solutions movements for appropriate directions during a time unit using the numeric interpretation of the filtration velocity at the element sides. Considering the quadratic pressure interpolation does not guarantee the continuity of its derivations at the element sides, the counted movements balancing is performed by the least squares method.

The materials transport and the chemical reactions are solved in a separate part of the model. The acid and uranium concentrations in the solution and the reagents and residual uranium concentrations in the rock are counted in separate elements and time steps. Two groups of reactions are considered: the sulphuric acid with rock reaction and the uranium leaching itself. Their process velocity depends on the acid concentration. The reagents are divided into several complexes with different kinetics. The complexes are not defined mineralogically, but technologically only, based on the lab data. The model meets the substance balance at a very precise level.

A model for the concrete area is completed according to geotechnological cuts defining the separate layer thickness, average permeability, uranium content and the acid consumption per 1 t of the rock. The parameters for the reaction kinetics equations of elder fields are estimated according to lab tests and precised according to operational results. As concerning the leaching fields, where the long term tests are not completed, the recovered deposit parts analogy is used there.

For better understanding of the underground processes, it is possible to assess the leaching process on the computer screen.

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Socio-economic and environmental aspects of uranium mining, decommissioning and remediation in the Czech Republic

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Czechoslovak uranium industry became a myth between 1945 and 1990. It connected main features of planned economic system and ideological rules of a totalitarian regime. Its development was connected with declaration of uranium medical use at the end of the 1940s. In the 1950s and 1960s this was replaced by its use for "peace-keeping" needs and after 1970 with its use for developing nuclear energy supply. Anyhow its production has always been much higher then the NPPs demand.

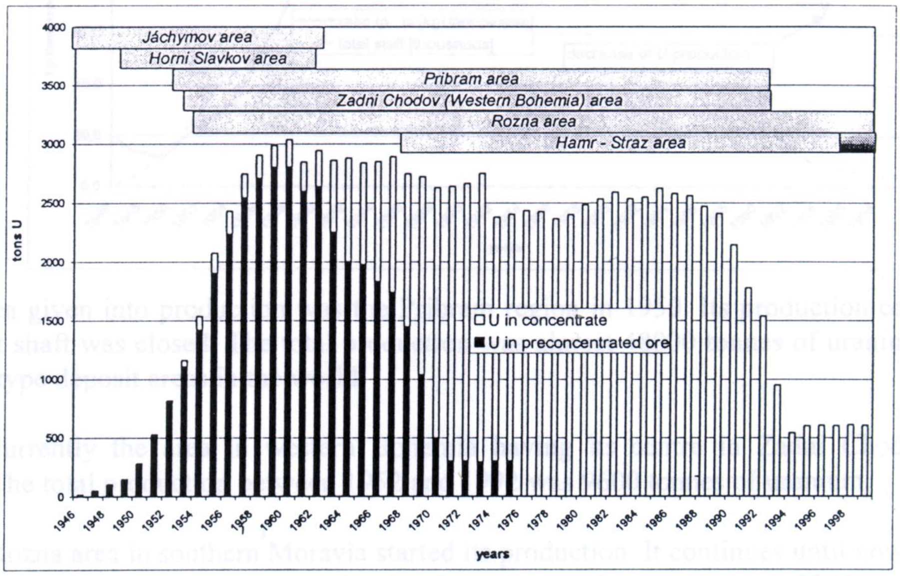

FIG. 1. Uranium production between 1946 and 1999.

Between 1945 and 1999 the total production of Czechoslovakia (almost entirely of the Czech Republic) was almost 108 thousand metric tons of uranium. Based on two-sided long-term agreements almost 100 thousand metric tons of it was exported to the USSR.

Export of pre-concentrated ore started in 1945 and continued till 1975. During the time this was slowly replaced by export of uranium in chemical concentrate between 1953 and 1990.

Industrial uranium production started in 1945 in Jachymov area. This region had been famous in previous silver mining (five-element formation - Ag, Co, Ni, Bi, U). Historically, this region gave the world some world-wide used words like dollar arising from Johannisstaller coins shortened to Taller, used in Czech as tolar and then phonetically reused as dollar in English speaking countries. Also pitchblende (Pechblende in German) as pitchy looking or pity bringing stone, which replaced silver in the depth of silver mines is the worldwide used word. Discovery of radium and polonium by Curies in 1898 set the foundations of a new, use of uranium ores, which were used only for dyeing in glass and pottery until that time.

The Jachymov area was not of a very high industrial importance because of its resources, but of a high political influence. There were practically no operating uranium mines in the Soviet Union zone of influence in 1945. Therefore the Jachymov mines were occupied by the Red Army on September 11,

1945 and total production since that time was shipped to the Soviet Union. Total production between 1945 and 1964, when the mines were closed, was 7000 tonnes of uranium. In comparison with the northern part of the Krusne hory (Ore Mountains), the former GDR part, the total production was less than 10%.

The second production area was situated about 30 km south of Jachymov. It was Horni Slavkov. Its total production was only 2700 tonnes of uranium between 1948 and 1962 and it had no higher industrial importance.

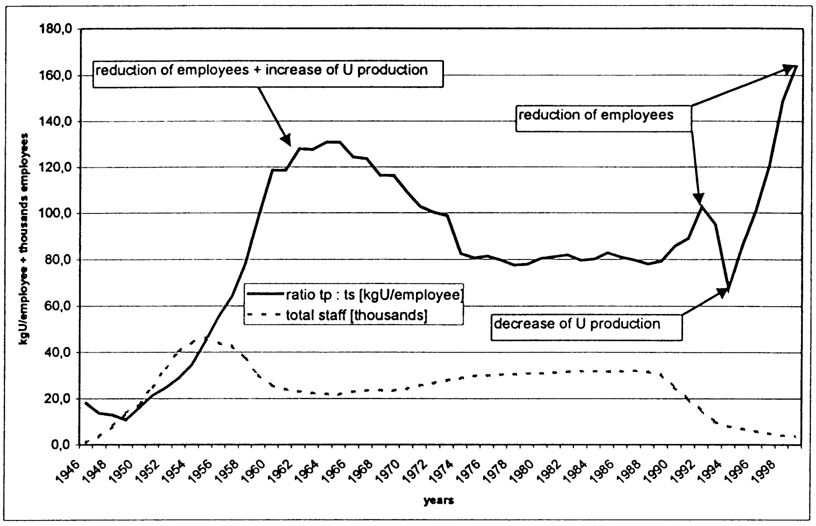

FIG. 2. Uranium production per employee and employment development between 1946 and 1999.

The third area given into production was the Pribram region in 1950. Its production continued until 1992, when the last shaft was closed. The total production was almost 48000 tonnes of uranium. It belongs to the biggest vein type deposit areas in the world.

Almost concurrently the area in western Bohemia having its centre in Zadni Chodov was given into production. The total production between 1952 and 1992 was 9600 tonnes of uranium.

In 1953 the Rozna area in southern Moravia started its production. It continues until now and its close-down is planned for 2001. The total present production from the area has been almost 22000 tonnes of uranium.

TABLE 1: OVERVIEW OF URANIUM DEPOSITS AND OCCURRENCES

Reserves and production	Number of deposit
> 10 000 t U	6
1 000 – 10 000 t U	15
50 – 1 000 t U	22

In total 164 discovered and explored deposits and occurrences, 72 mined

The last and very different area in northern Bohemia was discovered in the middle of the 1960s and was given into production almost immediately in 1967. These deposits are not situated in hard rocks, but in sandstone sediments of Cretaceous age. Two different mining methods were applied – ISL and deep mining. The total present production is about 27000 tonnes of uranium. Some uranium production will continue until the remedial actions focused mainly on groundwater after ISL are finished.

TABLE 2: PRODUCTION FROM MINING AREAS

Area	Period of production	Percentage
Jachymov	1945 – 1964	7
Horni Slavkov	1948 – 1962	2
Pribram	1950 – 1992	37
Zadni Chodov	1952 – 1992	9
Rozna	1953 – now	17
Hamr-Straz – deep mining	1970 – 1994	11
Hamr-Straz – ISL	1967 – now	15
others (exploration)	1948 – 1990	2

During the uranium industry history it became a state in state. It started in September 1945, when the first uranium producing mines were occupied by the Red Army and the first negotiations on the situation of Czechoslovak uranium started. On November 23, 1945 an agreement on exclusive delivery of radioactive ores to the Soviet Union was signed. In 1946 in Jachymov the production was ensured with support of almost 70 Soviet citizens. At that time "Jachymov Mines" were established and subordinated to the Group for Special Tasks in former Central Directorate of Czechoslovak Mines. In 1949 inspectorates for regions were established and in 1952 Main Administration for Research and Production of Radioactive Materials was established and subordinated directly to the Prime Minister. In 1955 "Jachymov Mines" were divided into several national enterprises according to regional interests, which were subordinated to Central Administration for Research and Production of Radioactive Materials having rights and duties on the ministry level. In 1960 the headquarters were moved from Jachymov to Pribram, 50 km south-west of Prague and in 1967 the Central Administration was renamed to Czechoslovak Uranium Industry having several not only mining branches. In 1992 Czechoslovak Uranium Industry was renamed to DIAMO, state-owned enterprise in Straz pod Ralskem. Since 1989 the company has been reconstructed, number of employees is at the level of about 12%, when compared 2000 with 1989. All the activities, which were not directly connected to uranium production have been privatised or cancelled.

TABLE 3: MAIN MINING AND MILLING PRODUCTS AND WASTES "STATISTIC" OVERVIEW

Type	Volume	Ratio (per 10 million)
U in concentrate	approx. 110 000 t	11 kg/inhabitant
waste rocks	58 500 000 m^3	5.85 m^3/inhabitant
mill tailings	56 000 000 m^3	5.6 m^3/inhabitant
ISL contaminated water	200 000 000 m^3	20 m^3/inhabitant

Between 1946 and 1989 many of supporting activities became a part of uranium industry to ensure its high priority activities. It was created by the situation in the economy, which was not able to fulfil the request of uranium industry. The main activities were as follows:

- machinery and building activities,
- social activities (blocks of flats, lodging-houses, culture clubs, groceries etc.)
- transportation activities,
- local telecommunications,
- equipment for geophysical measurements, medicine, automation etc.

In 1986 the first measures to decrease losses in uranium industry were done. In 1989 the Czechoslovak federal government issued the decree on uranium production contraction programme. It was many times innovated many mines were closed and uranium production decreased rapidly. The main activities were focused at decommissioning and remediation works.

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Radioactivity of waste materials produced from the inchass uranium extraction pilot plant

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A pilot plant was constructed at Inchass, Cairo for uranium processing from conventional ore materials consists of 4 rubber lined leaching tanks fitted with the required impellers beside having procured two columns ion-exchange unit from Permutite Company LTD of London and a mixer settler from Henkel USA. The capacity of this unit is 100 kg yellowcake per year (Fig. 1). The aim of this work is to study the radioactivity of wastes produced from the pilot plant. Uranium ore, dust, airborne material, solid waste (tailings) and liquid effluents have been collected and analyzed by gamma spectrometry.

The results of the radiometric analysis show that the radium content in the ore fractions ranges between 17,863.8 + -27.1 Bq/kg to 27,517.7 + -449.5 Bq/kg with an average 22690.7 of Bq/kg. Results indicate that the radium content increase in the fine grain size more than that in the coarse gain sizes. This can be explained by the presence of uranium as coatings, flakes and filling fractures [1]. On the other hand the radium content in the solid waste samples ranges between 7, 713.0 Bq/kg to 31,950.0 Bq/kg with an average of 22,832 Bq/kg. It is observed that ^{226}Ra increases after the leaching processes, which may indicate that ^{226}Ra is firstly dissolved and then precipitated as radium sulfate after the reaction with H_2SO_4 [2]. The radiometric analysis results of dust and airborne samples (collected on filter papers) show that the count rates is varying between 0.012 to 0.16 Bq/kg, where the system background is 0.003 Bq/h.

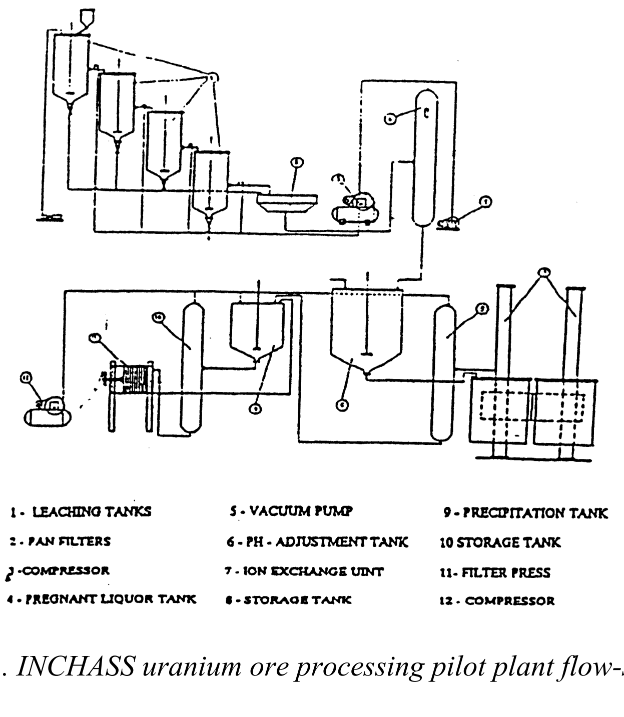

FIG. 1. INCHASS uranium ore processing pilot plant flow-sheet.

This indicates that the activity increases with the increase of grinding. So, the workers at roll crusher (the last stage of grinding) will be exposed and affected by higher level of radioactivity more than the others. The dust concentration in the vicinity of the crusher can be controlled by use of water sprays and wet impingement dust collectors.

From the results of the liquid samples analysis, it is found that ^{226}Ra content ranges between 1.6 + -0.2 Bq/L to 10.6 + 0.2 Bq/L with an average of 6.1 Bq/1. These samples were taken after the precipitation of the yellow cake by NaOH at pH 7.

On the other hand the chemical analysis results of the collected liquid waste samples were also carried out. The correlation between sulphate content and radium content in the liquid waste was investigated. It is observed that ^{226}Ra increases with the increase of sulphate ion content. This is because of using the sulphauric acid as leaching agent. On the other hand, ^{226}Ra increases with the decrease of chloride ion content, it is also shown that the ^{226}Ra content decreases with increases of sodium ion content. This is due to using sodium chloride for the displacement of uranium from the loaded ion exchange resin (elution process by NACl) [3] suggested that hydrochloric acid leaching is more convenient to environmental aspects than sulphuric acid for uranium recovery since the sulphuric acid leaching of uranium ores causes a lot of environmental problems including the dissolution of radium besides the dissolution of both heavy metal nuclides (Co, Cu, Ni and Ti) and the highly toxic radionuclides namely ^{230}Th and ^{210}Pb. The dissolution of these elements is due to the generation of H_2SO_4, as an oxidation product of the sulphide minerals especially pyrite originally found in the ore.

Accordingly, the present work shows that the ^{226}Ra content in the analyzed solid wastes resulted from ranges between 0.285 Pci/g and 1.182 Pci/g. These levels are below the standard permissible level which ranges between 5–15 Pci/g (US-EPA). On the other hand, ^{226}Ra in the liquid waste samples ranges between 1.6–10.6 Bq/L. These levels are higher than the maximum permissible level of ^{226}Ra in water which is 0.1 Bq/L [4] and [5]. However the liquid wastes are recycled in the process.

Finally, some recommendations should be applied to reduce the effect of the produced wastes especially the liquid waste on the environment. These recommendations can be summarized as follows:

(1) The site selection for the mill should be near the mine. Hydrochloric acid leaching should be used to avoid the environmental problem caused by using sulfuric acid.

(2) The choice of the location and design of the tailing area, should be based on factors such as topography, hydrology and the characteristics of the tailings.

(3) To contain the effluents as much as possible within the impoundment area, various liners should be developed such as clays and asphalt.

(4) Plantation of the decommissioned mill site by suitable types of plants.

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Radioactivity in soil and air near the Sillamäe tailings depository

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Radiological situation outside the Sillamäe plant and U/Th tailings depository is studied by soil monitoring and modelling methods. In the Sillamäe region, the reliable monitoring and assessment of the technological impact to public exposure is significantly interfered with the complex nature of natural background (e.g., elevated and variable soil concentrations of ^{226}Ra in the range of 40 .. 320 Bq kg^{-1}, high outdoor ^{222}Rn levels, etc.) [1, 2].

The releases of radionuclides from the tailing depository to the ground and tap water are negligible [3]. The major water pathway is the release to the Gulf of Finland and specifically the consumption of fish. The isotopes ^{234}U, ^{238}U (about 6.2 GBq a^{-1} or 0.025 % of the total U per year) and ^{210}Pb (~ 0.05 GBq a^{-1}) dominate in the source term. A compartmental modelling of this pathway has demonstrated a low radiological impact to the population with the individual and collective committed doses of 1 μSv and 1 manSv, respectively, for both current leakage and sudden dam collapse scenarios [4].

We have determined the depth distribution of radionuclides in soil profiles to find an evidence for air-borne radionuclide deposition. Samples collected in the Sillamäe town (up to 1 .. 2 km from the depository) have been analysed by using low background Ge(Li) and HPGe gamma spectrometry. The results demonstrate an enhanced (relative to the bottom layers) ^{226}Ra and ^{238}U content in the surface soil layers (FIG. 1). A similar observation has been found near the oil-shale-fired power plants in NE Estonia, which we attributed to the long term deposition of fly-ash radionuclides [5]. It should be noted that in the non-polluted locations over Estonia the ^{226}Ra concentration in the uppermost 0 .. 3 cm layer is about 11 % less than in the next 3 cm thick soil layers. In the ground level air, the mean dust loads of 0.23 mg m^{-3} (0.02 to 1.6 mg m^{-3}) have been measured (V. Nossov, SILMET, 1997, private communication and [6]) with the aerosol beta radioactivity levels of 4 mBq m^{-3} (LLD to 40 mBq m^{-3}). At Sillamäe the contributions of different sources (plant, depository, power plant, etc.) of the suspended dust particles, as well as their radionuclide composition, have not been identified. If raw material or tailing particles contribute to the composition of dust, the annual individual inhalation doses may readily reach tens of μSv.

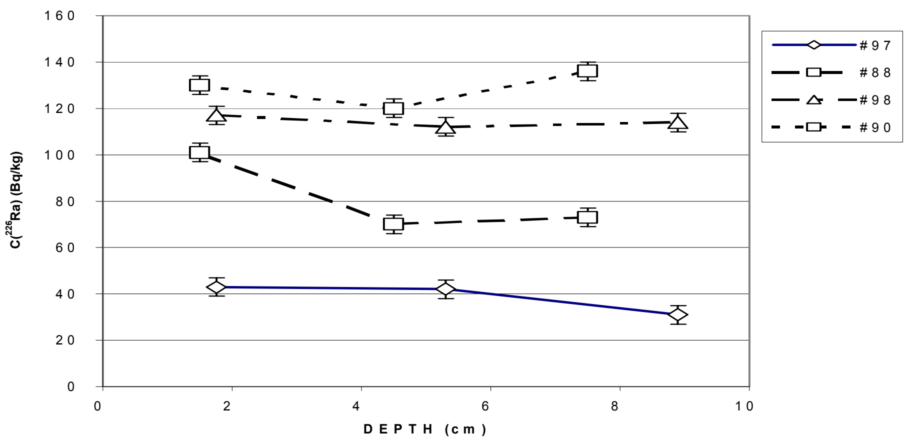

FIG. 1. Depth distribution of ^{226}Ra activity concentration in soil profiles collected in 4 locations at Sillamäe.

Radon progeny released from the waste depository and inhaled by population is considered as the major radiological hazard at Sillamäe. Outdoor radon concentrations in the ranges of 200 .. 600 Bq m^{-3} and 14 .. 130 Bq m^{-3} were measured on and near the depository wall and in the town, respectively [3]. A preliminary attempt to assess the Rn source term, the radiological impact of Rn progeny released from the depository and its geographical distribution has been performed. For this purpose the CAP88pc2 (DOE, USA) Gaussian plume modelling software has been applied. FIG. 2 presents the dependence on distance of the measured outdoor Rn concentrations in Sillamäe [3] and the corresponding air concentration modelling results. A good qualitative correlation of the measured and modelled dependencies on distance was observed. The performed simulation agrees well with the measured data assuming the mean value 45 MBq s^{-1} of the ^{222}Rn source term. It should be noted that a significantly lower source term follows from the calculations using the available data on radon emanation factors and the Ra inventory in tailings and in the dam wall material. The reason for the observed discrepancy is not clear, but the possible influence of other radon sources (e.g., abandoned mines and mining waste area), local geographical structure etc., can not be eliminated [7].

The geographical distribution of annual doses caused by Rn progeny was also simulated. The maximum annual doses higher than 1 *mSv* were evaluated for the locations near the tailings depository. Doses decrease rapidly, while the distance from the depository increases.

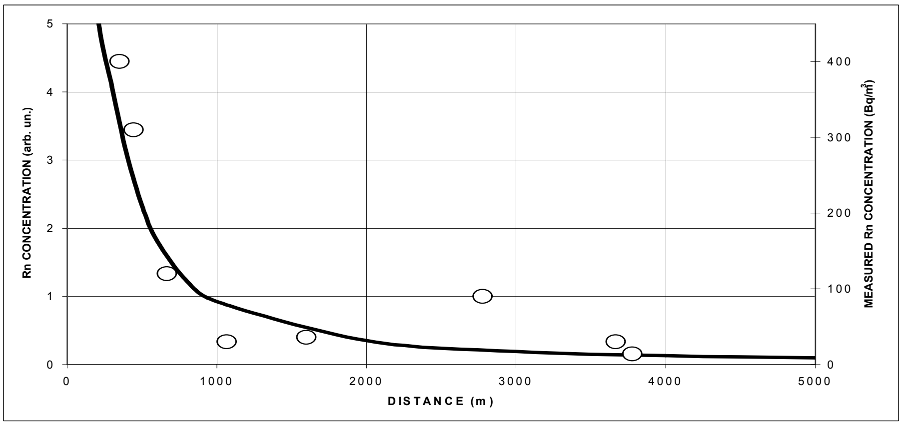

FIG. 2. ^{222}Rn concentration in outdoor air as a function of distance from the Sillamäe depository (in the direction ESE): solid curve - simulation by using CAP88pc2 and circles - measurements [3].

At present no definite limit for release rates of specific radionuclides to air or water is established in Estonia. At Sillamäe mining and milling tailings and work activities involving natural radionuclides cause exposures of regulatory concern for population and workers mainly via atmospheric pathway and external exposure. Hopefully the radiological impact will radically decrease in the course of the planned remediation activities.

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Environmental and social costs of the uranium mining and milling in Poland from 1948 to 1972

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The extensive uranium exploration and mining activities were carried out in the Lower Silesia (SW Poland) in the early 1950's, under direction of Soviet Union experts. Prospecting for uranium in Poland was initiated in 1947 when a bilateral agreement between the Polish and USSR governments was concluded. According to that agreement all uranium produced in Poland was transported to the Soviet Union. A systematic exploration programme, including geological, geophysical and geochemical surveys and related research, was carried out until 1966. The extensive uranium exploration was undertaken in number of localities in the Lower Silesia.

In 1948 the Zaklady Przemslowe R-1 (ZPR-1) enterprise in Kowary town was opened. From that time to 1962 more than 600 tons of ore were enriched radiometrically and exported to the Soviet Union.

In 1965 a ill was built and from 1966 to 1972 all remaining ore was processed in the plant ZPR-1 was closed at the end of 1972. The crew and the immovable were passed on to Wroclaw University of Technology who became the owner of the tailing pond. However, there is no legal successor of ZPR-1 in Kowary. Because of that, according to the Geological and Mining Law, the State Treasury is liable for uranium remediation.

Environmental costs: A situation in Poland is characterised by a large number of small scale liabilities after uranium exploration. Most of them are located in the Lower Silesia District (the map will be done). Remediation is necessary in particular for the Kowary region with the tailing pond, dumps and shafts.

Thanks to the equipment received in the framework of the PHARE Project PH4.02/94 from the beginning of 1999 the Office of the National Atomic Energy Agency has provided the radiological monitoring of the former liabilities in Kowary region. According to the results of those measurements the remediation programme the Lower Silesia region are prepared by the local authorities.

The remediation programme for the tailing pond, prepared in 1997 by the Wroclaw University of Technology, is still carried out. A number of bodies have contributed and are contributing to the project:

- Wroclaw University of Technology
- Regional Environmental Protection Fund
- National Environmental Protection Fund
- European Commission, DG XI

Total costs of the implementation of the Project - 750 000 ECU.

Social costs of the uranium production have been borne all the time by the Polish authorities. There are: 1) financial and 2) psychological costs.

Ad 1) From the beginning 1992, the National Atomic Energy Agency's Office for ZPR-1 Former Workers Claims Service was opened in Jelenia Gora town by the NAEA President's decision being a result of a parliamentary discussion. The Office paid annuities, allowances and indemnities for former workers or their family. Total amounts (in PLN) paid in the course of the last seven years are presented on the Figure 1.

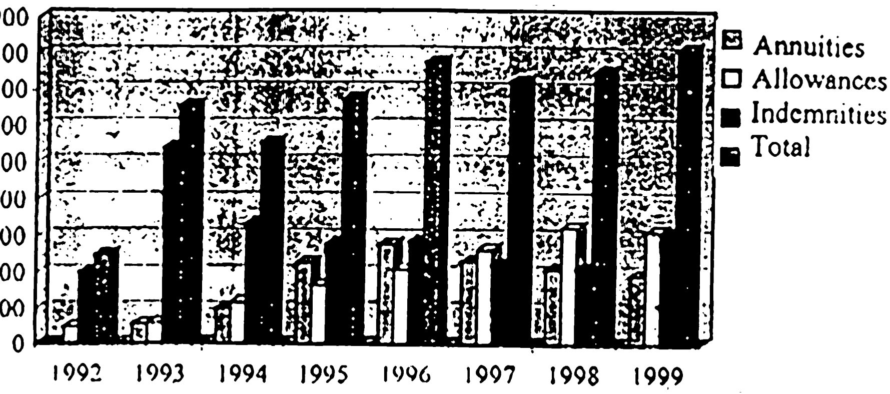

FIGURE 1.

A total number of paid claimants during the same period are shown on the Figure 2.

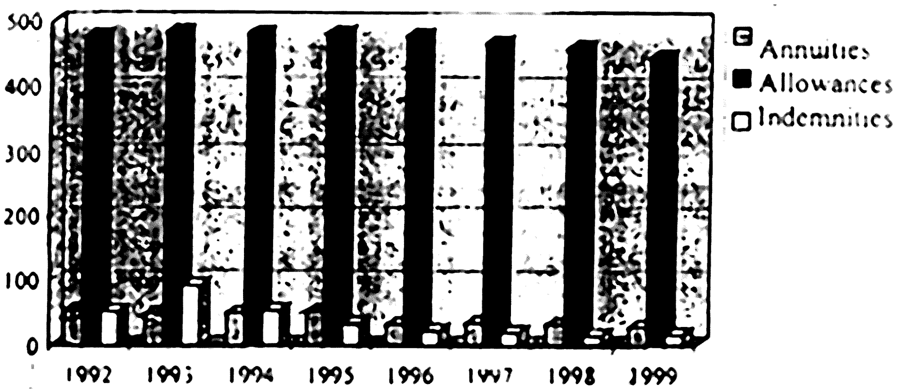

FIGURE 2.

In accordance with the new Law from 01.01.2000, the government is obligated to pay compensations to soldiers who were directed to work at uranium mines.

Ad 2) Incommensurable costs are above all:

- sense of wrong and less of health in case of former workers and soldiers.
- sense of environmental threat in case of local population.

The paradoxical situation consist in the fact that in Poland there were extracted only 600 tons of uranium and the value of them is considerably less than the annual costs of the former uranium mines workers compensations.

Radioactive waste accumulations at non-uranium facilities as a potential source for uranium production

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Among mineral sources for natural radionuclides it is possible to distinguish traditional (uranium, uranium-bearing and thorium deposits) and not traditional sources (a wide spectrum of non-radioactive deposits of noble, rare, colour, black and other metals, gas, oil, coal, construction materials, etc.) which result to natural radionuclides mobilization.

Natural radionuclides containing in sub clarke (background) amounts in non-radioactive ores and host rocks can accumulate during mining, milling, enrichment, metallurgical and chemical processing, transportation in various products, wastes and equipment. From one side they can present economic interest as potential source for reprocessing and uranium production. From the other side they are regarded as a source of water, ground and atmosphere contamination, expanding harmful influence on population and surrounding environment.

Large volumes of non-radioactive ores development suppose significant natural radionuclides amounts in processing products and wastes.

Uranium and radionuclides recovery and reprocessing from these products and wastes can satisfy some future nuclear power plants fuel requirements as well as solve the problem of territories rehabilitation and wastes disposal. Costs for uranium production from such non-traditional sources should be partly covered from environmental budget.

Non radioactive resources can be classified into three types basing on degree of their contaminating effect and negative influence on the environment:

I. Most dangerous: Natural radionuclides concentrations exceed allowable concentration in atmosphere: recent and buried Au, Pt, Sn, Zr, Ti, W, Ta, Nb, REE placers; ores of Ta, Nb, REE deposits; coal, lignite, fuel slates, peat.

II. Medium danger: High concentrations of radioactive elements occur in some cases: glass sand; construction materials (gravel, sand, clay); oil and accompanying waters, fuel gases.

III. Potentially dangerous: Dangerous elevated concentration of radioactive elements occur occasionally: ores of noble, rare, colour and black metals within uranium provinces; mining-chemical materials (phosphorite, apatite, potassium salt, mica, feldspar, brines, mineral waters); drinking and technical water; construction materials of by production.

The allocation of obviously pure and radioactive free resources is difficult as radionuclides can mobilize under certain conditions in deposits and sites with below clarke grades.

Three types of products and wastes from non-radioactive resources are determined basing on their environmental influence:

I. Most dangerous containing easy leachable uranium forms and radon;

II. Medium danger containing mobile chemical compounds of Th and ^{40}Ê;

III. Rather safe containing isomorphic thorium and uranium admixtures in non-radioactive minerals and thorium minerals refractory to oxidation.

Summarizing and systematization of above information provide proper organization of environmental activities during non-radioactive resources mining, production and wastes management.

Effect of a bentonite/soil mixture as a barrier for uranium ponds

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Uranium mill tailings need safe management as they contain long-lived uranium and its daughters. Chemical treatment applied on these tailings to neutralize the acid solution and to stabilize the remaining radioactive elements. Then they are stored in ponds. These ponds are used for the accumulation of the solids and evaporation of the liquids. Sometimes the liquid returned to the plant for reuse. These applications are used to isolate the tailings from the environment.

The purpose of this laboratory test is; initially to determine the effectiveness of bentonite/soil mixture as a barrier for uranium ponds. In this study, two experimental ponds equipped; with different two barriers in laboratory. Dimension of this container is; 120 cm in length, 100 cm in width and 100cm in depth. Sampling pipes were placed at different places of the container. First pond includes ordinary soil (Fig. 1A); second pond includes soil/bentonite mixture (Fig.1B). Uranium mill tailing ponds were placed at the surfaces of these two systems. Uranium solution was prepared by using natural uranium ore.

The solution was put into these ponds. These test carried out more than for 10 months. Passed solution was collected by sampling pipes and recorded. Amounts of passed solution were determined according to the location of discharge pipes. At the last stage of these tests, sampling from the different parts o the system has been carried out by small holes, which were opened from the surface by special sampling device. By this way, migration information about the upper parts of the sampling pipes has been received. Behaviour of uranium radionuclides and the effectiveness of the bentonite/soil mixture were experimentally determined.

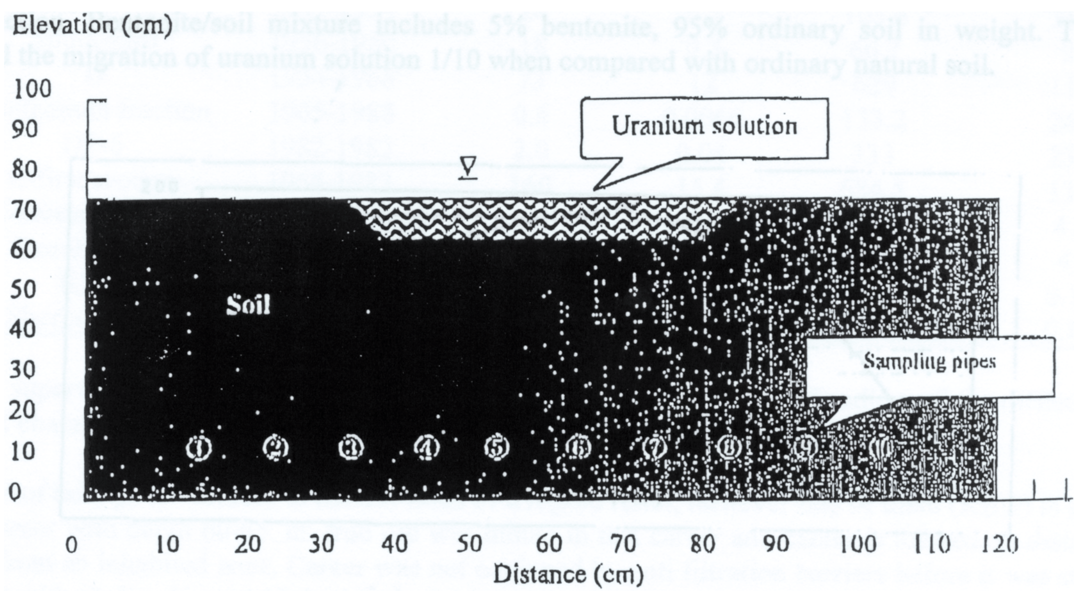

FIG. 1A. Experimental uranium pond equipped with ordinary soil.

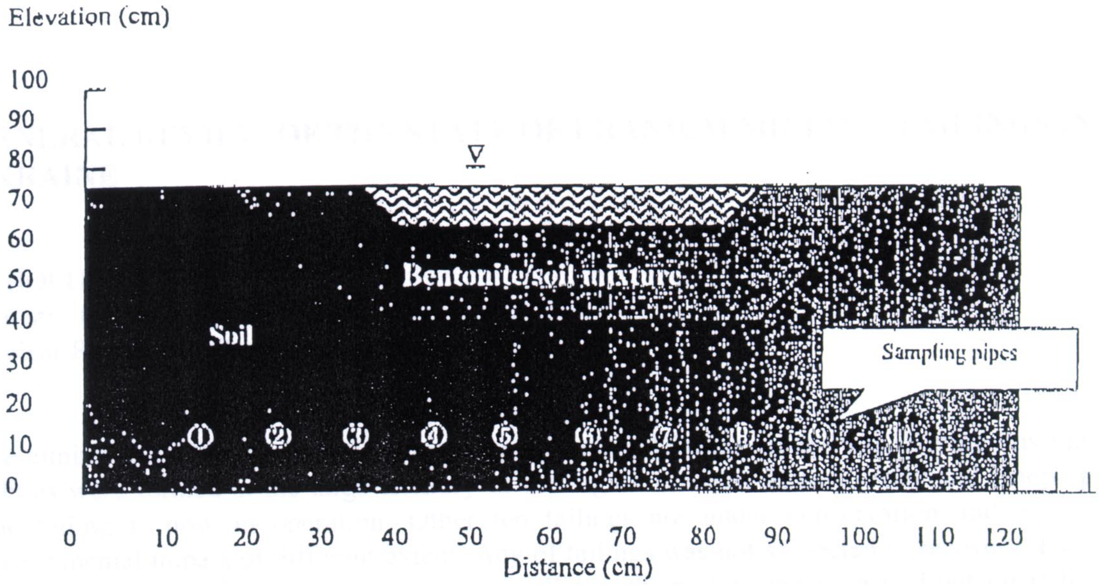

FIG. 1B. Experimental uranium pond equipped with bentonite/soil mixture.

TABLE 1. SPECIFICATION OF THE SOIL AND BENTONITE/SOIL MIXTURE

Specification of the layers	Soil	Bentonite/Soil
Dry density (g/cm^3)	1.86	2.05
Wet density (g/cm^3)	1.48	1.72
Water content (%)	28.4	22.3
Porosity (%)	43.7	32.4

Bentonite/soil mixture layer has better ability to restrain the migration of uranium radionuclides. The performance of the ponds at the natural soil can be improved simply by mixing with bentonite during construction. Bentonite/soil mixture includes 5% bentonite, 95% ordinary soil in weight. This mixture reduced the migration of uranium solution 1/10 when compared with ordinary natural soil.

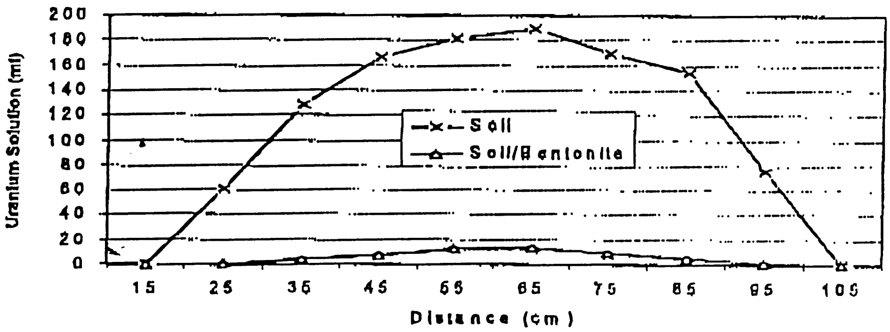

FIG. 2. Discharge amounts of uranium solution for two different layers.

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General review of the state of uranium milling tailings in Ukraine

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The mining and milling of uranium ore are produced in Ukraine since 1948. During this time eleven tailings were formed at the large territory in the region of cities Zhovty Vody and Dnepropetrovsk. One tailing is now in operation. Other ten tailings are under conservation and are producing environmental impact of different extent. Any of tailings was not subjected to recovery. By means of the enterprises, which have on their territory tailings, the monitoring is carried out for radionuclides coming in underground waters. The samples of underground water are taken from wells that are located at the tailing perimeter. The list of tailings, quantity of stored material, and radionuclides activity are submitted in the table

Following table shows the list of tailings, quantity of stored material and radionuclides activity.

TAILINGS NAME	OPERATION PERIOD	OCCUPIED AREA, $\cdot 10^3$ m^2	SLUDGE MASS, $\cdot 10^6$ t	GENERAL ACTIVITY, TBq	DOSE RATE, мGy/h
West	1951–1954	60	0.7	181	21.8
Tzentralny Yar	1949–1954	24	0.2	103.6	38.4
Southeast	1956–1980	18	0.3	66.7	20
D	1954–1968	73	12	629	11.3
Lanthanum fraction	1965–1988	0.6	0.0066	133.2	26.2
DP-6	1982–1982	2.0	0.04	333	23.5
C-first section	1968–1983	160	15.4	684.5	13.9
C-second section	1983–1993	390	7.4	296	4.4
Storehouse C	1960–1991	250	0.3	444	41
KBG	1964–1991		19.3	999	0.17
Sherbakovsko	From 1959	2250	43.2	2220	0.88

The supervision shows, that all tailings to some extent are the issue of radionuclides diffusion. The brief characteristic of the largest tailings is submitted below.

Most of tailings are located in natural folds of a region relief, however one of them (KBG) is arranged in career with depth 60–65 m. Iron ore was mined in this career and career is located on distance 2.5 km from an inhabited zone. Career was not equipped by anti filtration barriers before it was started to fill it with sludge. In total 12.4 • 10^6 ì^3 of tails is placed in it with general activity about 1 PBq. When tailing's filling was finished at 1991 its surface was covered by 1,7 m layer of loamy soil. The tailing creation resulted in change of hydro-geological conditions of a platform and in appearance of man-caused water-bearing horizon. The halo of pollution of underground waters is moving from the bounds of the site towards the inhabited zone of Zhovty Vody city. Now polluted by radionuclides water is detected at the distance of 1.5 km from tailing. According to forecast estimations in 15 years the pollution will move forward from tailing to distance 2.4 km, i.e. will reach the bounds of an inhabited zone of city Zhovty Vody.

Large threat is posed by tailing “D”, that is located in Dneprodzerjinsk city on distance of 1.5 km from the Dnieper river and is containing 5.84 • 10^6 m^3 of sludge of uranium mining with general activity 630 TBq. The tailing “D” is covered by phosphogypsum, which general weight is 12 • 10^6 tons. The tailing “D” dam is made from material of final tailings of chemical recovery production and its operating conditions are not properly surveyed. Meanwhile, water samples from wells in the area of tailing “D” location have the concentration of Ra226 from 1.59 Bq/l till 5.55 Bq/l. Dose rate, that was measured tightly to one of water samples, was 13.1 мGy/h. Underground waters in area of tailing location flow in the direction of the Dnieper river.

One tailing is in operation — Sherbakovsko, that is located in 1.5 km to the south of Zhovty Vody city. Shcherbakovsko tailing is located in a natural gully. Its first section was filled in 1959–1980 years and occupies the area 890 000 m^2. The second section is in operation from 1979 and occupies the area 1.390.000 m^2. In total 27 • 10^6 m^3 of tailing sludge is stored with general activity 2.22 PBq. Any works for its first section conservation are not carried out. The operation condition of a dam of tailing is under control and each year the works for dam strengthening are carried out. Nevertheless, the part of water is filtering through a dam into underground water horizons. Now halo of pollution of underground waters moved from the tailing to distance 1.8 km and, according to forecast estimations in 15 years this distance will be 3 km.

Tailing “C” also is located in a natural gully and consists of two sections. The first section was filled in 1968–1983 years and occupies the area 160 000 m^2. The second section is in operation since 1983 and occupies the area 390 000 m^2. In total 12.2 • 10^6 m^3 of tailing sludge is stored with general activity 98 ÒBq. Four settlements are located near tailing at distance 1.0, 1.0, 2.0, and 3.5 km. Distance up to the Dnieper river is about 4 km. In underground water samples from wells in the area of tailing “C” location Ra226 is detected in amount exceeding background meanings 10 times and the greatest Ra226 contents is detected in a well on a bank of the Dnieper river.

In Ukraine the State program for contaminated areas decommissioning and recovery is adopted. However, in view of suffered by Ukraine economic crisis, this program is suspended. Moreover, the scope and volume of carried out monitoring is insufficient for fulfilling of correct estimation of tailings environmental impact and for correct estimations of the contribution of radiating pollution into public exposure.

Uranium leaching and recovery from sandstone ores of Nong Son Basin (Viet Nam)

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Sandstone ores containing uranium in Nong Son area were treated to recover uranium in the form of MDU. These ores are classified into 3 categories depending on the weathering degree, giving different chemical composition as shown in Table 1.

The amount of calcium carbonate (g $CaCO_3$/100g of ore) reacted with HCI under different conditions of temperature and time (Table 2) shows that stirring method requires high acid consumption.

The results obtained from static leaching of the 3 ore categories (Figure 1) shows that leaching efficiency largely depends on the weathering degree and particle size of ore.

TABLE I. CHEMICAL COMPOSITION OF NONG SON URANIUM ORE

Uranium ores	**U(%)**	**ThO_2 (ppm)**	**Ra (ppb)**	**Fe (%)**	**SiO_2 (%)**	**Al_2O_3 (%)**
Non-weathered	0.104	45.9	0.30	1.816	69.77	4.74
Semi-weathered	0.197	59.9	0.54	0.811	78.78	3.88
Weathered	0.060	48.2	0.27	0.633	76.90	4.13

TABLE II. AMOUNT OF CALCIUM CARBONATE (g $CaCO_3$/100G OF ORE) REACTED WITH HCI

Uranium ores	Duration 2hrs Temperature 30ºC	Duration 8 hrs Temperature 30ºC	Duration 8 hrs Temperature 60ºC
Non-weathered	2.143	3.100	6.058
Semi-weathered	0.169	0.259	3.131
Weathered	0.539	1.428	3.396

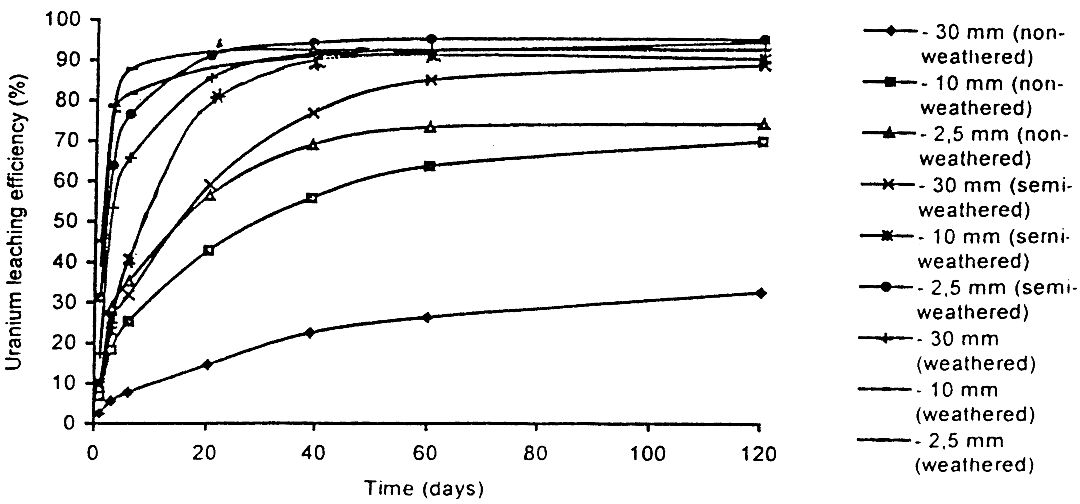

FIG. 1. Dependence of leaching efficiency on the weathering degree, particle size and time.

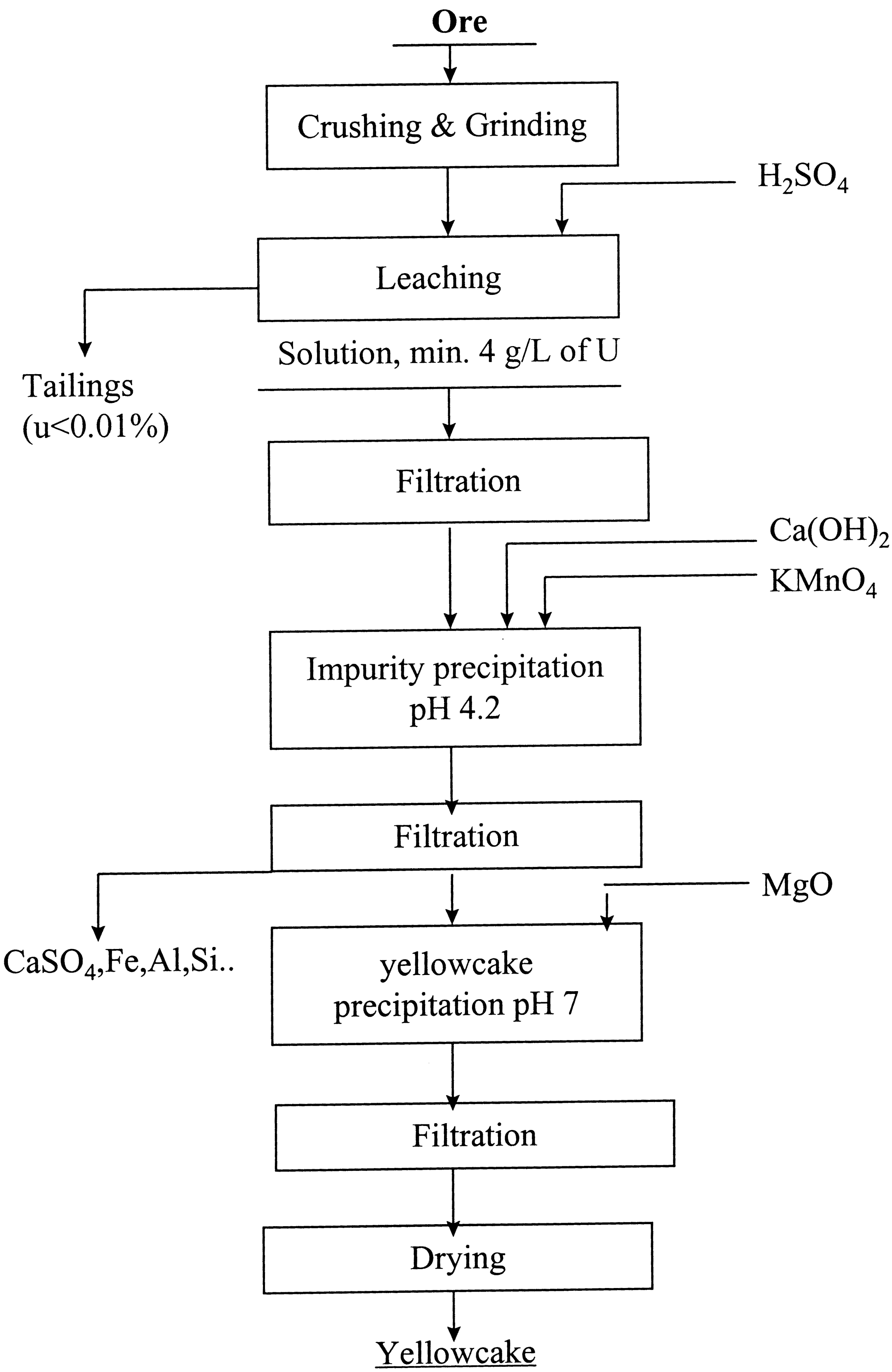

FIG. 2. Diagram of processing uranium ores to produce yellowcake.

The lowest leaching efficiency was observed for non-weathered ore. In order to increase uranium extraction this ore was ground to the size of max. 2.5mm, and then incubated by 40% H_2SO_4 for 48 hours with the addition of $KClO_3$ (3 kg/tone of ore) as oxidant. The results of acid pugging showed that uranium extraction efficiency reached min.92%.

Figure 2 represents proposed flow-sheet for obtaining yellowcake. The leaching experiments were carried out under the following conditions:

- Particle size of ore:
  Weathered: max. 30mm
  Semi-weathered: max. 10mm
  Non-weathered: max. 2.5mm (incubated by 40% H_2SO_4)

- Temperature 25 - 30ºC
- Redox potential
- pH1, acid consumption: 40-50 kg/ore tone

Leaching efficiency reached 90%. Uranium concentration in the solution after 8-stage counter-current leaching was min.4 g/L, uranium content in solid waste 0.01%.

Leaching solution was filtered and directly neutralized through two stages to precipitate yellowcake. Experimental data showed that the uranium recovery reached 90%. Yellowcake product met the relevant specifications and had U_3O_8 content of minimum 76%.

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