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Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2009)

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in Cooperation with the OECD Nuclear Energy Agency,
the Nuclear Energy Institute and
the World Nuclear Association
held in Vienna, Austria, 22–26 June 2009*



IAEA

International Atomic Energy Agency

URANIUM RAW MATERIAL FOR THE
NUCLEAR FUEL CYCLE: EXPLORATION,
MINING, PRODUCTION, SUPPLY
AND DEMAND, ECONOMICS AND
ENVIRONMENTAL ISSUES (URAM-2009)

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THE NUCLEAR ENERGY INSTITUTE AND THE WORLD NUCLEAR ASSOCIATION
AND HELD IN VIENNA, AUSTRIA, 22–26 JUNE 2009

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FOREWORD

This IAEA symposium is a third in a series which began in 2000 to discuss issues related to uranium raw materials. The symposia covered all areas of the uranium production cycle — including uranium geology, exploration, mining; milling and refining of uranium concentrates; and safety, environmental, social, training and regulatory issues — and reported on uranium supply and demand, and market scenarios. The first symposium was held in October 2000 — a time of extremely depressed market prices for uranium and of mines being closed — and primarily addressed environmental and safety issues in the uranium production cycle. By the time the second symposium was held in June 2005, the uranium market had started to improve after nearly two decades of depressed activity because of increased demand due to rising expectations for nuclear power expansion. Since then, there has been a dramatic rise in the uranium spot price, which in turn has promoted a significant increase in uranium exploration activities all over the world.

The international symposium on Uranium Raw Material for the Nuclear Fuel Cycle (URAM-2009) was held at the IAEA, Vienna, 22–26 June 2009, at a time when nuclear energy was emerging as a viable alternative to meet the ever increasing demand of electricity in a sustainable manner, without degrading the environment. However, the global recession and credit crunch could impact the growth of the uranium industry. Since 2000, the identified uranium resource base has grown by more than 75%, exploration efforts have continued to increase in greenfield as well as brownfield sites, annual uranium production has risen, and the issue of social licensing and uranium stewardship has become increasingly important for public acceptance of the uranium industry.

Some 210 delegates from 33 States and four international organizations participated in the symposium. In total, 120 technical papers were presented in the oral and poster sessions, and an exhibition on the uranium production cycle was organized. The topic for the panel discussion was the gaps in the uranium production cycle and the impact of recession. The symposium included technical sessions on: uranium market and economics; social licensing in uranium production cycles; uranium exploration and geology; uranium mining and processing; environmental and regulatory issues; and human resource development.

The IAEA acknowledges the contributions of the experts who participated in the pre-symposium consultancy for evaluation and selection of papers for oral and poster sessions and outlining the programme of the symposium. The IAEA is grateful to M. McMurphy and G. Grandey for their contributions to this symposium. In particular, the IAEA would also like to acknowledge F. Dahlkamp for his contributions to this symposium and numerous past IAEA activities.

The IAEA officers responsible for this publication were C. Ganguly, J. Slezak and A. Hanly of the Division of Nuclear Fuel Cycle and Waste Technology.

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SUMMARY

The opening session provided the opportunity to set the scene for the six technical sessions that would follow during the symposium. In his welcoming address, Y. Sokolov (former DDG-NE, IAEA) said that the global situation of the uranium industry has changed markedly in the time since the last symposium in 2005. There has been a marked increase in activity in all phases of the uranium production cycle, from exploration to mining and production. Remediation of legacy sites remains a significant issue, but even there some progress has been seen. M. McMurphy, in his keynote address went on to say that the upsurge in activity is due to several factors which are dominated by the continuing shortfall of supply from annual mining production against the current market demand, the depletion of secondary sources of supply and an increased interest in the development of nuclear power to help address concerns about climate change and energy security. To meet the increased demand, new uranium discoveries as well as addressing the modern challenges in exploration, project management, infrastructure and human resources are deemed essential.

The President of the Symposium, F. Dahlkamp, in his address commented that since 2005 there has been a modest expansion in uranium primary production but despite new mines coming into production in Namibia, Malawi and Kazakhstan and expansion of production in several existing facilities, this increase has failed to keep pace with market demands. Thus the scene is set for continued development activity. Another issue that has continued to concern the industry is the lack of adequate numbers of experienced and skilled workers to replace the rapidly aging and retiring workforce who are the mainstay of today's uranium production industry. Apprehensions remain regarding effective transfer of knowledge from the retiring workforce to the incoming younger generation. R. Vance (OECD/NEA) in his address remarked that much of the current development effort is concentrated on resources that have been known about for some time but were uneconomic to exploit under the previous market conditions. However, in the years since 2005, exploration efforts continued to increase in greenfield as well as brownfield sites, only to be curtailed sharply with the onset of the global financial crisis in 2008. At the same time the proponents who have been trying to implement new projects have been much more aware of the need to improve the industry's public image and raise acceptance of their developments by the community. In 2005 there was mention of "social licensing" but nowadays it is regarded as an essential element in the development of a new uranium production facility, be it a mine or a processing plant. Also since 2005, the uranium industry has begun to develop the concept of uranium stewardship as further means of improving public acceptance and showing that the modern uranium industry is socially and environmentally responsible.

In concluding the opening session C. Ganguly and J. Slezak (both IAEA) in their presentations reminded the audience that throughout all of these developments the IAEA has continued to work with Member States to support the improvement efforts of both the established producers as well as assisting newcomers to the industry, be they regulators or operators. A joint IAEA programme with the World Nuclear Association resulted in their publishing a policy document containing a statement of principles for sustainable development in uranium mining. The OECD and the IAEA have continued to update and publish biennially "Uranium Resources, Production and Demand" also known as the "Red Book" as a statement of the world's uranium resources. Further support provided by the IAEA includes maintaining a suite of databases on all aspects of the nuclear fuel cycle activities and publishing technical documentation on best practices in all phases of the

uranium production cycle. Finally the IAEA has continued to maintain Technical Cooperation programmes supporting Member States' requests for assistance through expert missions, training courses, scientific visits and fellowships. Peer reviews by the Uranium Production Site Appraisal Team (UPSAT) are being initiated and actively promoted. The volume of work in these activities has doubled in recent years and continues to grow, presenting a significant challenge to the IAEA. It is in this atmosphere of expansion and increasing activity, but at a time of constraints in financial and human resources, that the symposium was held.

SESSION 1 — URANIUM MARKETS AND ECONOMICS

G. Capus opened the proceedings with a paper entitled "Nuclear Power has a Bright Outlook and Information on Uranium Resources is our Duty." While explaining his optimism for nuclear power and uranium mining, he emphasized that despite the best efforts of the Uranium Group, tough questions remain with respect to uranium resources. For example, are there sufficient resources to fuel nuclear expansion and why is the price so high when there appears to be an abundance of low cost resources? In his opinion, the low projections for nuclear energy growth discussed in the morning session were too low. He also voiced the opinion that nuclear power may in fact benefit, rather than suffer, from the global financial crisis. Consequently industry, governments and resource specialists need to work to underpin this growth. Based on his vision of strong growth, he estimated that an additional 3 million tU resources will need to be identified by 2030.

K. Welham's presentation, entitled "Four Years On: Review of Market Developments," looked at changes in the time since the last IAEA Uranium Symposium in 2005. Over this time he believes uranium has been "dragged more into the mainstream," and has become subject to speculative demand. He felt this accounted for much of the spot price volatility witnessed since 2005. He went on to outline a number of changes in both supply and demand over the last four years that led to his conclusion that now is the best time ever to be in the nuclear business.

M. Roche then presented his paper "Uranium Stewardship — the Unifying Foundation," in which he outlined the program being developed under the auspices of the World Nuclear Association (WNA). He noted that his employer, BHP Billiton, went from having no interest in uranium to being the fourth largest producer virtually overnight with the purchase of Western Mining Corporation and its principal asset, Olympic Dam. With past experience in full life cycle stewardship (e.g. Green Lead), the company was interested in developing the same sort of program for uranium. With WNA membership covering all uranium producers, the Stewardship program has moved ahead rapidly and a set of Stewardship Principles and Best Practice Guidelines has been developed. Efforts are now being directed toward methods of assessing current operations and their adherence to the principles of stewardship throughout the uranium life cycle.

A. Petoe from IAEA, Department of Safeguards, then made a presentation on "Safeguards Obligations Related to Uranium/Thorium Mining and Processing," reminding all Symposium participants about the safeguard obligations and requirements that begin with the production of yellowcake at mine and mill sites and also apply to the extraction of uranium from unconventional sources, in particular phosphate rocks. Early detection of the diversion of nuclear materials is a critical component in the efforts to stop possible subversive programs. He also noted further obligations for all signatories to Additional Protocols such as, declaring the location, status and estimated annual production capacities of all types of mines

and mills. He concluded his presentation by noting that inconsistencies in the information provided will trigger follow-up actions to see if they indicate undeclared activities.

A. McKay then presented “A Review of Uranium Resources, Production and Exploration in Australia.” He noted that recent activities in Australia have led to increases in the overall uranium resource base. These included a 30% increase in uranium resources at Olympic Dam and development of in-situ leach mines in South Australia, including the relatively rapid development of the Four Mile deposit adjacent to the operating Beverley mine. He also noted that increased exploration activity is mainly directed at known deposits (i.e. virtually no greenfield activity). Mr. McKay then presented the recently developed map of natural radioactive occurrences in Australia and noted its potential for use in future exploration.

J. Marlatt followed with a presentation entitled “Paradigmatic Shifts in Exploration Process: The Role of Industry-Academia Collaborative Research and Development in Discovering the Next Generation of Uranium Ore Deposits.” He highlighted the value of such collaborative approaches in developing new models of uranium deposition, occurrence and discovery, suggesting past activities suffered from not developing collaborative approaches. He also highlighted the potential for discovering new high-grade deposits in the Athabasca Basin.

A. Boytsov presented his paper “Uranium Mining Capabilities in the Russian Federation,” in which he outlined the ambitious plans to expand uranium production to 16 000 tU by 2026. He noted that his employer (ARMZ) is relatively immune to the global financial crisis given the national priority given to nuclear power and uranium production. He also highlighted the four-fold increase in uranium resources in recent years (principally through re-evaluation of previously discovered deposits), the increasing importance of ISL (now 13% of production) and the move to make use of western based systems of resource classification, such as the JORC code and the NI 43-101 system.

W. Cong then discussed “Nuclear Energy in China,” providing an overview of significant efforts to develop nuclear power, part of a larger drive to provide adequate electricity to support economic development. The pace of nuclear development is impressive, with 9 units currently operating, 13 under construction and another 24 planned. However, such is the pace of the development of the country’s generation capacity that nuclear power will only comprise 5% of the total generation capacity after realization of the current development plan. He described the country as “resource hungry,” and went on to highlight current plans to provide uranium through a combination of the development of domestic resources and joint ventures overseas. He also noted efforts to develop domestic capacity to produce components for new nuclear plants and to develop associated aspects of the front-end nuclear fuel cycle.

R. Gupta closed the session with a presentation entitled “Technical Developments in Uranium Mining and Milling in India.” After listing the potential means of electricity generation available in the country he outlined the limitations of each form of generation in India. For nuclear power, he noted the nation’s small and low-grade uranium resources as a limitation, but recent changes to India’s status in nuclear trade is now seen as eliminating this. Nonetheless, the country is still working to develop domestic resources in support of its goal to have about 270 GW(e) of installed nuclear capacity by 2050. He also outlined India’s plans to work toward security of energy supplies by developing fast breeder reactors and the

thorium fuel cycle. Finally he outlined the challenges in developing domestic uranium resources in particular managing negative public opinion.

SESSION 2 — SOCIAL LICENSING IN THE URANIUM PRODUCTION CYCLE

The issues of poor public opinion of uranium mining (and the nuclear fuel cycle in general) were mentioned several times in the opening addresses of the conference and the preceding session. This session looked at these issues in detail with presentations by 5 speakers from 4 continents. R. Gladue gave a presentation on “AREVA’s Social Licensing Experience in Northern Saskatchewan, Canada”; A. Dari described “Social Licensing In The Uranium Production Cycle (Case Of Niger)”; P. Waggitt spoke on “Uranium stakeholder engagement in northern Australia”; and Y. Marignac gave a talk on “A pluralist expertise approach to the management of closed uranium mining sites in France”; Finally, H. Monken-Fernandes gave a presentation on behalf of M. Franklin from Brazil, entitled “Social License and Environmental Protection: When Compliance with Regulations is not Enough”.

The topics covered included:

- Communications and social/technical programs involving indigenous people — Canada, Australia, Niger;
- Frameworks for communication, consultation and technical review — Australia, France;
- Regulatory processes and compliance — Niger, Brazil;
- Case studies of social development programs — Canada, Niger;
- Examples of mine site remediation — Niger, Australia.

Regardless of the geographical origin, or the detail of the cases presented, the primary messages regarding stakeholder/community consultation and expectations were consistent. i.e.:

- The public, particularly local and indigenous communities have increasing expectations of both mining companies and regulatory bodies and expect to gain some benefit from mining in their region;
- Innovative approaches are needed to communicate and work effectively with indigenous/remote communities to overcome cultural differences and logistical difficulties;
- All stakeholders should be represented in consultations which need to be conducted in a transparent and relevant manner, i.e. a manner consistent with the culture and background of the specific group.

Another strong message was that regulatory frameworks covering uranium mining are complex and can lead to the community losing confidence in the processes and outcomes on environmental, health and safety performance, regardless of the scientific evidence. This is further exacerbated by the power of persuasion some NGO groups have and the damage that misinterpretation of evidence can cause. To combat these weaknesses the following were recommended:

- Simplification of processes and co-ordination between different levels or departments of government to form a united approach;

- More consistent, proactive and strategic approaches to communication from both industry and government rather than an ad-hoc approach of dealing with issues as they arise or communicating after an event or milestone is reached;
- Transparent processes for evaluating and reviewing information that is inclusive of not only independent technical experts but members of the public and effected communities;
- Transparent processes for decision making on short, medium and long term issues.

A common theme in programs addressing social responsibility is building capacity among locals through business development or education and training focused on long term employment opportunities, support for local infrastructure (e.g. water and transport) and increasing local participation in the mining workforce. The AREVA Corporate Social Responsibility program provides good examples of these and other socially responsible practices.

SESSION 3 — URANIUM EXPLORATION AND GEOLOGY

L. Ainslie in his presentation on “Uranium exploration, resources and production in South Africa” began with a history of uranium in South Africa including the development of the nuclear sector. Significant uranium is contained in the Witwatersrand formation, however only a small amount has been recovered commercially, with substantial amounts remaining in tailings from gold mining. South Africa has adopted a strategic approach to uranium and has sufficient resources to cover near term demand for domestic nuclear generation, while stockpiling is being considered to cover future shortages.

M. Fairclough in his talk “South Australian Uranium Mineral Systems: A spectrum of mineralization across the ages and across styles (‘uranium is where you find it’)” presented the recent advances in mineral potential mapping and modeling, with a focus on mineral systems approaches for several common uranium deposit styles. A. Chaki in his talk “An overview of uranium exploration strategy in India” summarized the current status of uranium resources, including current and potential uranium production and the major potential regions in India. In response to audience questions he noted that India’s Red Book reported resources do not have a price category associated with them, however they are included if they are considered to have extraction potential within India’s uranium production plans.

F. Hawari presented on “Potential and existing uranium resources of the Middle East and North Africa” and reported the uranium potential of the Middle East and North Africa (MENA). While these studies are still at an early stage, there is growing interest in nuclear power in the MENA region due to projected demand from desalination facilities as well as power generation. In terms of uranium supply, phosphatic uranium is considered to have the greatest potential. However, as pointed out in an audience question, uranium from these sources is only feasible if there is proportional market support for the primary phosphate product.

L. Gonzalez-Oviedo described some field results from early stage exploration in the paper “Uranium exploration in Paipa and Iza area (Colombia), new contributions (preliminary report)”. Uranium exploration began in Columbia in the 1980’s. However, most regions remained untouched until the current uranium cycle which has seen some junior companies carry out exploration in the country.

M. Matolin in the talk “Levelling airborne and ground gamma-ray spectrometric data to assist uranium exploration” summarized the process, and the importance of, levelling and calibration of large scale airborne gamma-ray spectrometer surveys, and used the example of a country-wide levelling of airborne radiometric surveys in Australia. G. Wood in the talk on “The application of borehole seismic techniques in mine development at the Millennium uranium deposit” suggested these surveys have significantly improved the information available for development leading to cost savings and reducing the risk of mine development in poor ground conditions. A. Bisset in the paper “Applied electromagnetic methods in the search for shallow unconformity related uranium mineralization in Australia” stressed the importance of understanding the physical properties of the key rock units to be surveyed and, related to this understanding, making the correct choice of EM technology to maximize the success of the survey. S. Fedyanin in the talk on “X-ray and radiometrics in geo-ecological and geochemical mapping” commented on recent results from the radiometric scanning of uranium material, whereby disequilibrium has resulted in poor results from gamma ray spectrometry. XRF analysis in the field has improved sampling precision.

This was followed by two papers that were relocated from other sessions to accommodate some administrative changes. W. Swiegers in his talk “The Namibian uranium mining model: Voluntary sector initiatives underpinned by a regulatory safety net ensures best practice” summarized Namibia’s recent initiatives on uranium stewardship, standards and safety regulations. X. Shuibo’s presentation on “The Composite Interception Technology of Biochemistry (CITB) for uranium pollution control at the uranium tailings” provided details of research on study on fixation of U(VI) by hematite and sulfate reducing bacteria which resulted in uranium removal rate of up to 98.1%.

SESSION 4 — URANIUM MINING AND PROCESSING

A. Boytsov presented on “Elkon — A new world class Russian uranium mine.” This project is at the feasibility study stage, with startup planned for 2015. The main uranium mineral is brannerite, and autoclaving has been chosen to process this refractory mineral. Heap leaching is being considered for recovery of uranium and gold from low-grade ore.

G. Catchpole described the “Licensing status of new and expanding in-situ recovery uranium projects in the United States.” There are relatively few operations, but several sites are on standby, and more are planned. Were all the planned operations to come into production, United States in-situ recovery production would increase from about 3 Mlb/a U_3O_8 (1 361 tU/a) annually to approximately 20–25 Mlb/a (9 072–11 340 tU/a).

Norman Reynolds talked on the “Uranium potential and socio-political environment for uranium mining in the eastern United States of America with emphasis on the Coles Hill uranium deposit.” The project would provide economic development in an area of Virginia that has recently suffered job losses and plant closures. The project is ready to move into the pre-feasibility study stage but awaits state approvals and the results of a National Academy of Science study, expected to be completed in 2012.

M. Csövari discussed lessons learned in “Experience gained from the former uranium ore processing and the remediation of the site in Hungary”. The aim is to provide tools for use in the development of new uranium production facilities. To date, €83 million has been spent on remediation, with €2.5 million required annually for the long term. He emphasized the need for the industry to learn from past errors and unintended consequences.

C. Edwards presented and analyzed the new concept of “Underground milling of high-grade uranium ore”. This scheme promises to deliver significant environmental benefits, with expected capital cost savings of about 35% and operating cost savings of about 30% relative to conventional mining and milling.

L.A. Gomiero talked about “Converting the Caetité mill process to enhance uranium recovery and expand production.” Heap leaching is to be changed to conventional agitated tank leaching. This is expected to increase uranium recovery from 76–93%. Optimizing the choice of processing options is now in progress.

D. Marsh described “Development and expansion of the Langer Heinrich Operation in Namibia”. Mechanical and process issues meant the ramp-up to initial nameplate capacity of 2.6 Mlb/a (1 180 tU/a) took 12 months. Production now exceeds nameplate and lessons learned have been incorporated into the expansion to 3.7 Mlb/a (1678 tU/a) which is currently nearing completion.

J. Otton discussed “In-situ recovery uranium mining in the United States: Overview of production and remediation issues”. In 2007, in-situ recovery (ISR) methods provided about 95% of U.S. uranium production. Major issues affecting ISR site planning and remediation include baseline water quality, control of fluid flow during operations and ground-water restoration standards and technologies.

A. Castillo presented the “Uranium production cycle: Argentine situation”. Argentina desires increased national uranium production to fuel eight planned new reactors. Efforts to restart the Sierra Pintada uranium mine are being frustrated by new and conflicting national and state laws, community issues and concerns from the local tourism and wine industries.

SESSION 5 — ENVIRONMENTAL AND REGULATORY ISSUES

M. Iles presented the paper “Uranium in aquatic sediments: Where are the guidelines?” She focused on the concerns with uranium in the sediment and the toxicity. Currently there are no established international guidelines for addressing what is an acceptable level at the end of life of a uranium project. Furthermore, in her efforts to establish a level in Australia the scientific community would not accept proposals based on experience in the United States. One of the underlying concerns is temperate zones, vs. tropical zones, vs. arid zones — should there be one guideline for all zones or should it be specific to a zone? It was recommended that IAEA or another international body take on the task of developing an international guideline taking climatic zones into consideration. It is also recommended that the working group include the scientific community, the regulators and the operators.

A. Suri’s paper entitled “Recent pilot plant experience on alkaline leaching of low grade uranium ore in India” provided an overview of a process which has been successfully developed in India for the extraction of uranium from very low grade ore. Even with a recovery rate of 75% there were significant benefits. Firstly, that extraction can be done economically and secondly, that the waste stream had very low uranium content.

G. Maerten presented a paper entitled “Uranium ISR mine closure — general concepts and model-based simulation of natural attenuation for South Australian mine sites”. This presentation provided an overview of the state of art in the closing of an in-situ uranium mine and being able to take advantage of natural attenuation for groundwater restoration.

M.-A. Charette (WNTI) presented a paper entitled “An overview of the international transport of uranium concentrates”, which also provided an industry guide for blocking and bracing of concentrates while being transported in an ISO container. The guidance is available on the World Nuclear Transport Institute web site. He also discussed some of the other issues related to releasing ISO containers after shipments of Class 7 materials. It was recommended that the industry and the regulators work together on these issues. The questions from the floor also raised the issue of delays and denials of shipments of Class 7 material. The recommendation was that IAEA should expand its efforts in this area to minimize shipping delays or denials.

F. Carvalho’s presentation entitled “Environmental remediation and radioactivity monitoring of uranium mining legacy in Portugal” discussed some of the issues which are faced whilst addressing the remediation of an orphan mine or mill with no operator funding available. He made it clear that remediation costs need to be included in the operational analysis so that this situation will not be repeated in the future. Some states have adopted this policy, but not all. Legacy sites are detrimental to the industry as it moves forward and works to open new mines and mills.

D. Schryer spoke on “The regulatory perspective on radiation protection in Canadian uranium mines” and provided an overview of the various radiation exposure scenarios for a uranium miner. He focused on the source of exposure and monitoring, as well as the precautions which can be taken to reduce the worker’s exposure. His recommendation to mine operators was to consider all exposure pathways and develop the mining plan with the concept of built-in measures rather than try to develop them once operations begin.

In his presentation entitled “What is world's best practice for in situ leach uranium mining?” A. McKay provided a history of the development of mining regulations for in-situ uranium mining in Australia. The situation has progressed to the point where a mine has to operate using “best practice”, but without guidance on how to define this. The regulator has drafted a guidance document which is now out for public comment. Participants were asked to review this guidance document and provide comments to him.

D. Feasby provided an overview of the challenges associated with opening a new uranium mine in his paper “Issues in developing a new uranium mine in Canada”. The topics covered included addressing the protection of the worker, the public, and the environment and meeting the requirements of the regulator. However, the social issue can be the most complex and, if not appropriately addressed, can stop a mine before it ever opens. To address this concern he suggested that the operator engage the public well in advance of any substantial work on the project. The operator needs to be transparent and listen to the concerns of the community. It is helpful to bring in experts who are not directly employed by the operator and to bring in working staff from an existing operation. Another possibility is to take representatives from the prospective location to view another operating site and interact with the surrounding community.

P. Schmidt provided a history of the WISMUT rehabilitation project in his paper “Uranium mining and milling environmental liabilities management in Germany — lessons”. Although the work is nearly complete, issues have been identified which were not previously anticipated. The mine was operated with a positive pressure during the remediation and at the end of work the ventilation system was turned off. This resulted in a radon build-up in the houses on or near the site. This was not expected and work to remediate this situation continues. His message was that in any remediation work there may be events that were not

anticipated. Industry should be prepared to meet unexpected issues and have funding available to address them.

V. Riazantsev provided an overview of the options which were considered for the remediation of groundwater in his paper “Screening assessment of radionuclide migration in groundwater from the 'Dneprovskoe' tailings impoundment (Dneprodzerzhynsk City) and evaluation of remedial options”. In one case the selected option appears to be very effective. However, in a second case long term studies indicated that after spending considerable funds to relocate tailings the long term benefit would be of little value. The point is to look for answers which address the issues for both today and into the long term, remembering that when dealing with processed uranium, the risk may not be identified for hundreds or thousands of years.

S. Saint-Pierre (World Nuclear Association) made a presentation focused on considering the big picture. Entitled “WNA's worldwide overview on front-end nuclear fuel cycle growth, health, safety and environmental issues” the paper suggested that the regulator as well as the operator needs to consider all aspects of safety, health, and environmental issues as a single entity rather than individual matters. This is important as the world is starting to embrace the concerns of global warming and without this total concept the benefits of nuclear energy may not be fully or effectively realized.

SESSION 6 — HUMAN RESOURCES DEVELOPMENT

Throughout the session there were references to successful training partnerships between educational facilities and mining companies. The session confirmed that there is an increased level of interest in training but that it is strongly correlated with exploration budgets and the uranium price. All the presentations noted a general shortage of skilled personnel but the radiation safety sector seemed to be most affected, although the numbers of students studying appropriate sciences, specifically health physics, are increasing.

In his presentation “Training and Education in Uranium, Geology and Exploration”, M. Cuney pointed out that from past experience the amount of research conducted follows exploration budgets, which in turn are related to the uranium price. There is currently a lack of experienced uranium geologists and exploration has relied on retired geologists returning to work. The presentation provided the key aspects that are required in the education and training for exploration and gave some examples of the studies being undertaken at various uranium operations.

The presentation done by H. Ahmadzadeh and J.-L. Petitclerc, “Cooperation with Emerging Countries in Advanced Mining Training Programmes Involving an Industrial Partner”, gave a good example of a partnership of a training programme between education institutes and the mining company AREVA which focuses on the higher education of graduates in the mining sector and personnel already in the mining industry. AREVA has a partnership with the School of Mines and CESMA in Ales, France that have training programmes dedicated to uranium.

J. Trojacek presented his talk “World Nuclear University- School of Uranium Production: An internal training centre”. In his opinion a depressed uranium market has resulted in many experts leaving the industry and so in light of the current resurgence of activity new people need to be trained. He described how an International Training Centre has been developed in the Czech Republic to educate students on all aspects of the uranium cycle.

The training center also provides a forum for networking and helps to establish what is considered “best practice”.

“The United States Uranium Recovery Industry and the Current Nuclear Renaissance: A health physicists perspective” was the title of a presentation by S. Brown which provided an overview of the history of the uranium industry and how the uranium market is recovering. The current situation or renaissance is providing new and good opportunities for radiological scientists of which there is currently a significant shortfall; although there is an increase in the numbers of health physicists being trained. He also provided an overview of the various types of uranium mining conducted in the USA and outlined the contents of generic environmental monitoring and radiation safety programmes.

The final presentation was by J. Slezak who spoke on “IAEA Support to Training and Education in the Uranium Production Cycle — a new task”. He essentially provided a summary of the key aspects of the previous presentations and gave an outline of the network of training and education provided by the IAEA. He also discussed the thought processes required to develop the necessary training programmes.

INAUGURAL SESSION

ADDRESS OF THE SYMPOSIUM PRESIDENT

THE URANIUM WORLD IN TRANSITION FROM STAGNANCY TO REVIVAL

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This International Symposium on the Uranium Raw Materials for the Nuclear Fuel Cycle is in succession of previous uranium symposia organized and hosted by the IAEA over a period of almost four decades — the first conference of this kind took place in 1970.

Although delegates came and come from nations of various political systems, and ethnic or cultural heritage, all these symposia were characterized by a spirit of frankness and tolerance that permitted, in addition to the public presentations, an individual exchange of knowledge and experience beyond that of official directives.

Therefore let me begin by expressing my gratitude to the IAEA authorities, today represented by the Deputy Director General Mr. Y.A. Sokolov, for initiating this conference, and providing the facilities and services.

Mr. C. Ganguly and Mr. J. Slezak also deserve special mention and thanks since they conceived the multidisciplinary program and, together with their co-workers, organized it and put it into action. And as the agenda shows, the spectrum of topics covered this week is indeed broad, ranging from exploration to mining and milling through to environmental, socio-economic and regulatory aspects. Besides providing an update on the state of the uranium industry today, this multidisciplinary approach pursues two additional goals:

- First, to provide an indication of the wealth of information contained in numerous publications covering past and present uranium research, exploration and recovery results, concepts, techniques etc., and
- Second, to promote and facilitate communication, not only between the representatives of the various disciplines actively engaged in the uranium raw materials cycle, but also between professionals and the public.

With respect to the little-known wealth of previously published information:

After the decline of the uranium industry in the 1980s, exploration and mining activities fell dormant for almost a quarter century prior to the revival in the first decade of the 21st century. During that quiet interval, the uranium sector lost many well-trained, experienced and knowledgeable geologists as well as mining and metallurgical engineers. As a consequence, during the ongoing revival, the industry suffers from a lack of staff with depth in uranium-specific knowledge.

As traditional internal company education was largely abandoned — except by a few large corporations that kept their most experienced staff as tutors and mentors for younger trainees — most newcomers had (and still have) to educate themselves, which is not an easy task, especially without mentors. But which is the optimal option to achieve adequate education and, in consequence, professional competency?

To quote Thomas Alva Edison, “there are three ways to achieve education:

- (a) By learning/studying which is the hardest way requiring patience and endurance;
- (b) By copying, which may be the easiest mode, but which is subject to the caprice of fortune; and
- (c) By experience, which represents often the most unnerving or demoralizing and costly mode”.

Due to the lack of mentor and tutorship on one side and lack of patience, ignorance and/or understanding on the other, the younger generation — with few exceptions — tends to perform their duties and solve related problems by their own means without taking the, admittedly, often boring search for and study of relevant literature; in other words, they practically invest their time in trying to re-invent the wheel. In doing so they are acting in an inefficient and costly fashion. Indeed, the search for appropriate literature references has become an arduous task caused by the numerous publications on uranium subjects; but not only that, the content of papers is highly mixed in quality.

The organizers of this symposium hope, therefore, that presentations and discussions this week will provide those interested with sources of pertinent information and that all papers presented will include comprehensive bibliography with adequate accuracy.

With respect to facilitating communication:

There are examples showing that incomplete communication between the various disciplines involved in uranium projects can result in misunderstanding and misinterpretation of data. As this may result in the failure of a project, open communication across disciplinary boundaries needs to be maintained and encouraged at all times.

Not considering emotion-based staff-internal rivalry, clashes of personalities and competing characters fighting for priority of their concepts or methods, different ways of resolving issues and developing solutions are typically the result of profession-specific upbringing and working logic. And even though members of all technical disciplines involved in the uranium cycle may be speaking the same language and may be using the same professional terminology, misunderstanding or misinterpretation of documents and data is common.

A historical case may serve as an example. The exploration department of a mining company has compiled all relevant data of a discovered U deposit hosted in Precambrian rocks in comprehensive reports, maps and tables.

What did the mining department do? Neglecting the distribution of ore properties, the pit was designed in agreement with topographic requirements.

How did the metallurgical department use the deposit documentation? It decided to install autogenous grinders for ore crushing under the assumption that Precambrian rocks are hard and massive. And, by assuming an ore with an average carbonate content of about 3 %, it implemented an acid leach process.

After the first truck loads of ore had been treated, the process engineers complained that

- (a) The grinding technique does not function due to too much argillaceous ore components and that

- (b) The acid consumption exceeds by far the calculated amount. Subsequent analyses of the ore treated showed a carbonate content of some 8–9 %.

What were the reasons for these difficulties? Simply put, the mill designers had ignored the petrographic-mineralogical description of the ore and the miners had ignored in their open pit design the heterogenous carbonate distribution in the deposit.

A scape-goat was quickly found: the geological department, but only for a short while. The geologists could easily show that all features of the deposit were properly documented but were not taken into consideration by the engineers. Clearly, a proper exchange and mutual check of data interpretation by the three departments would have avoided the unpleasant experience.

In order to help to overcome or at least to reduce such interdepartmental communication breakdowns, everybody in this symposium is encouraged not only to attend his profession-specific presentations but also those of the other specialists.

With respect to environmental, socio-economic and public relations aspects:

Last but certainly not least, in these times not only economic conditions but also environmental, socio-economic and social licenses to mine an ore deposit are required, hence trans-disciplinary communication should also be an obligation in the following areas:

Environmental surveys: Underdeveloped co-ordination of geochemical surveys during the exploration stage with environmental studies has been noted. Soil and water sampling by exploration staff and collecting samples for certain environmental studies could easily and cost-efficiently be combined if both parties are capable and willing to co-ordinate their programs.

Socio-economic aspects: Indigenous people like Inuit, Papuas, or Aborigines have historically and culturally different lifestyles and attitudes toward development, compared to people of industrialized nations. Developing cross-cultural understanding and communication skills should be included in standard training programs for company personnel destined to work in regions with indigenous people.

Public relations: Individuals working in the uranium industry are at times asked to respond to critical questions from the public, that are not necessarily friendly in nature. How does one best react to these questions, in particular to those of anti-nuke al-gore-rythms? The tried and true way is still to respond with facts. This, of course, requires the capability to respond in a simple, accurate, and understandable way what one is doing technically but also how his work complies with environmental and regulatory constraints.

In short, this conference attempts to:

- Comprehensively describe the state of the industry;
- Indicate the wealth of information available as a basis for more efficient work and development of new ideas;
- Enhance communication between generations of uranium specialists, separated by a lengthy period of stagnation in the industry;
- Open lines of communication to facilitate understanding between the professional factions and, finally;

- Provide guidance on how to communicate efficiently and tactfully with the public, arguably the industry's most important stakeholder.

OPENING ADDRESS

Y.A. SOKOLOV
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Vienna

Dear ladies and gentlemen, dear colleagues, good morning.

The objective of the IAEA's programme on nuclear power and related nuclear fuel cycle activities is to promote the development of nuclear power and fuel cycle technologies that are economically viable, safe, environmentally friendly, proliferation-resistant and sustainable. Natural uranium is one of the basic raw materials for nuclear fuel.

And so with this in mind we have come together here to participate in the 2009 International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle, URAM-2009. This is the latest in a series of symposia devoted to issues relating to the Uranium Production Cycle (UPC) and many of you will have been at the two previous meetings in 2000 and 2005. Looking back on those meetings we should remember how the intensity and scale of activity in the uranium production cycle has changed since 2000. At that symposium we were looking at how to keep the industry going whilst cleaning up the legacies of the past, ensuring minimal environmental problems for operating mines then and into the future and working out how the long term future of the industry would look. In addition we also considered the issues of maintaining our skills base and ensuring that exploration would continue so we might be prepared for the future.

By the time we had organised the 2005 symposium the global situation had changed dramatically. Uranium prices were increasing steadily towards what would eventually become a record high in 2007. Worldwide there was growing concern about the effects of industrial activity causing climate change and the need to supply more electricity to both industrial and developing nations at a time when fossil fuels were seen to be either significant factors in climate change or of limited life span or both. Nuclear power was increasingly seen as a part of the solution. Expectations about the expansion of existing programmes, the growing interest of many new countries in starting nuclear power programmes and the upward projections for nuclear power capacity for the next 20–30 years led to an increasing demand for nuclear fuel and for uranium. There are no strong signals that this trend is changing under the pressure of economic crisis. In April 2009 the Agency organized an *International Ministerial Conference on Nuclear Energy in the 21st Century* in Beijing. This was the first high level nuclear power conference since the start of the global financial crisis. It was significant that no country reported any scaling back of its nuclear power expansion plans. We are aware that some companies and countries can postpone near-term construction plans for nuclear power, but the important message for the Agency from the Beijing Conference is that we should expect continued high demand for our assistance from Member States exploring the nuclear power option.

In his summation of the 2005 event, the Symposium Chairman from that year, M. Tauchid of Canada indicated two issues.

The first issue was balancing supply and demand with no new mines for many previous years and the prospect of diminishing sources of secondary supply. This is especially important as 10–15 years is the lead time for new production facilities to come on line. Also he mentioned future shortages of skilled personnel in all areas of the UPC, problems of the public perception, and the issues of legacy sites with their adverse impacts on people and the environment.

The second issue was the IAEA's role in addressing the full spectrum of problems of uranium demand and supply. He mentioned a lead in education in the broad sense. This would include helping with the education of the general public and specific communities. Such education would need to be at all levels in all areas of society, including the mining industry and the regulatory community. Another major objective should be to increase efforts to promote the application of good practices in all phases of the UPC to help to prevent the creation of "new legacies". Finally, and perhaps most importantly, M. Tauchid said that the IAEA should be helping to meet the increasing demand for skilled labour through the ongoing interregional and regional training courses and fellowship programmes within the Technical Cooperation programme.

And since 2005, what has happened? New uranium mining companies have been founded all over the world looking to become involved in uranium exploration and mining, perhaps more than 500 of them. One new open pit mine was established in Namibia and the ISL mining in Central Asia in Kazakhstan and Uzbekistan has expanded. Former uranium mines, previously closed in times of low uranium prices were re-examined to see if they would now be profitable. Since the 2005 symposium, we have seen a few new uranium mines brought into production, one in 2007 — the Langer Heinrich mine in Namibia — and three this year alone — and a number of new players, both countries and companies, have emerged to take a significant part in the global expansion of uranium production cycle activities. In addition, a number of IAEA Member States have approached the Agency seeking information about starting up nuclear fuel cycle activities and/or constructing new nuclear power plants, as well as developing their own domestic uranium production cycles with new mines and updated exploration programmes.

Thus, we are in a time of buoyant activity for the uranium production cycle. As a consequence the Agency is busier than ever with increasing numbers of projects being implemented under the Technical Cooperation programme, as well as increased activity in regular budget activities. It must be said that whilst the world is in a period of economic recession, the levels of activity in the uranium mining business seem to be continuing unabated — at least for the larger producer companies and countries. Just some examples: At Olympic Dam in Australia expansion plans are going ahead to create the world's largest open pit uranium mine. Kazakhstan starting two new mines this year and has challenging plans to be the world's leading uranium producer. There is a new mine in Malawi, a new producer country. And in several other countries in Africa, America, Asia and Australasia we will see new uranium mines opening in the next few years, as well as expansion plans at existing facilities.

However, all this activity only exacerbates a growing shortage of people as current training programmes cannot really keep pace with demand. New training facilities are required and new trainers. There are some trends for improvement. In Australia, mining engineering courses at universities are being brought back to life after many years of being dormant; and in the USA, training for the radiation protection to be used in all industries, including uranium mining, has been made a priority development. In France, the Government

sponsors training programmes for overseas students at the various mining schools with increasing levels of participation in the past few years.

The IAEA is providing another form of assistance through promotion of the development and application of leading practices in the uranium mining industry. The project has involved both regulators and operators from the major production countries and has so far seen the publication of the WNA's principles for sustainable development in uranium mining last year, as an output from the joint project. A Technical Meeting held in Vienna last October also followed on this theme and plans are being prepared for the next stage of the project. Further efforts are planned and the support of the larger players from both sides of the industry is being channelled to assist and mentor the up and coming players, be they operators or regulators or new producer countries.

In another support effort, the IAEA has revived the Uranium Production Site Appraisal Team (UPSAT) programme to meet the needs of some Members States. This peer review process has already been requested by one Member State for a review of existing uranium mining activity and proposed expansion plans; this review is scheduled for October this year. Further UPSAT review requests are being contemplated by other Member States for implementation next year.

It is in this dynamic environment, therefore, that we are proudly hosting the URAM 2009 Symposium together with our three cooperating agencies: the Nuclear Energy Agency of the Organization for Economic Cooperation and Development, the Nuclear Energy Institute and the World Nuclear Association. All of these organisations have been associated with our previous symposia in 2000 and 2005. I thank them on your behalf for their on-going interest and association with this event.

And of course I must also acknowledge the significant assistance of our sponsors AREVA SA and Cameco Corp. Limited who have contributed so generously towards the side events at this meeting.

I hope that this will prove to be a week when old networks can be revived and reinforced as well as new contacts made. We hope the programme, which will be described by those who follow me, will meet your expectations. It remains only for me to welcome you again to Vienna and the IAEA and to wish you every success in your discussions this week in what I am sure will be a fruitful and rewarding symposium.

IAEA ACTIVITIES ON URANIUM RESOURCES AND PRODUCTION, AND DATABASES FOR THE NUCLEAR FUEL CYCLE

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Abstract

In recent years rising expectation for nuclear power has led to a significant increase in the demand for uranium and in turn dramatic increases in uranium exploration, mining and ore processing activities worldwide. Several new countries, often with limited experience, have also embarked on these activities. The ultimate goal of the uranium raw material industry is to provide an adequate supply of uranium that can be delivered to the market place at a competitive price by environmentally sound, mining and milling practices. The IAEA's programme on uranium raw material encompass all aspects of uranium geology and deposits, exploration, resources, supply and demand, uranium mining and ore processing, environmental issues in the uranium production cycle and databases for the uranium fuel cycle. Radiological safety and environmental protection are major challenges in uranium mines and mills and their remediation. The IAEA has revived its programme for the Uranium Production Site Appraisal Team (UPSAT) to assist Member States to improve operational and safety performances at uranium mines and mill sites. The present paper summarizes the ongoing activities of IAEA on uranium raw material, highlighting the status of global uranium resources, their supply and demand, the IAEA database on world uranium deposit (UDEPO) and nuclear fuel cycle information system (NFCIS), recent IAEA Technical Meetings (TM) and related ongoing Technical Cooperation (TC) projects.

1. INTRODUCTION

Nuclear power is emerging as one of the viable options to meet the ever increasing demand of energy and electricity without degrading the environment. The present fleet of some 436 operating nuclear power reactors in 30 countries, with a total installed capacity of ~ 370 GW(e), generates more than 14% of the world's electricity. Fifty-two reactors are in different stages of construction and rapid expansion of nuclear power programmes is foreseen. The IAEA low and high projections for nuclear power in 2030 are 473 GW(e) and 748 GW(e) respectively [1].

Natural uranium is the basic raw material for nuclear fuels. The present generation of nuclear power reactors derive energy from the fission of ^{235}U , the only fissile isotope in nature. Light water reactors (LWR) account for more than 85% of the operating power reactors followed by pressurized heavy water (PHWR) reactors which contribute ~6%. The PHWRs and LWRs use natural uranium (0.7% ^{235}U) and low enriched uranium containing <5% ^{235}U , respectively, as fuel in the form of high density uranium oxide pellets, encapsulated in zirconium alloy cladding tubes. The LWRs and PHWRs also transmute the more abundant ^{238}U 'fertile' isotope to the man-made 'fissile' isotope ^{239}Pu . In-situ fission of ^{239}Pu contributes ~30% of the fission heat energy in operating reactors. Reactors operating with 'once-through' 'open' fuel cycle utilize only 1% (even less) of the uranium that is mined and processed for making nuclear fuel, the rest is locked in the tailings of ^{235}U enrichment plants and in spent fuel. The spent nuclear fuel contains ~1% plutonium and ~94% unutilized uranium, mostly in the form of U^{238} . The reprocessed uranium (Rep.U) and plutonium could be subjected to multiple recycling in fast breeder reactors, where more plutonium would be bred from ^{238}U than consumed during fission. Thus a fast reactor with a closed $^{238}\text{U} \rightarrow ^{239}\text{Pu}$ fuel cycle would ensure at least 60% utilization of natural uranium resources, thereby reducing the demand for uranium and facilitating the long-term sustainability of nuclear energy.

The nuclear fuel cycle with its different steps is shown in Figure 1. The front end of the fuel cycle consists of mining, processing and refining of uranium ore to form uranium concentrate known as yellow cake, followed by conversion to oxide and hexafluoride, ^{235}U enrichment, reconversion to oxide powder, pelletization of oxide fuel, encapsulation in cladding tubes and forming of fuel assemblies for loading into the reactor. PHWR fuel does not require the conversion and enrichment steps.

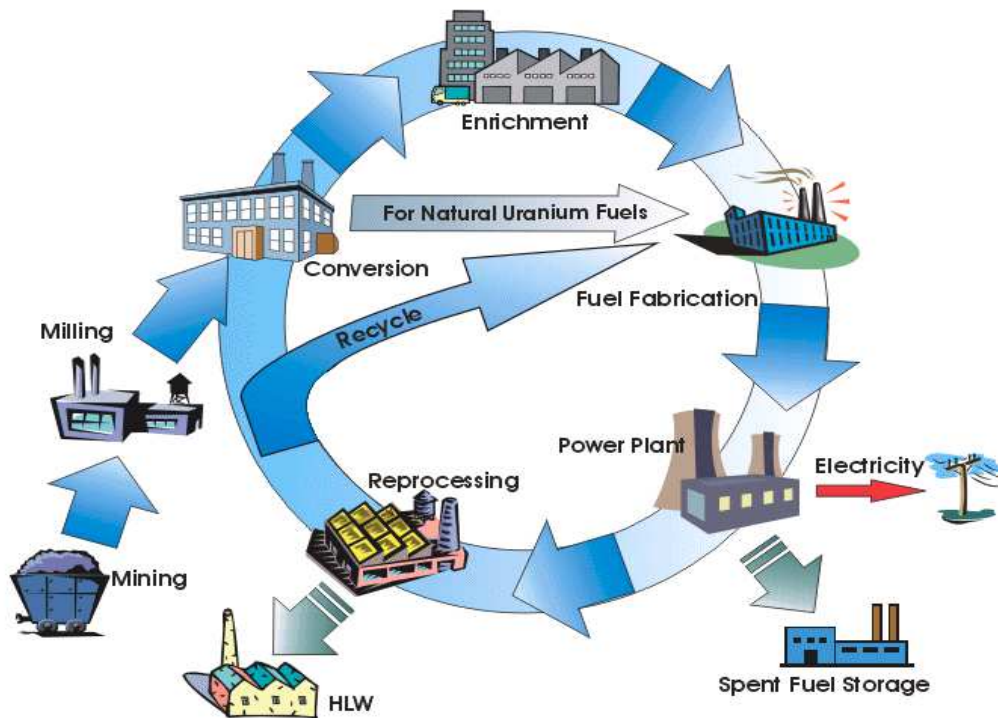


FIG. 1. Stages of front and back ends of nuclear.

The IAEA's Major Programme 1.2 (often referred to as Programme B) on 'nuclear fuel cycle and materials technology' aims to facilitate the development of nuclear power reactor fuel cycle options that: i) are economically viable; ii) make efficient utilization of natural uranium and thorium resources; iii) are safe and environmentally friendly, iv) are proliferation resistant and v) sustainable. One of the Sub-programmes under Programme B (or 1.2.) is B 1 (or 1.2.1.) on 'uranium resources and production and databases for the nuclear fuel cycle'. The ultimate goal of the uranium raw material industry is to provide an adequate supply of uranium that can be delivered to the market at a competitive price by environmentally sound mining and milling practices. Accordingly, the following two projects have been included in the sub-programme B1:

- B1.1.) updating uranium resources, supply and demand and nuclear fuel cycle databases; and,
- B1.2.) supporting good practices in uranium production.

2. URANIUM RESOURCES: DEMAND AND PRODUCTION

During the previous IAEA international symposium on ‘uranium production and raw materials for the nuclear fuel cycle’ in June 2005 [2], the uranium industry appeared to be at the dawn of a new era after nearly two decades of an extremely depressed market for natural uranium (spot price: <US \$10/lbU₃O₈) and mine closures all over the world. But from 2005 onwards, there has been a dramatic expansion of uranium exploration activities all over the world. The uranium spot price shot up from ~US \$30/lbU₃O₈ in June 2005 to US \$138/lbU₃O₈ in July 2007. However, in 2008 the uranium spot price fell significantly and was in the range of US \$50–60/lbU₃O₈. The uranium spot price stabilized in the area of ~US \$50/lbU₃O₈ in the middle of 2009.

The IAEA, in collaboration with OECD/NEA, prepares an authoritative report, popularly known as the Red Book, on uranium resources, production and demand, based on the input from the governments of producing countries. The Red Book is published biennially by OECD/NEA. The Red Book 2009 is under preparation and will include the data as on 1st January 2009. The Red Book 2007 has reported that the total of identified uranium resources, at a price < US \$130/kgU, is about 5.47 million tonnes as shown in Table 1 [3]. The total undiscovered uranium resources is about 10.5 million tonnes. Fig. 2 summarizes the changes in the uranium resources base, demand and production during the period from 2000–2006, based on the information in the different editions of the Red Book. The uranium resources base has increased over the years but the annual demand and production of uranium has remained in the range of 66 000 tonnes and 40 000 tonnes respectively. The identified uranium resource of 5.47 Mt is sufficient for about 100 years of supply assuming an annual rate of uranium consumption at the level of the year 2006 (~ 66 500 tonnes per year) for ‘once through’ use of nuclear fuel in the reactor [3]. By using fast reactors and the closed fuel cycle involving multiple recycling of RepU and Pu, the identified uranium reserves will last for 2 500 years as shown in Table 1.

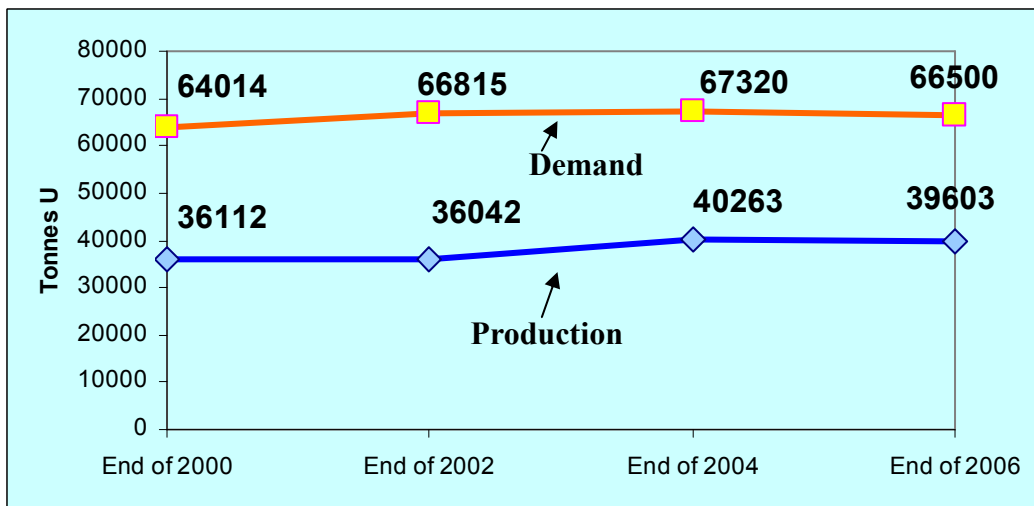
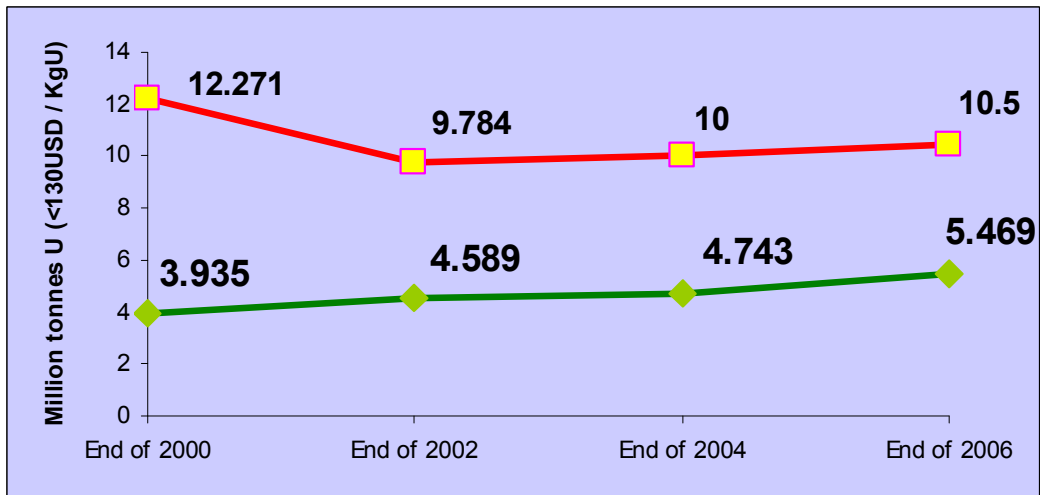


FIG. 2. Uranium resource base (top) and demand and production (bottom) during the period from 2000–2006.

TABLE 1. CONVENTIONAL AND UNCONVENTIONAL URANIUM RESOURCES AND THEIR UTILIZATION FOR NUCLEAR

Identified Uranium Resources (< 130 US\$ per kg U)	5.47 Mt	Number of Years Uranium Resources will last assuming annual uranium consumption of ~ 66 500 tonnes (corresponding to the year 2006)		
Total Conventional Uranium Resources	15.9 Mt			
Unconventional Uranium Resources (rock phosphates)	22			
Reactor/Fuel Cycle		Using only Identified Resources	Using total Conventional Resources	Using Total Conventional and Unconventional Resources (Rock Phosphate, etc.)
Current Technology		~ 100 years	300 years	> 675 years
Fast reactors with closed fuel cycle and recycling		> 2 500 years	> 8 000 years	~ 20 000 years

So far, the largest identified uranium resources are in Australia (23%). This is followed by Kazakhstan (15%), Russian Federation (10%) and Canada (8%). However, Canada has the highest grade of uranium ores and is also currently the largest producer of uranium. Preliminary information collected for the Red Book 2009 indicates that the identified resource base is likely to increase by 10–15%. The annual uranium production in 2008 has also increased to ~ 43 930 tonnes. The uranium production in 2008 in Australia, Canada, Kazakhstan, Namibia, Niger and Russian Federation has been 8 430 t, 9 000 t, 8 521 t, 4 366 t, 3 032 t, and 3 521 t, respectively.

The uranium resources are more or less uniformly distributed in the five continents, as shown in Fig. 3.

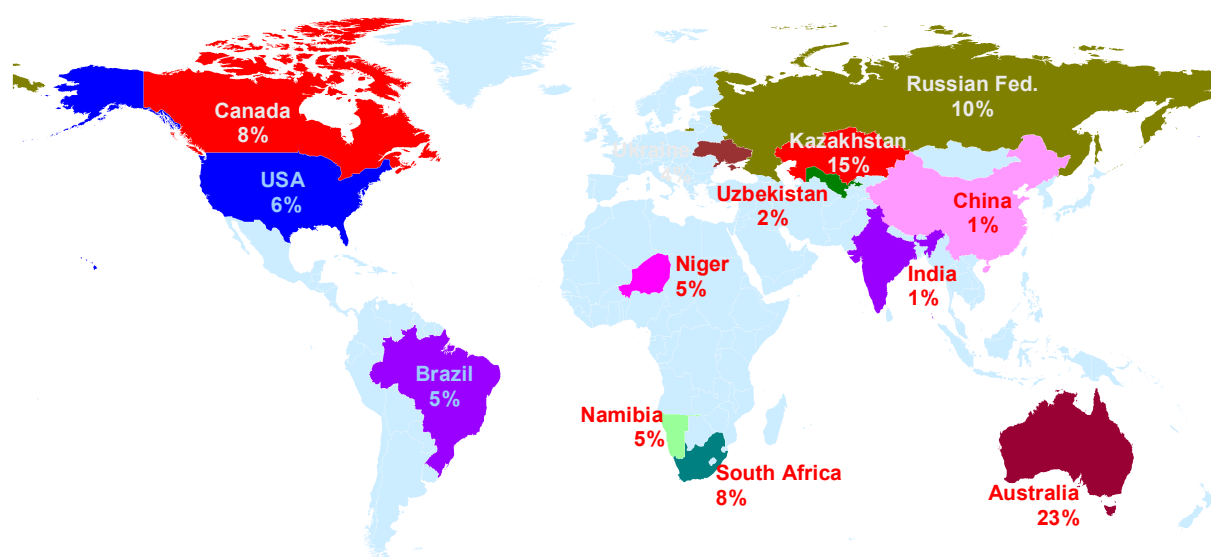


FIG. 3. Uranium resources worldwide [3].

But most of the uranium is mined and produced in countries not having a nuclear power programme and is consumed in countries having no uranium, as shown in Table 2.

TABLE 2. COUNTRIES WITH MAJOR URANIUM RESOURCES AND NUCLEAR POWER REACTORS

Country	Uranium Resources (tonnes U)	% of World Uranium resources	No of nuclear power reactors (% total electricity)
Major Uranium Producers without any Nuclear Power Plants			
Australia	1 243 000	23	NIL
Kazakhstan	817 300	15	
Namibia	275 000	5	
Niger	274 000	5	
Major Uranium Producers with Nuclear Power Plants			
USA	339 000	6	104 (20%)
Canada	423 200	8	18 (15%)
South Africa	435 100	8	2 (5%)
Russia	545 600	10	31 (17%)
Brazil	278 400	5	2 (3%)
China	67 900	1	11 (2%)
India	72 900	1	17 (2%)
Major Nuclear Electricity Producing Countries without Uranium Resources			
France	NIL		59 (76%)
Germany			17 (28%)
Japan			53 (25%)
Republic of Korea			20 (36%)
United Kingdom			19 (13%)
Sweden			10 (42%)

3. IAEA DATABASES ON URANIUM RAW MATERIALS

The integrated nuclear fuel cycle information system of the Agency (iNFCIS) contains two databases relevant to uranium raw materials, namely, i) World Distribution of Uranium Deposits (UDEPO), and ii) Nuclear Fuel Cycle Information System (NFCIS).

Presently, the UDEPO database contains detailed technical and geological information for more than 1 000 uranium deposits in 64 countries [4]. The database is on-line and freely accessible. It includes deposits containing more than 500 tonnes of uranium with minimum average grade of 0.03% U. All types of deposits namely, unconformity, sandstone, hematit breccia complex, quartz pebble conglomerate, volcanic, intrusive, vein, metasomatic, etc., are included.

A similar database on world distribution of thorium deposits (ThDEPO) has been planned.

The NFCIS is an on-line directory of civilian nuclear fuel facilities worldwide. Presently, 689 facilities in 55 countries are covered in the directory. The facilities include details and capacities of uranium mines, mills and conversion, enrichment and fuel fabrication plants, spent fuel storage facilities and reprocessing and mixed uranium-plutonium fuel fabrication plants [5].

4. URANIUM PRODUCTION CYCLE

Fig. 4 shows the essential steps in the uranium production cycle including exploration, mining, milling and mine and mill reclamation and remediation. Since most of the ‘easy to find’ uranium deposits have already been identified, advanced exploration techniques based on airborne and ground geophysics would be needed for finding new uranium deposits which are deeply burried and do not have a surface expression.



FIG. 4. Uranium production cycle.

Starting from a greenfield situation, it usually takes around ten years to identify and characterize a uranium deposit. This is followed by another five years to develop the deposit and get the necessary licenses for uranium production. The IAEA organized some technical meetings in 2006, in Argentina, China, India and Kazakhstan, where, state-of-the-art information on geophysical methods with geological models, airborne electro-magnetic measurements, seismic methods, etc. were disseminated.

The new uranium deposits that will be discovered are likely to be of lower grade and smaller in quantity. Advanced mining technology will need to be developed and adapted for improving the efficiency and economics of uranium mining. Historically, underground, open pit and In-Situ Leach (ISL) mining are the main methods for exploiting uranium deposits. The In-Situ Leach (ISL) mining technique has been gaining popularity over the last decade in Australia, China, Kazakhstan, Russian Federation, USA and Uzbekistan, and presently accounts for nearly 30% of the uranium production worldwide. The ISL mining utilizes acid

or alkaline solutions to extract uranium directly from the deposit. However, ISL mining could only be utilized in porous ore bodies in sandstone deposits.

Uranium and its daughter products are radioactive and present some health hazards. Regulatory requirements are becoming increasingly stringent, particularly in relation to annual radiation doses to mine and mill personnel, water discharge quality and tailings disposal. The IAEA has recently revived the Uranium Production Site Appraisal Team (UPSAT) procedure to assist Member States in improving the operation and safety of uranium mine and mill sites through a system of peer review involving international experts. The first UPSAT mission is planned at the uranium mine and mill site in Caetite, Brazil, in the last quarter of 2009.

5. HUMAN RESOURCE DEVELOPMENT AND TECHNICAL COOPERATION PROJECTS

Significant and growing challenges for the expanding activities in the uranium production cycle are the ageing of working personnel in the uranium industry and the shortage of young and experienced geologists, mining engineers, chemical engineers and metallurgists, and environmentalists scientists. The ongoing and forthcoming IAEA programmes have given a lot of emphasis to human resource development. Several training programmes and workshops covering best practices in the uranium production cycle have been organized, mainly for the benefit of the new countries in the uranium exploration and raw material industries. Table 3 gives a list of the IAEA technical meetings conducted during the period from July 2005 to June 2009.

TABLE 3. IAEA TECHNICAL MEETINGS ON URANIUM RAW MATERIALS FROM 2006–2008

Date	Place	Title
20–24 March 2006	Sighbhum, India	TM on ‘Aerial and Ground Geophysical Techniques for Uranium Exploration and Advanced Mining and Milling Methods and Equipment’
30 August–1 September 2006	Almaty, Kazakhstan	TM on ‘In-Situ Leaching (ISL) of Uranium Deposits’
2–6 October 2006	Mendoza, Argentina	TM on ‘Uranium Exploration, Mining, Production, Mine Remediation and Environmental Issues’
19–22 June 2007	Vienna, Austria	TM on ‘Uranium Small-Scale and Special Mining and Processing Technologies’
1–5 October 2007	Swakopmund, Namibia	TM on ‘Uranium Exploration, Mining, Processing, Mine and Mill Remediation and Environmental Issues’
1–2 November 2007	Vienna, Austria	TM on ‘Recent Developments in Uranium Exploration, Resources, Production and Demand’
15–17 October 2008	Vienna, Austria	TM on ‘the Implementation of Sustainable Global Best Practices in Uranium Mining and Processing’
17–20 November 2008	Amman, Jordan	TM on ‘Uranium Exploration and Mining Methods’

A number of IAEA Member States have asked for Technical Cooperation (TC) projects in uranium exploration and production cycle. Table 4 gives the list of the recent TC project

TABLE 4. RECENT IAEA TECHNICAL COOPERATION PROJECTS

Country/Region	Title of the Technical Cooperation Project
Argentina	Geology Favourability, Production Feasibility and Environmental Impact Assessment of Uranium Deposits to be Exploited using In Situ Leaching Technology
China	Study of the Key Problems in Prospecting for Sandstone-Type Uranium Deposits and their Amenability to In-Situ Leach (ISL) Mining in the Basins in Northern China
Egypt	Airborne and Ground Gamma-Ray Spectrometry for Radio-element Mapping for Environmental Purposes and for Exploration of Uranium Resources
Pakistan	Uranium geochemistry, mineralogy and host rock uranium deposit description
Regional Latin America	Regional Upgrading of Uranium Exploration, Exploitation and Yellowcake Production Techniques taking Environmental Problems into Account
Algeria	Contribution to the development of activities for the processing of Algerian ores and purification of uranium concentrates
Brazil	Practical guidance tools for nuclear safety analysis of remediation and decommissioning actions of the first uranium ore mining and milling facility in Brazil
China	Techniques And Methods For Optimization Of Uranium Exploration in Both Sedimentary and Volcanic Basins
China	Integrated assistance to institutions supporting nuclear power programme
Egypt	Evaluation of some selected uranium resources in Egypt and production and purification of the yellow cake
Jordan	Uranium exploration
Jordan	Uranium extraction
Regional Africa	Strengthening regional capabilities for uranium mining, milling and regulation of related activities
Venezuela	Exploración de los recursos uraníferos de Venezuela

The IAEA has also published several documents highlighting good practices, occupational radiation protection in uranium mines and mills and management of radioactive wastes from mining and milling of uranium ores. Some of these documents are listed below:

- (1) 'Current Practices for the Management and Confinement of Uranium Mill Tailings', Technical Reports Series no. 335, 1992;
- (2) 'Measurement and Calculation of Radon Releases from Uranium Mill Tailings', Technical Reports Series no. 333, 1992;
- (3) 'Guidebook on Good Practice in the Management of Uranium Mining and Mill Operations and the Preparation for their Closure', IAEA Tecdoc-1059, 1998;
- (4) 'Occupational Radiation Protection', IAEA Safety Standards Series no. RS-G1.1, 1999;
- (5) 'Impact of New Environmental and Safety Regulations on Uranium Exploration, Mining, Milling and Management of its Waste, IAEA Tecdoc-1244, 2001;
- (6) 'Monitoring and Surveillance of Residues from the Mining and Milling of Uranium and Thorium, Safety Reports Series no. 27, 2002;

- (7) 'Management of Radioactive Waste from the Mining and Milling of Ores', IAEA Safety Standards Series no. WS-G1.2., 2002;
- (8) 'Occupational Radiation Protection in the Mining and Processing of Raw Materials', IAEA Safety Standards Series no. RS-G1.6, 2004;
- (9) 'Guidebook on Environmental Impact Assessment for In Situ Leach Mining Projects, IAEA Tecdoc-1428, 2005;
- (10) 'Assessing the Need for Radiation Protection Measures in Work Involving Minerals and Raw Materials', Safety Reports Series no. 49, 2006.

6. CHALLENGES AHEAD

The nuclear fuel cycle in general should meet all requirements related to economics, environmental protection, safety, proliferation resistance and security. In the uranium production cycle during the last two decades, primary supplies of uranium from mines have provided less than two thirds of the annual uranium demand. With rising expectations for nuclear power, uranium demands are increasing and new mines will be needed because the secondary resources of uranium will be progressively reduced in coming years. New countries with limited experience in uranium exploration, mining and production, have recently entered the uranium raw material industry. The following are the major challenges in the uranium industry which need to be addressed for long-term sustainability of uranium supply to fuel the operation and forthcoming nuclear power reactors:

- The uranium resource base has to be increased by adapting advanced geophysical and geochemical methods for exploration. The gap between uranium in the ground and the yellow cake (uranium concentrate) in the can has to be reduced by shortening the time taken for licensing and deploying efficient mining and milling processes; the licensing time could be minimized by pro-active initiatives on best practices in the uranium production cycle, radiological and mine safety, environmental protection and mine reclamation and remediation;
- Issues related to 'Social Licensing';
- Issues related to ageing and retiring human resources and the shortage of experts.

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- [3] OECD NUCLEAR ATOMIC ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, A Joint Report by the OECD Nuclear Energy Agency and the IAEA (2008).
- [4] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Database on World Distribution of Uranium Deposits (UDEPO), IAEA, Vienna (2009).

- [5] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Fuel Cycle Information System — A Directory of Nuclear Fuel Cycle Facilities, IAEA-TECDOC-1613, IAEA, Vienna (2009).

URANIUM MARKETS AND ECONOMICS
(Session 1)

PARADIGMATIC SHIFTS IN EXPLORATION PROCESS: THE ROLE OF INDUSTRY-ACADEMIA COLLABORATIVE RESEARCH AND DEVELOPMENT IN DISCOVERING THE NEXT GENERATION OF URANIUM ORE DEPOSITS

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Abstract

Uranium exploration increased over the past decade in a sympathetic response to a rapid increase in the price of uranium, inspired by fuel supply-demand and stock market dynamics. Exploration activity likely peaked during this cycle in 2008 with in excess of 900 companies engaged in the global exploration of a portfolio of over 3000 projects. Global uranium exploration expenditures for the period 2004–2008 are estimated at US\$3.2 billion — from US\$130 million in 2004 to an estimated peak of US\$1.2 billion in 2008. A major focus of the exploration effort has been on brown-fields exploration in historical uranium districts. Less effort has been devoted to exploration at green-field frontiers. A significant reduction in global exploration expenditures in 2009 and beyond is anticipated concurrent with the global recession. There is not much evidence to indicate that brand-new, large, and higher grade, uranium deposits have been discovered during this uranium exploration cycle. It is likely that future uranium explorers will need to be more efficient and effective in their efforts and to adopt new and innovative business strategies for their survival and success. This paper addresses some of the fundamental reasons why major economic discoveries of uranium ore bodies have been elusive over the past two decades, through a cyclical model known as the 'learning curve', using the prolific Athabasca Basin, Saskatchewan, as an exemplar. This model relates exploration expenditure, quantities of discovered uranium, and the sequence of uranium deposit discoveries, to reveal that discovery cycles are epochal in nature and that they are also intimately related to the development and deployment of new exploration technologies. The history of uranium exploration is parsed into the early 'prospector' exploration phase (1960–1980) and the current 'model driven' phase (1981–present). The future of successful uranium exploration is envisaged as 'innovation exploration' where a paradigmatic shift in the exploration approach will take the industry toward new discoveries by leveraging research and technology development. Effective engagement within the 'innovation exploration' paradigm will require that exploration organizations adopt industry-academia research, development, and technology transfer as a priority long-term, systematic strategy. Leadership and management strengths need to be co-opted to bring the academic and industry team systems together for success, through the use of informational, relational and reflective learning strategies.

1. THE ATHABASCA BASIN EXPLORATION LEARNING CURVE

Uranium exploration increased over the past decade in a sympathetic response to a rapid increase in the price of uranium, inspired by fuel supply-demand, and stock market dynamics. Global uranium exploration expenditures for the period 2004–2008 are estimated at US\$3.2 billion — from US\$130 million in 2004, to an estimated peak of US\$1.2 billion in 2008. A major focus of the exploration effort has been on brown-fields exploration in historical uranium districts. Less effort has been devoted to exploration at green-field frontiers. A significant reduction in global exploration expenditures in 2009 and beyond is anticipated concurrent with the global recession. Exploration activity likely peaked during this cycle in 2008, with in excess of 900 companies, engaged in the global exploration of a portfolio of over 3 000 uranium exploration projects (Figure 1).

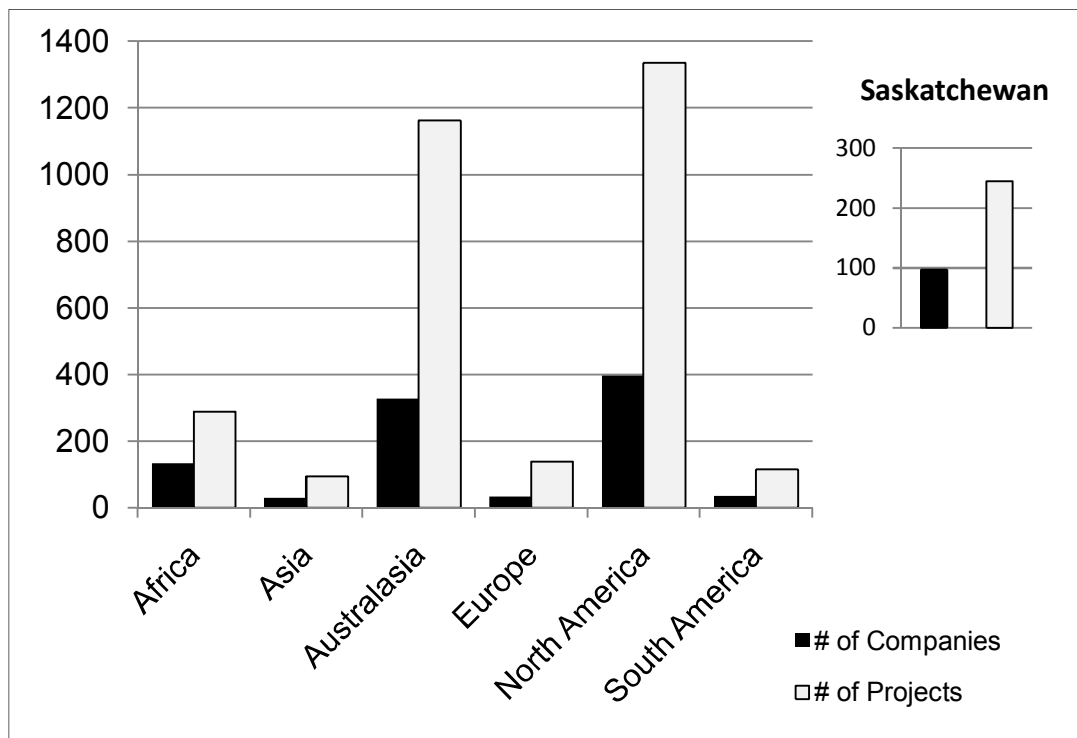


FIG. 1. Global distribution of publicly traded uranium companies, and uranium exploration projects (966 companies and 3 149 properties as of May 2009; Source: Intierra Minmet database).

By way of example, in Saskatchewan about 100 companies claimed some sort of ownership in over 200 uranium exploration projects. Approximately CDN\$650 million will have been invested in uranium exploration in this jurisdiction during the period 2000–2009 (Fig. 2). In Saskatchewan the focus has been on exploring for high grade unconformity related deposits in the Athabasca Basin, which has yielded economic deposits with exceptional grade, and tonnage characteristics (Fig. 3). There is not much evidence to indicate that significant brand-new, large, and higher grade, economic uranium deposits have been discovered in the Athabasca Basin or around the world during the most recent uranium exploration cycle.

This paper addresses some of the fundamental reasons why major economic discoveries of uranium ore bodies have been elusive over the past two decades, through a cyclical model known as the ‘learning curve’, using the prolific Athabasca Basin, Saskatchewan, as an exemplar (Fig. 4). This model incorporates elements relating exploration expenditure, quantities of discovered uranium, and the sequence of uranium deposit discoveries, to reveal that discovery cycles are epochal in nature, and that they are also intimately related to the development, and deployment of new exploration technologies. The history of uranium exploration is parsed into the early ‘prospector’ exploration phase (1960–1980), and the current model driven phase (1981–present). The future of successful uranium exploration is envisaged as ‘innovation exploration’ where a paradigmatic shift in the exploration approach will take the industry towards new discoveries through research, and technology driven exploration. The authors believe that this new epoch of innovative uranium exploration has arrived in the Athabasca Basin, and globally.

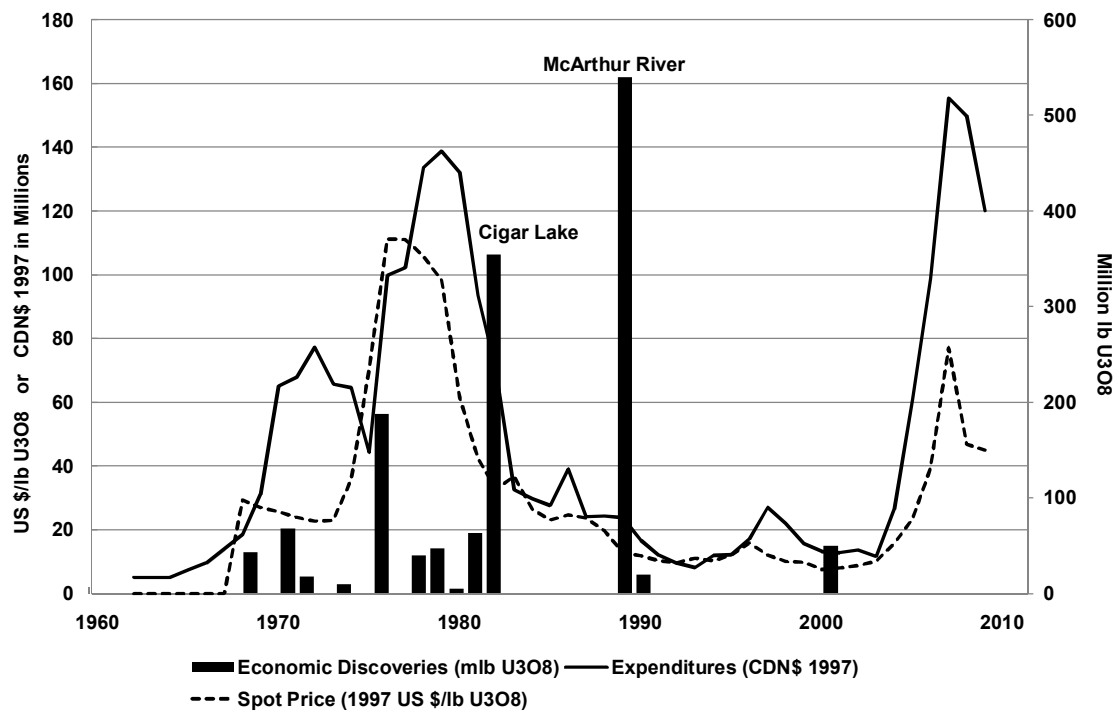


FIG. 2. History of economic uranium deposit discoveries in the Athabasca Basin (dollar values adjusted for inflation) with reference to spot price, and exploration expenditures

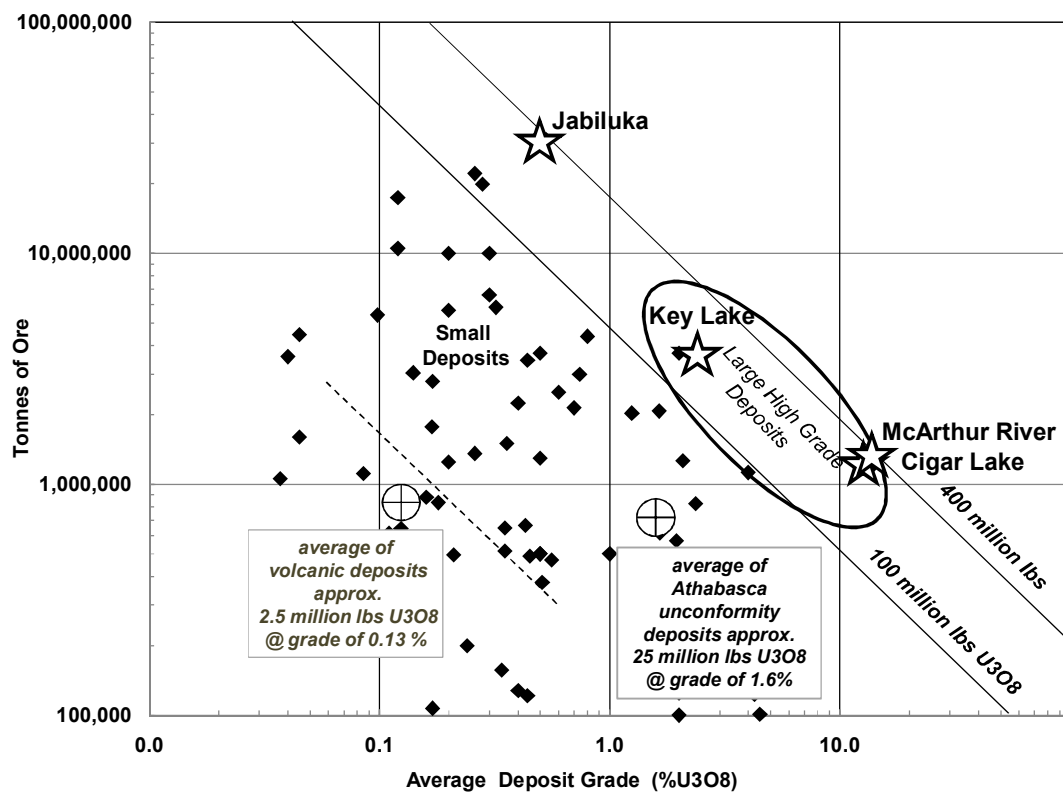


FIG. 3. Grade-tonnage plot of global distribution of unconformity-related uranium deposits (economic and uneconomic).

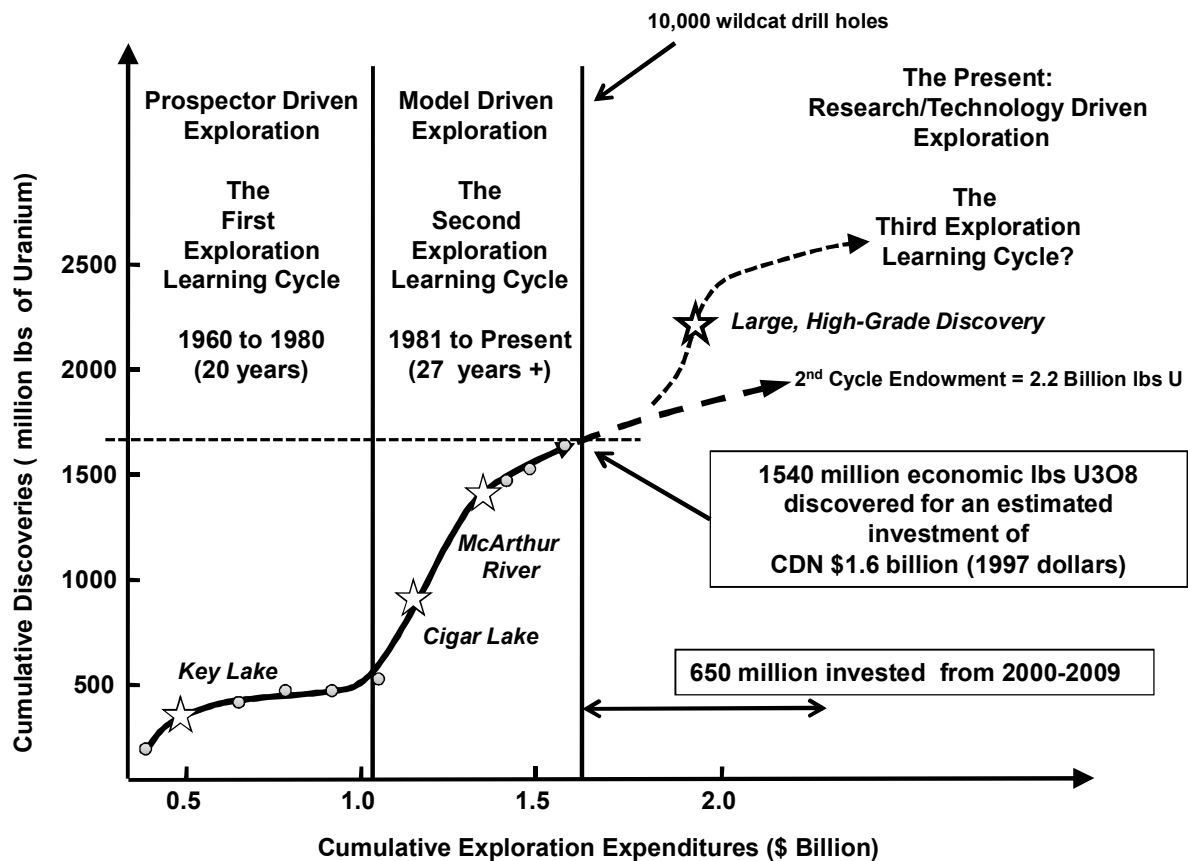


FIG. 4. The uranium exploration 'Learning Curve' using the Athabasca Basin as an exemplar, after Harris, Zaluski and Marlatt [1].

A learning curve was developed for the Athabasca Basin to better understand the relationship between exploration effort (as measured by expenditure) and exploration outcomes (as measured by economic mineral resource discovery) [1]. A framework of correlating cumulative historical expenditures and historical economic resource discoveries was developed based on historical expenditure and discovery data. A two-cycle learning curve was developed for the basin, with the first cycle correlating with early-stage exploration in shallow basin environments (Prospector Phase) and second-cycle correlating with deep basin exploration (Empirical/Genetic Deposit Model Phase) [2]. Several mathematical models were developed for the learning curve system. Outcomes of the analysis included: a mathematically robust method to estimate the total basin endowment of economic mineral resources for the Athabasca Basin, a probability density function (or cumulative frequency distribution) depicting the expected quantum of economic mineral resource discovery given additional future exploration expenditures, and a framework for assessing the implication of incremental innovation (staying on the same learning curve) and radical innovation (moving to a new learning curve). Similar complementary assessments were investigated including the use of Hubbert curves described by Harris [3], and the development of historical cost curves based on the work of Mackenzie and Woodall [4].

The 'prospector' driven exploration cycle covered the period from 1960 to about 1980 and was defined by the discovery of the Key Lake deposit. During this cycle deposits were discovered at relatively shallow depths of Athabasca sandstone cover of <400 m. The Key

Lake deposit became the exemplar of the unconformity related uranium deposit, and the correlation of the deposit with sub-sandstone basement graphitic gneisses offered an efficient exploration target focus that is still pursued to this day. Radioactive boulder prospecting and airborne and ground electromagnetic technologies were successfully deployed during this cycle. The discovery of the large Cigar Lake and McArthur River deposits demarcated the 'model driven' exploration cycle from around 1980 to present. Deposit models were further refined and empirical 'fingerprints' were established. Exploration focused on searching for typical lithogeochemical, geological, and geophysical expressions of unconformity related deposits. The development of deeper penetrating airborne and ground electromagnetic platforms allowed the definition of prospective basement conductive targets at depths from about 400 m to in excess of 800 m.

Recent advancements in airborne magnetotelluric technologies offer the potential to identify basement graphitic gneisses at depths in excess of one kilometre and correlative, favourable, sandstone hosted hydrothermal alteration cells. Another emergent technology focus is the development of refined biogeochemical and lithogeochemical technologies. These events are viewed as harbingers of the third 'innovation' exploration cycle.

In tandem with these developments, industry-academia research was initiated during the first learning cycle, and has continued to this day with a diverse focus including the study of the metallogeny of ore deposit systems, holistic basin analysis, and the development of innovative geochemical technologies. Uranerz, Cameco, and Areva were key industry players in facilitating independent and collaborative studies with M. Cuney, the Queen's Facility for Isotope Research, and many others.

The analysis of the learning curves and associated data indicates that approximately 1.55 billion economic lbs U_3O_8 (830 000 tonnes U) have been discovered in the Athabasca Basin at a cost of CDN\$ 1.6 billion (1997 dollars). The total economic uranium endowment of the Athabasca Basin is estimated at about 2.2 billion lbs U_3O_8 (1.2 m tonnes U), leaving about 650 million lbs U_3O_8 (350 000 tonnes U) available for discovery on the second learning curve. From 2000–2009 approximately CDN\$650 million has been spent exploring for these economic resources, with no large new economic discoveries. Generally speaking larger discoveries are typically made early in the evolution of the learning cycle, and the exploration for depleting economic resources late in the evolution of the learning cycle will entail greater cost, effort, and more time. Mathematical modelling predicts that discoveries on the asymptotic tail of the second learning curve will be, on average, relatively small in comparison to the larger deposits discovered earlier in the cycle (Fig. 5). This model suggests that a future incremental investment of CDN\$150 million in reconnaissance exploration should lead to the discovery of an economic deposit with an average size of 80 million lbs U_3O_8 (43 000 tonnes U) although smaller or larger deposits can also be expected. An expenditure level of over 4 times during this amount has yielded no large new economic discoveries.

The absence of economic discoveries during the most recent uranium exploration cycle defines a mature and heavily explored exploration environment that is not responding to the deployment of conventional exploration technologies. The recognition of ineffective exploration signals the requirement to move to a new learning cycle for discovery, or to consider exiting the basin as a business strategy.

2. INVESTMENT WORTH OF INDUSTRY-ACADEMIA COLLABORATIVE RESEARCH

At an intermediate level of our analysis, the role that investing in industry-academia collaborative research, and development can play in facilitating paradigmatic shifts in exploration process, and increasing the probability of discovery of the next generation of uranium ore deposits over the next decade is assessed. The return on investment of industry-academia collaborative research, development, and technology transfer is investigated from a qualitative perspective. Key success factors, and hurdles, in uranium research, development, and technology transfer programs are illustrated by reference to a long term collaborative research project that originated in the exploration for unconformity related uranium deposits in the Kombolgie Basin, Australia.

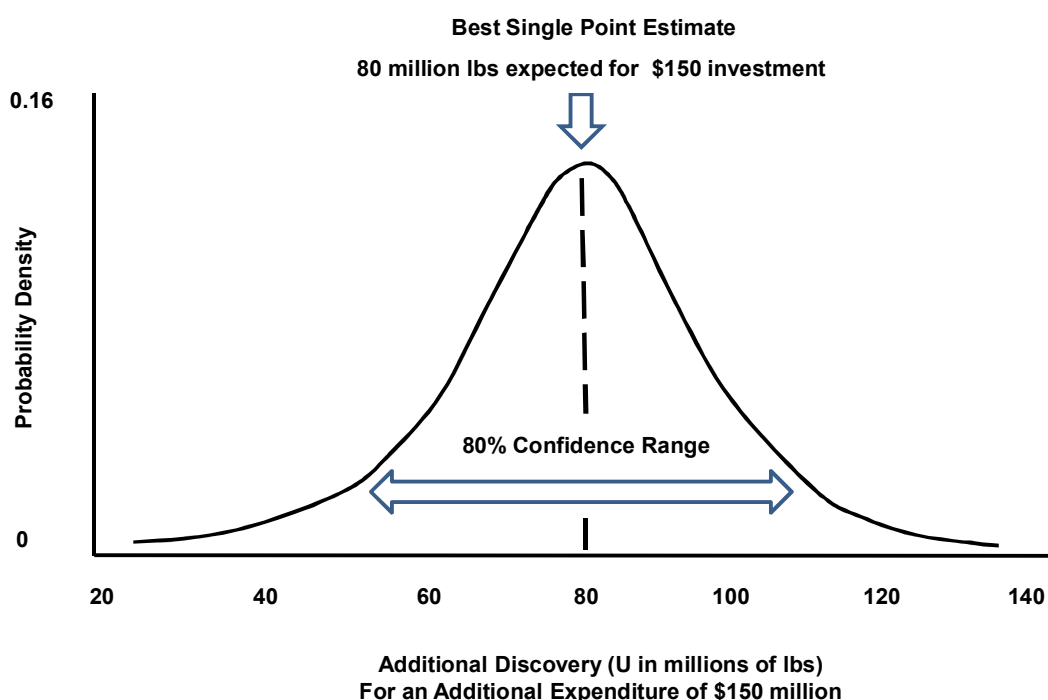


FIG. 5. Expected discovery of uranium in the Athabasca Basin given an expenditure of \$150 million, after Harris, Zaluski and Marlatt [1].

Mineral exploration is the business of transforming geoscientific knowledge into economic mineral deposits for competitive advantage, through the effective and efficient management of people, processes and resources involved in basic and applied research and geotechnology development and deployment. One of the key drivers of success in the mineral exploration business is the pursuit of competitive advantage through incremental or radical innovation — introduction of new processes or new ways of understanding and doing things. In particular, successful innovation is typically borne out of wise data gathering, collation and organization of information, and the derivation and dissemination of knowledge within a collaborative and team oriented environment. Innovation can be achieved through leveraging intellectual capital or the development and deployment of new geotechnologies.

Exploration projects are generated through the complex area selection process. Favourable geological terrains are identified and targets within these prospective assessment

units are defined. Drill testing commences. Approximately one in one thousand exploratory drilling tests can lead to the identification of a significant sub-economic to economic prospect. With further evaluation one in 10 prospects can pass the hurdle to economic potential. And perhaps one in three advanced projects moves through the feasibility study to development. As a rule of thumb, one in 1 000 tests of a prospective grassroots geological terrain may yield an economic deposit of some quality. And one in 10 000 tests might yield a super deposit such as McArthur River.

The exploration discovery process is analogous to the well defined manufacturing process. Exploration success statistics were developed based on analogous success curves identified for manufacturing projects and benchmarked against actual statistics for discovery in the Athabasca Basin (Table 1) [5]. Greater uncertainty exists in the early stages (1 and 2) of exploration that may be similar to those known for the pharmaceutical industry and point to the high number of exploration drilling targets that need to be tested to yield economic discovery. It is at these stages that collaborative industry-academia collaborative research can play a significant role in increasing the probability of success through the assessment of exploration targets—drilling fewer holes to get to discovery.

TABLE 1. A COMPARISON OF SUCCESS STATISTICS FOR MANUFACTURING AND EXPLORATION PROJECTS

Stage	Industrial Projects	Manufacturing Ideas	Exploration Projects	Exploration Targets
1	raw ideas	3 000	conceptual drill targets	10 000
2	ideas submitted	300	reconnaissance drill tests	1 000
3	small projects	125	showings	100
4	significant developments	9	advanced projects	10
5	major developments	4	pre-feasibility	3
6	launches	1.7	feasibility	1.5
7	commercial success	1	economic deposit	1

Exploration managers need to continuously evaluate numerous complex technical and political risk factors as projects move down the exploration runway. Risk factors that need to be addressed by the successful exploration company include the primary risk factors of prospectivity and explorability and secondary factors of country risk, social risk, environmental risk, mining risk and reputational risk. Evaluating prospectivity is directed towards ensuring that the exploration effort will be focused on the correct geological environment that has the potential to host economic uranium deposits. The enterprise can try to answer the question “What is the status of nature’s natural endowment of economic mineral deposits in this terrain?” The geological assessment of the mineral endowment of a region is a knowledge-based activity involving a complex process of applied geoscience that is focused on understanding the geological and economic characteristics of the spectrum of mineral deposit commodity models. Talented geoscientific people working in a functioning learning organization [6] are a prerequisite for discovery. Evaluating explorability is focused on answering the question “Does the enterprise have the technology to search for and discover the economic deposits?” If not, “Can the enterprise develop new technologies?” Exploration

geologists, geophysicists and geochemists should constantly assess the applicability of exploration tools in the search of deposits while bearing in mind the probability of discovery.

A model for the exploration of a geological exploration environment (basin) can be defined by following the change of exploration risk with time (Fig. 6). Early stage exploration in new basins is a high-risk activity. The probability of missing a deposit is high. The geological risk associated with demonstrating the existence of a deposit may even be higher. Failure is imminent but the potential for an early discovery of a super-deposit exists. With time the enterprise learns more about the basin and approaches becomes more sophisticated. Discoveries may occur more frequently. Late in the history of the basin exploration the enterprise faces lower probabilities of discovering economic deposits due to the depletion of the natural resource endowment with sustained exploration effort over time. The basket of economic deposits is relatively small. Average discovery costs tend to rise with time. In the case of the Athabasca basin it costs more to drill deeper holes. And with time discovery becomes more elusive as there are fewer economic deposits to hunt for. The effective mineral exploration enterprise has a core exploration activity that relates to reducing exploration discovery risk and impeding the rise in average discovery costs through the application of knowledge that equates to innovative approaches to exploration, geoscientific research, and development, and management. In summary the simplified equation for economic mineral resource discovery can be written as long time frames, plus adequate and sustained budget levels, plus talented people working, and related to, the well managed exploration company equals improved opportunities for the discovery of an economic discovery.

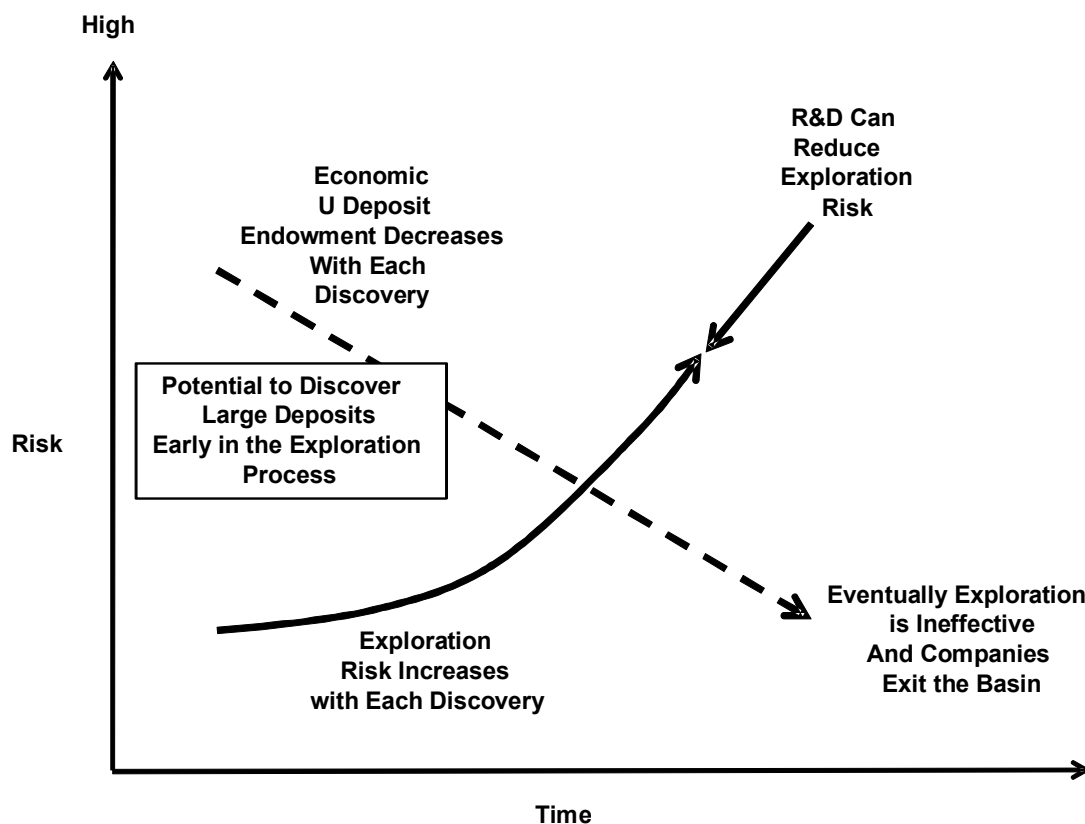


FIG. 6. A model for the investment worth of exploration research and development.

The nurturing of collaborative research with academic institutions can lead to innovative R&D outcomes in support of improved discovery rates. The development and measurement of the effectiveness of the R&D project portfolio is a key strategic activity of the effective exploration enterprise. Periodically, knowledge breakthroughs lead to a rapid (radical) gain in scientific understanding or a paradigm shift in technology; that can provide a period of competitive advantage for the company. Effective mineral exploration programs leverage pure and applied geoscientific research and exploration technology development as an integral part of the learning process, with the goal of improving discovery success rates. The mineral exploration process can be modeled by a series of learning curves involving researchers who gain an incrementally evolving understanding of a geological environment through the application of excellent and creative scientific research.

An example of an exploration learning curve for a specific multi-year geological research program is presented in Fig. 7. Here we depict the evolution of research in a relatively unexplored basin with a focus on understanding the nature and potential of unconformity related deposits. Geologists and academic researchers work together to develop both pure and applied knowledge to satisfy both organizational and institutional constituencies. A better understanding of the complexity of the geological system is garnered through discourse during the collaboration. A model system [7] is constructed and more robust and evolving typifications of favourable exploration terrains is one outcome. Co-authors publish selected results, increasing the effectiveness of the discourse, and continue to build knowledge capacity. Opportunities for the identification of new problems, new questions, and new phenomenon are created and research evolves in complexity and focus. Prototype technologies are developed with the opportunity for commercialization. In our model, collaborative research is positioned as a synergistic, multi-year, knowledge (capacity) building activity that satisfies both industry, and academic constituencies. The onus is on both researchers and collaborators to co-create. This approach is the antithesis of a more common call by industry on academia to produce a “magic bullet” that will guide explorers to discovery.

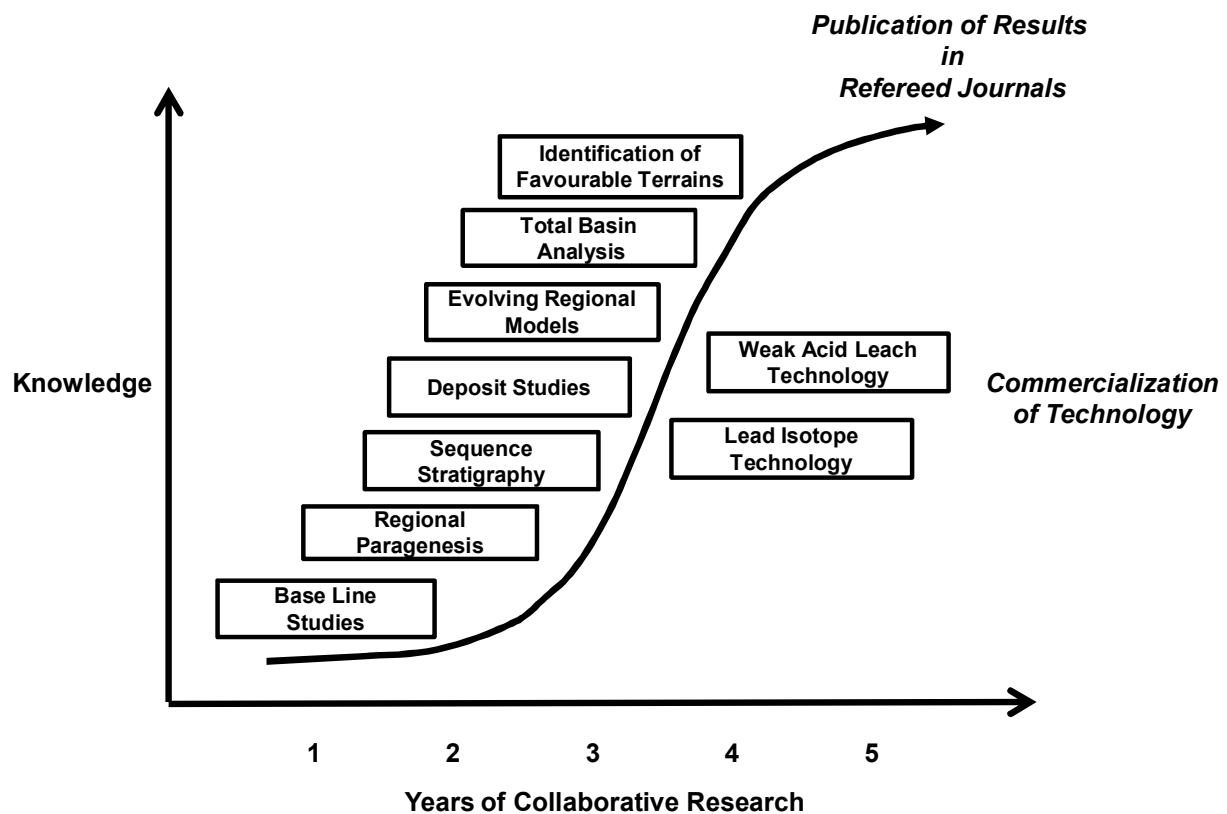


FIG. 7. Collaborative research and the Kombolgie Basin knowledge curve.

Effective management practices can increase the rate of incremental knowledge gains and establish an organizational learning culture where opportunities for incremental and radical innovation are possible. Neufeld, Simeoni, and Taylor [8] present a balanced scorecard framework modified after the work of Norton and Kaplan [9], associated with ten attributes of high-performance research organizations focusing on the key success factors associated with people, leadership, research management and measuring organizational performance (Table 2). Neufeld et al [8] point out the inherent difficulty involved in nominating tangible success measures associated with the more intangible success attributes of an R&D environment. Developing success measures for an embryonic exploration program focused on leveraging basic and applied research is particularly challenging given low probabilities of economic success and long time frames to economic discovery.

People

- (1) Management knows what research and other talent it needs to accomplish the mission, and recruits, develops and retains the right mix of people;
- (2) Employees are passionate about their own work, have confidence in management, and are proud of their organization

Leadership

- (1) The current and anticipated needs of dependent constituencies drive the organization and its research program;
- (2) Employees and dependent constituencies share management's visions, values and goals;
- (3) The portfolio of programs represents the right research at the right time and at the right investment.

Research Management

- (1) Research projects embody excellent science, involve the right people, and are on track and within budget;
- (2) Research projects leverage external resources;
- (3) Organizational knowledge is systematically captured and turned into needed work tools.

Organizational Performance

- (1) The organization is widely known and respected;
- (2) The organization meets the needs of dependent constituencies.

3. THE HUMAN FACTOR IN COLLABORATIVE RESEARCH

At a micro-level of our investigation, the nature of the 'human factor' in achieving successful collaboration, effective research outcomes, and efficient applied technology transfer is portrayed as a critical ingredient in the recipe supporting paradigmatic shifts in exploration process. Much good science never makes it to exploration industry application; and many embryonic research ideas generated by industry are never embraced by the academy—and as a result the new exploration paradigm is never tested. Success in collaborative research is as much about the development of sustainable trusting and appreciative relationships, as it is about creativity in science. A model of collaborative research and practice is presented to encourage the re-evaluation of the research, and development practices of collaboration (Fig. 8).

The process of collaborative research is depicted as a triadic system of the academic inventor, industry collaborator, and the sponsor organization. The focus is the research and development of new ideas, the transmission of new ideas to the organization through the collaborative intermediary and the uptake of new ideas into the organization through a process of learning and culture change. An important nuance in this model is the creative dialogic interaction between the inventor and collaborative intermediary that maps a process of co-creation and transmission of new ideas. A dynamic leadership interaction between the collaborator and organizational members is oriented towards the consideration and uptake of new ideas and is depicted as learning strategy. The goal of the process is to satisfy the needs of both the academic and organizational stakeholders.

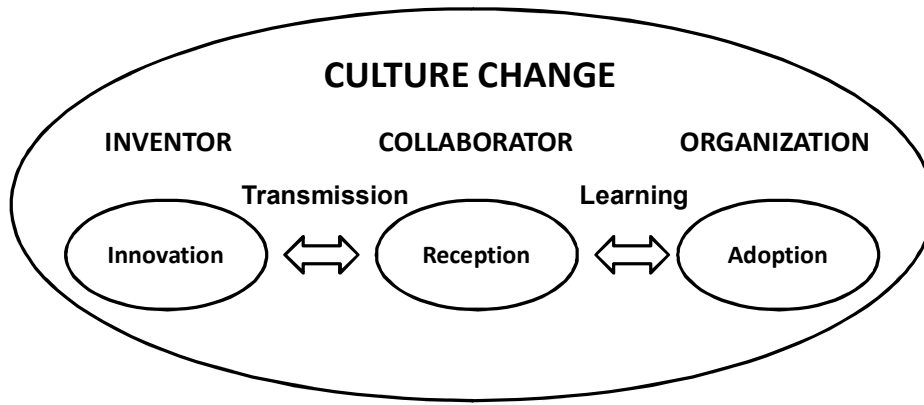


FIG. 8. A system model of collaborative research.

Innovation is a creative act. Commons and Bresette [10] suggest that creativity is facilitated by both depth of knowledge in a field, and breadth of knowledge across other fields. True creative acts can have a long gestation period and need to be intentionally channeled through the relevant socio-political culture. Creative people are adept at leveraging societal interaction to penetrate new ideas into the culture and are more likely to have substantial autonomy in their work environment, permitting an unfettered focus on their inventive passions. It is likely that only individuals at later human developmental stages have the capacity to negotiate such change [11]. People learn with the support of others in an increasingly complex way, through an evolution from reliance on telling from others, to mimicking, to direct problem solving, to problem finding, to question finding, and sometime to phenomenon finding. Learning and innovation are a function of human development (Table 2).

TABLE 2. HUMAN DEVELOPMENT AND LEARNING PROPOSITIONS, AFTER COMMONS AND BRESETTE [10]

Human Development Realm	Human Development Stage	Learning Catalyst	Learning Guide	Learning Support	% Of Population	Task
Post-typical Human Development	Paradigmatic	No Stimulus	Unassisted	Novel, no tradition, unsupported	<1%	Phenomenon finding
	Metasystemic				<5%?	Question finding
Typical to Post-typical Human Development	Systemic				20%	Problem finding
	Typical	Stimulated	Unassisted to Assisted	Guided by existing tradition	>70%	Direct problem solving
	Abstract					Pervasive imitation (mimesis)

The rarity of paradigmatic innovation can be attributed to the paucity of individuals inventing at late human developmental stages. It is our opinion that innovation in a scientific field is more commonly catalyzed by individuals who are at post-typical developmental stages; several stages later than that exhibited by the main population. Innovators lead the

culture in this respect, and invent through their independence, building on the history of invention within their field of interest. The creative act of innovation is not complete until the innovation permeates into the cultural milieu from the individual to the collective. The path from innovation, to reception, and the adoption of new technologies within a given culture is complex and uncertain. Even if the innovator has the savvy to successfully launch a new innovation into culture, receptivity will be a function of cultural acceptance, and readiness. Adoption will be a function of learning capacity of the recipients or culture, and tactical approaches to teaching, and training, and messaging. From this perspective it would appear that propagation of innovation and cultural and organizational evolution is a political process—loading pressure on the pool of rare innovators, and collaborators to transmit their messages through the complex socio-technical organizational culture.

Leadership, and management strengths need to be co-opted to bring the academic, and industry team systems together for success, though the use of informational, relational, and reflective learning strategies that take into account the capacities of individuals to successfully engage in creative acts, collaboration, and nuanced culture change, with a goal of embedding prospective innovations into the organizational setting.

4. THE INNOVATION EXPLORATION PARADIGM AS A RESPONSE TO CRISIS

Our assessment is that the uranium exploration industry is at a crossroads with respect to the discovery of new economic uranium deposits. Exploration expenditure during the last two decades has not lead to the discovery of any large new economic uranium deposit discoveries, and this observation can be interpreted as a severe and prolonged anomaly—an emerging crisis. Thomas Kuhn analyzed some of the conditions of paradigmatic shifts in his landmark work *The Structure of Scientific Revolutions* and offered what we interpret as a cautionary note when scientists are confronted by such anomalies. *“Though they may begin to lose faith and then to consider alternatives, they do not renounce the paradigm that has lead them into crisis. They do not, that is, treat anomalies as counterinstances, though in the vocabulary of philosophy of science that is what they are ... the decision to reject one paradigm is always simultaneously the decision to accept another, and the judgment leading to that decision involves the comparison of both paradigms with nature and each other [12].”*

The history of science and the history of exploration demonstrate that paradigmatic shifts do happen (Fig. 9). In this example the Beaverlodge uranium deposit model was co-opted by the Elliot Lake uranium deposit model, and then by the refocus of exploration on the new unconformity-related deposit model. Each model demanded different exploration approaches. Our question is “What are the options for the future of uranium exploration?” In the instance of the exploration for unconformity related uranium deposits the immediate opportunity is for the development of new technologies for the evolution of discoveries on the third learning curve. The development of variations of the unconformity related deposit model in support of the drill testing of virgin terrain in the Athabasca Basin, for example, is another. The intentional development and testing of brand new deposit models is the most challenging activity of all from both an intellectual and funding perspectives, but may be one of the futures of the uranium exploration industry. And as Thomas Kuhn suggested a new paradigm needs to be available if an old paradigm is to be rejected.

It is likely that future uranium explorers will need to be more efficient, and effective in their efforts, and to adopt new, and innovative business strategies for their survival, and success. Effective engagement within the ‘innovation exploration’ paradigm will require that exploration organizations adopt research, development, and technology transfer as a priority

long-term, systematic strategy. Exploration managers will need to more critically define their exploration targets, and elevate the status of the research, and development effort within the operationally driven organizational system to increase the probabilities of the discovery of economic ore deposits. They will need to more clearly identify the innovation frontiers they need to confront, and develop a deep commitment to their endeavor. Exploration managers will also need to build their leadership capacity to identify and support rare innovators and their collaborative partners. They will need to help these people to negotiate through the organizational, political, and jurisdictional labyrinths to accurately portray their research. They will also need to lobby for the research and development imperative, and to secure sustained funding, and access to research environments, for all of the stakeholders involved.

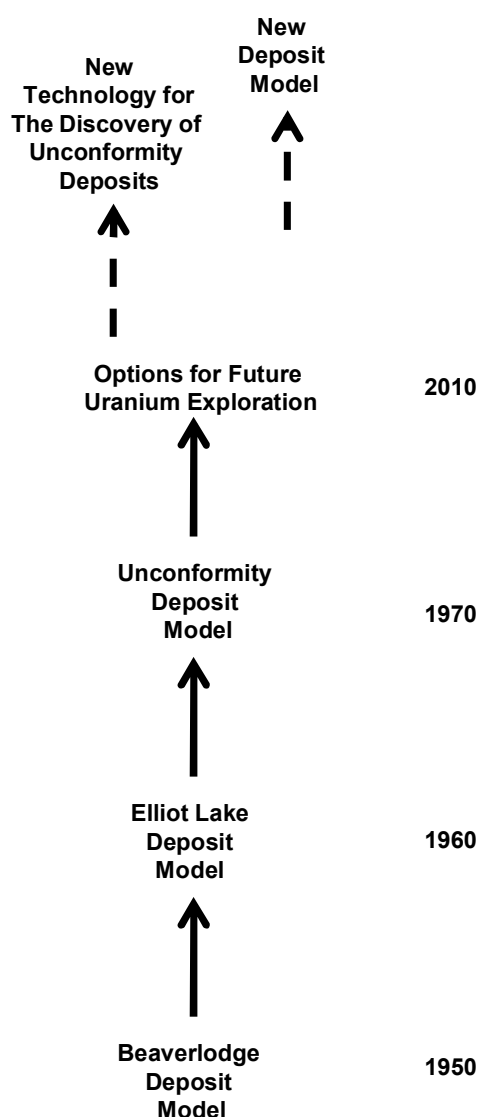


FIG. 9. A Selective history of paradigmatic shifts in exploration process from a deposit model perspective.

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NUCLEAR INDUSTRY IN CHINA

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Abstract

The paper presents an overview of the present situation and future plans for the development of nuclear power in China. In particular it looks at the present electricity generation system, future demand and plans for nuclear power plants to meet the increasing demands for electrical power in the country. It summarizes the state of uranium exploration activities and planned production of uranium resources, both nationally and internationally. In addition, it provides a brief overview of the existing administrative situation in the nuclear power industry in China and sets out the main challenges to future development.

1. INTRODUCTION

This presentation will discuss the role of nuclear energy in China. It will commence with a summary of the overall situation for electricity generation and the importance of nuclear energy, outlining the major electrical power entities, why nuclear power currently only provides 1.9% of the electricity generated in China, why nuclear power has a major future in China along with coal and hydro power, and the roles of the China National Nuclear Corporation.

It will then provide more information on the 11 operating NPPs, the 11 reactors under the construction in China, and the plans for the future. The current plan for 2005–2020 is to reach 40 GW(e) for NP by 2020, but the Chinese government is modifying this plan to increase the nuclear power target to 70 GW(e) along with other 30 GW(e) under the construction. Is it dream or will be implemented in the future?

Finally the presentation will examine uranium requirements and production. There are plans for production from 10 major uranium deposits, linked to 6 milling and processing centers in China. China is intensifying its exploration and development program; last year, it drilled more than 0.5 million meters in exploration for more uranium resources. Meanwhile, China is increasing its international activities, including the construction of new mines and mills abroad, and direct purchases from the international market. It will outline how the government is developing policies to help meet future requirements of uranium.

The nuclear power will play the important role both in the future and the part of economical stimulus package applied recently in China. The government is structuring the energy pattern in China that the northern China will depend on the thermal power consuming coals, the southwestern China on hydropower and the eastern coasts -- economical developed areas on nuclear. That is due to the policy change with regarding to the nuclear power from “The actively develop the nuclear power” to the “To devote the major effort to develop the nuclear power”.

Why the nuclear power in China? And what are they and how to realize the goal of nuclear power program. Those may provide some hints of solution. China is heavily relying on the fossil burning power which account for the 80% of the electricity generated with 1.3

billion tonnes of coal consumption in 2008, which results of great amount of emission of green house gas and creates a series of social problems in China. The nuclear power generated 68.4TWh electricity which is equivalent of reduction of over 80 million tonnes of CO₂ and 400 thousands tonnes of SO₂ in 2008, meanwhile, it has received the confidence and public support due to the safety operating records over past 30 years.

There are three major administrations under the governmental ministry to regulate the nuclear industry. The National Energy Administration of National Development and Reform Commission are responsible for planning and approving the nuclear power program, oversea uranium supply as well. The China Atomic Energy Agency regulates the most parts of nuclear fuel cycle exception of nuclear power. The National Nuclear Safety Administration of The Ministry of Environmental Protection regulates the environmental-related issues of the nuclear industry.

There are several major corporations is involving the nuclear powers named China National Nuclear Corporation (CNNC), China Guangdong Nuclear Power Holding Co. Ltd. (CGNPC), and China Power Investment Corp., the government approved the China Huangneng Group and China Datang Corporation to join the industry. China's nuclear industry originated in 1955 because of military purpose, the civil use of nuclear power have started in the early of 1980s and the names of industry from the Ministry of the Third Industry into the China National Nuclear Corporation which inherited the most parts of nuclear fuel cycle including exploration, mining, milling, conversion, enrichment and nuclear power plant in 1988. There are three nuclear power bases named Qinshan, Daya Bay and Tianwan, six NPPs and eleven units in operation with the total installed capacity 9 078 MW(e), which is account for the 2% of the electricity generated in China in 2008. There are 13 NP units with the installed capacity of 13 350 MW(e) under the construction, the government has approved 24 units with over 25 000 MW(e) to commence the construction, meanwhile, 17 units with a total capacity of over 17GW(e) now were given the green light to carry out siting and preliminary preparation works. According to the "China's middle-long term economic development plan (2005–2020)" approved by the State council in 2007, It is going to build NPP with a total capacity of 40 GW(e) and 18 GW(e) under the construction, which will a equivalent of reduction of 296 millions tonnes of CO₂ and over 1 million tonnes of SO₂ in the year of 2020. The PWR will be widely used now; however, the fast breeder reactor will be applied in the near future while the first experiment FBR will reach the critical in September of 2009 and connect with the grid in 2010.

Major uranium deposits in China

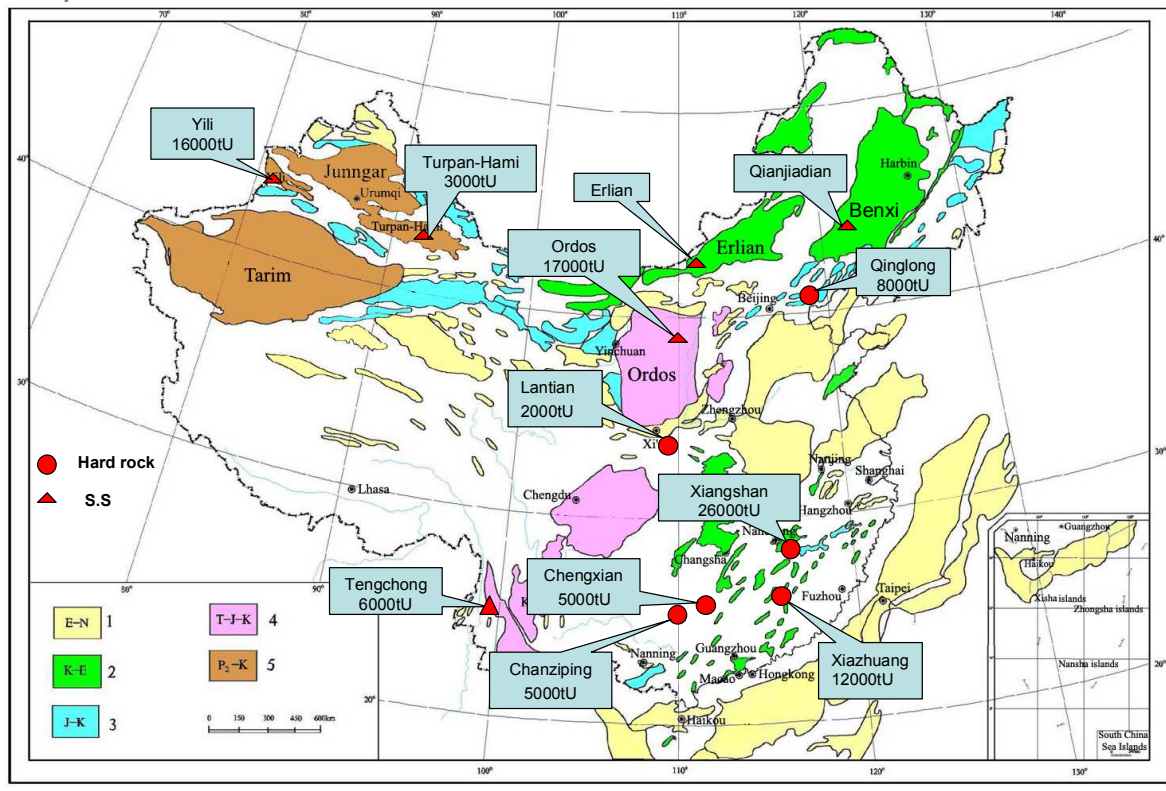


FIG. 1. Major unraium deposits in China.

The uranium supply will be critical for guaranteeing the health and the faster development of nuclear power in China; it is intensifying its activities both in uranium exploration and mining development in recent years (Fig 1). The major targets are given to the ISL type uranium deposits in Mesozoic and Cenozoic basins in the northern China and other types such as granite-related, volcanic-related and black shale are supplementary; the total 9.5 million meters of drilling program for last two years had been accomplished to looking for the more uranium deposits, the discovered uranium resources have been dramatically increased due to the input and endeavor. Meanwhile, China has finished the expansion of existed mine in Fuzhou and Yining. Apart from the domestic development, Chinese companies have turned their eyes into the world; CNNC is developing its mine in Niger, CGNPC in Kazakhstan and Sinosteel in Australia. At the same time, uranium is imported from Australia, Africa, Russia and central Asia counties etc. In conclusion, the uranium supply will be secured through domestic production, oversea exploration and mining, and trade with foreign counties as well.

The five major issues shall be most addressed in order to make sure of health and faster development of nuclear power in China, that is, R&D, manufacture ability, nuclear fuel supply, human resources capacity and establishment of safety culture. To meet the challenge of the fast growing of nuclear program development, the exploration for more uranium orebodies have been intensified, more mines and mill are constructed in line with the growing demand for uranium resources, meanwhile, the conversion plant is accomplished and new enrichment plant has started construction. The capacity for nuclear NPP related manufacture

has been raised, there are now over 40 universities and institutes have subject related to the nuclear sciences.

Now China is revising its nuclear power development program, the goal for 2020 to reach 80 GW(e) is a big challenge for Chinese nuclear workers and world peers.

SOCIAL LICENSING IN URANIUM PRODUCTION CYCLE
(Session 2)

SOCIAL LICENSING IN THE URANIUM CYCLE PRODUCTION (CASE OF NIGER)

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Abstract

In Niger Republic, uranium exploitation has begun since 1970. It is an economic resource but also causes social and environmental problems. To exploit according to the rule, to protect social environment, to work in safe conditions and contribute to the development of local population one side and Niger Republic in the other side, a mining law was voted in March 1993. It is about the ordinance n°93-16 on mining law which was modified in August 2006 by a new mining law, the ordinance n°2006-26 of 9 August 2006. As well as the presidential decree affecting the application of this new law was issued. Other legislative and regulatory texts have been taken as far as exploration and exploitation mining. For example, the mining agreement, the order n°0073/PM of 4 July 2005 relative to the transparency on mining exploitation; ordinance n°97-001 of 10 January 1997 appointing the environmental studying impact and the law 98-56 of 29 December 1998 relative to the management of environment. For acquisition of an exploration licence or a mining licence, a mining agreement is signed between the mining company and Niger Republic which makes clear social, environmental, financial, and economic conditions in which the mining company must exploit natural resources. The ordinance n°93-16 of 2 March 1993 related to the mining law in chapter IV, clarifies conditions for acquisition of exploration and mining licence in Niger Republic. It clarifies again in the same chapter, title VI, rights and obligations relating to mine or quarry operations for companies and tax provisions relative those activities. In the same order, in title VIII, hygiene and security conditions in mines are been specified. The mining agreement in title IV, specify rights, obligations and administration in mining activities, particularly article 18.2 which stipulates “the mining company undertakes to contribute to the development of municipalities in which it shall carry out activities, by contributing to the funding of collective infrastructure”. The government must look after the application of this mining convention. This new mining law and the others legislative texts provide for in some articles the social obligations of the mining company in which the exploitation must be done for the local population in the way of lasting development. In this presentation, all articles of the mining law and other legislative, regulatory that treat the Social Responsibilities Companies (SRC), the social obligations of the company will be more detailed.

1. INTRODUCTION

Niger is a West Africa sahelian country, a member of ECOWAS organisation. The capital is Niamey. The mining sector represents the most significant export industry for the country. For this reason a legislative and regulatory frame was set up, to regulate this sector in the exploration, exploitation, transport and commercialization activities of mineral substances, in particular uranium.

1.1 The mining code

The mining code is set up through the following legal instruments:

- Ordinance N° 93-16 of 2 March 1993 related to the Mining Law;
- Ordinance N° 99-48 of November 1999, supplementing Ordinance N° 93-16 of 2 March 1993 related to the Mining Law;
- Law N° 2006-26 of 9 August 2006, modifying Ordinance N° 93-16 of 2 March 1993 on Mining Law, supplemented by Ordinance N° 99-48 of November 1999;
- Implementing the Mining Law;
- Law N° 2008-30 of 3 July 2008 on great investments projects;
- Decree N° 2009-06/PRN/MME of 5 January 2009 determining details for implementing the law on huge investments projects.

1.2 Other regulatory texts

- Order N°0073/PM of 4 July 2005 relative to the transparency on mining exploitation;
- Ordinance N°97-001 of 10 January 1997 appointing the environmental studying impact;
- Law 98-56 of 29 December 1998 relative to the management of environment;
- Regulation N°18/December/CMC/WAEMU.

2. MINING TITLE ATTRIBUTION

The Law N° 2006-26 of 9 August 2006 clarifies that “on the territory of the Republic of Niger, natural deposits of mineral or fossil substances in the subsoil or on surface shall be exclusive of the State of Niger and are not liable to any form of private ownership, subject to provisions of this law.

The State shall consider, in all consider sovereignty, any application field for mining titles, or quarry opening and mining licences.

Rejection of such applications shall not entitle applicants to any appeals or compensations whatsoever” (article 2).

Related to the Mining Law, we have three (3) mining titles in uranium (art-13):

- Prospecting Licence;
- Exploration Licence and
- Mining Licence.

“Subjection to the provision of this ordinance, the Government may authorize one or several duly qualified persons (Niger or foreign nationals) or legal entities constituted as corporations under law in Niger to engage the prospecting, exploration or mining of mine or quarry substances of the Republic of Niger” (art-7).

2.1. Conditions for securing mining or quarrying titles

Article 9 — obligation to comply

No individual or legal entities, including land owners and surface rights holders, may engage in one of the activities or more referred to in article 1 above, on the territory of the Republic of Niger without complying with the provisions of this ordinance.

The total or partial refusal of the State to grant a mining or quarry titles shall not entitle unsuccessful applicant to any compensation, if their applications do not meet there requirement set forth in this ordinance.

Article 10 — requirements for individuals

All individuals may apply for:

- A prospecting card;
- A prospecting license for quarry substances;
- An artisan mining license and
- A permanent or temporary quarry development license.

No individuals may either obtain or hold one of the above-mentioned mining or quarry titles if:

- Their personal status is incompatible with the conduct commercial activities in Niger;
- They have been sentenced to prison for non compliance with the provision of this ordinance related to mining or regulations governing the detention, possession, movement and marketing of mineral substances in Niger;
- Their applications do not meet the requirements set forth in this ordinance.

Article 11 — requirements for legal entities

No entities shall obtain or hold a mine or quarry development title if they are not incorporated in conformity with the legislation governing the legal status of companies in the Republic of Niger.

3. MINE TITLES

The procedures for acquisition, mining title are determined by the Decree N° 2006-265/PRN/MME of 18 August 2006 determining details for implementing the Mining Law.

Prior to the issuance of exploration license as well as a mining license of uranium, a mining agreement shall be signed be amended by mutual agreement of the parties.

Mining agreement shall set forth the rights and duties the parties in relation to the legal, financial, fiscal and social requirements applicable to exploration and mining operations during the validity period of such agreement. It covers the first validity of mining permit and shall be valid for a maximum period of between the Niger Republic (by the Minister of Mine) and the applicant after it has been approved by the decree issued by the council of Ministers. Once effective, mining agreement can cover twenty years and can be renegotiated at the time of renewal of mining permit.

3.1. Prospecting licence

- One (1) year validity;
- Granted by the Director of Mines;
- Confers first refusal right for the Licence to get exploration.

Granting prospecting licence is liable to the following procedure:

- Submission of the application in triple copies to the director of Mines, it includes:
 - Statues, balance sheet and accounting statement of the applicant for the last year;
 - Object of the prospecting;
 - General projected working program;
 - Receipt of the fees payment.
- Application evaluation;
- Granting of the prospecting authorization within 30 days from the deposit of the application date.

3.2. Exploration licence

- Three years validity, renewable two (2) times by period of three (3) years;

- Could be expected one year to finalise feasibility study;
- Granted by order of the Minister of Mines and Energy.

3.2.1. Procedure for acquisition of exploration licence

- Confers exclusive rights;
- Submission of application to the minister of mines and energy in triple copies including:
 - Statues, balance sheet and accounting statement of the applicant for the last year;
 - Minerals for which the licence is requested;
 - Area and regions of the perimeter requested;
 - Limits of the perimeter and geographic points on a 1/200 000 map;
 - Duration of the licence;
 - Technical and financial capacities;
 - Commitment on investment;
 - General program and works schedule;
 - Copy of any joint-venture;
 - Receipt of fees payment;
 - Mining agreement proposal;
 - Commitment to submit to the director of mines a trimester report and annual exploration activities;
- Evaluation of the application by the direction of mines;
- Negotiation of the mining agreement;
- Signature of the mining agreement;
- Publication of the mining convention by decree of council of minister;
- Granting of the exploration licence.

3.3. Mining licence

- Validity of Ten (10) Years, Renewable for Five (5) Years until Complete Exploitation of Deposit;
- Granted by Decree of the Council of Ministers;
- Confers Exclusive right.

3.3.1. Procedure for acquisition of mining licence is as following:

- Production of positive feasibility study on the perimeter of the exploration permit;
- Registration of mining company in terms of niger law as specified in the mining agreement;
- Submission of application to the minister of mines and energy in triple copies including:
 - Statues of the mining company, it's headquarter and authorized capital; name, surname qualification, nationality and residence of the responsible of the mining company;
 - Reference of the exploration licence;
 - Coordinates and area of the requested mining licence perimeter;
 - Minerals for which the permit is requested;
 - Localisation of the licence on a 1/200 000 scale map;
 - Detailed plan of the perimeter at an appropriate scale;

- Report indicating the result of exploration works carried out on the exploration licence;
- Feasibility study report;
- Development plan and mining of the deposit;
- Environmental assessment report;
- Certificate of standard environmental conformity;
- Receipt of fees payment;
- Commitment to submit to the director of mines the annual working program and a monthly working report;
- Any joint-venture, agreement if so.

4. TAXES AND CUSTOMS PROVISIONS

The Law N° 2006-26 of 9 August, 2006 determines taxes and customs that a mining title holder must pay during the period of validity:

4.1. Fixed fees

“Any individual or legal entity applying for the issuance, renewal, expansion, extension, assignment, transfer, sublease, conversion, merging or division of mine or quarry titles, exploration licences, artisanal mining licences or trading licence in connection with substances extracted from artisanal mines, is liable to the payment of fixed fees at the rates determined in the budget act on a yearly basis” (Article-82).

4.2. Area taxes

“Any individual or legal entity applying for exploration licence, prospecting permits, mining permits, artisanal mining licences, quarry opening and development licences shall be liable to the payment of an annual area tax” (Article-83).

4.3. Mining royalties

“Any individual or legal entity conducting mining operations shall be liable to the payment of mining royalties, the tax base of which is the market value of the extracted product. Mining royalties shall be calculated when substances are removed from stocks for sale (Article-84).

When shipping tradable goods, mining companies are required to make an advance payment on the royalties at the rate of 5.5%. The balance, if any, shall be paid up after the annual financial statement of the company. Such taxes are deductible in calculating taxable profits.

Mining royalties shall be calculated according to a specific formula presented bellow:

A= Mining products
B= Operating income
C= B/A (%)

- (1) If $c \leq 20\%$, the mining royalty is 5.5%;
- (2) If $c > 20\%$ and lower than 50%, the mining royalty rate is 9%;
- (3) If $c = 50\%$ or above, the mining royalty rate is 12%.

4.4. Artisanal mining and taxes

4.4.1. Artisanal mining taxes

Artisanal mining licence holders shall be liable to the payment of mining taxes at the rate of 2.5% of the product value.

4.4.2. Extrated taxes

Quarry substances development and collection shall be subjected to the payment of extraction taxes at the rates of 250FCFA/m³ of materials extracted (Article-85).

4.5. Taxes on business profits and income

Holders of mine substances mining titles, legal entities holding quarry opening and mining licences and cooperatives or economic interest groupings with mine substance mining titles shall be subjected to payment of scheduler business profits taxes (IC/BIC)

Mining or quarry companies shall be subjected to payment of dividend taxes based on dividends, percentages and other products distributed to them (Article-88).

The article 21 of the mining agreement type stipulates that:

Art-21.1 “The State assures the company and the mining company that the general, legal, administrative, economic, financial and fiscal condition provided for in the agreement shall remain unchanged.

During the term of the agreement, rates specified thereof, regulations regarding tax base and tax collection shall remain as they were at the date of the signature, unless these rates are reduced in the meantime, in which case the company and the mining company shall benefit from these new rates at their request”;

Art-21.2 “The State assures the company, the mining company, its affiliated companies and their subcontractors and people they regularly employ, that they will never be subject to any legal or administrative discrimination, unfavourable in law and in act;

Art-21.3 “The State assures the company, the mining company, its affiliated companies and their subcontractors that all administrative authorizations and measures aimed at facilitating the conduct of prospecting and mining activities shall be granted and taken as expeditiously as possible, in accordance with applicable legal and regulatory provisions”;

Art-21.4 “The State assures the company, the mining company, its affiliated companies and their subcontractors that all administrative authorizations shall be granted as expeditiously as possible to facilitate marketing of products. It is understood that the mining company may negotiate with a specialized company, the marketing of products. However, the mining company shall remain accountable to the State for this operation and shall submit to the State any sales contract to be passed”.

4.6 Rights and Obligations relating to mine or quarry operation

The Law N° 2006-26 of 9 August 2006 in his article 99 specifies that “mine or quarry substance development operations are considered as commercial activities.

They must comply with laws and regulations regarding rational use of national resources and environmental protection.

To that end, companies must conduct their activities using techniques accepted in the mining sector and take the necessary steps to protect the environment, treat wastes and preserve forest and water resources.

Holders of prospecting and mining permits or quarry opening and development licences are required to submit, to the mining administration, an annual report on generally safety issues.

Holders of radioactive substance mining permits must also submit semi-annual and annual reports on protection against radiation.

5. SOCIAL RESPONSIBILITIES OF THE STATE AND THE MINING COMPANIES

5.1. Social responsibilities of the companies

Article 18: (Mining agreement) Infrastructure and Services

“In case the company and /or the mining company use roads to carry out its mining operations, it shall undertake to contribute to the maintenance of these roads so as to keep it in good condition. As such, it adheres to the maintenance agreement of road, adopted by Decree N° 2002-019/PRN/MEH/AT and any relevant future legislation.

The Mining Company undertakes to contribute to the development of municipalities in which it shall carry out its activities, by contributing to the funding of collective infrastructures”.

As example of AREVA NC which is the first company in uranium mining in Niger signed a partnership convention in the way to support municipalities where uranium is extracted. By COMINAK and SOMAIR, AREVA developed strategies to help municipalities in their local development. For example creation of:

- Orientation Committee (ORC) which determines priorities for the development of Arlit Department based the Development Plan of this Department;
- Partnership Committee of Niger (PNC): municipalities submit propositions of projects to this committee; It can be helped NGO or specialized offices in projects follow-up;
- Departmental Market Commission (DMC): this commission attributes contracts for achievement of accepted projects;
- Technical Committee (CT) to supervise achievement of adopted projects and their conformities as specified in original document.

5.2. Social responsibilities of Niger state

Article 95 (new):

The Mining Law defines the use of mining proceeds:

- National budget 85%;
- Budget of the municipalities of relevant areas: 15% to finance local development.

The distribution of the 15% is based on:

- Number of person per municipalities;
- Environmental impact relating to the proximity of the municipality;
- Economic resources mobilization effort;
- Equipment degree of the municipalities in the area;
- Area of the municipalities;
- Partnership for development municipalities.

Article 21: (mining agreement type)

Art-21.1:

“The State assures the company and the mining company that the general, legal, administrative, economic, financial and fiscal condition provided for in the agreement shall remain unchanged.

During the term of the agreement, rates specified thereof, regulations regarding tax base and tax collection shall remain as they were at the date of the signature, unless these rates are reduced in the meantime, in which case the company and the mining company shall benefit from these new rates at their request”;

Art-21.2:

“The State assures the company, the mining company, its affiliated companies and their subcontractors and people they regularly employ, that they will never be subject to any legal or administrative discrimination, unfavourable in law and in act;

Art-21.3:

“The State assures the company, the mining company, its affiliated companies and their subcontractors that all administrative authorizations and measures aimed at facilitating the conduct of prospecting and mining activities shall be granted and taken as expeditiously as possible, in accordance with applicable legal and regulatory provisions”;

Art-21.4:

“The State assures the company, the mining company, its affiliated companies and their subcontractors that all administrative authorizations shall be granted as expeditiously as possible to facilitate marketing of products. It is understood that the mining company may negotiate with a specialized company, the marketing of products. However, the mining company shall remain accountable to the State for this operation and shall submit to the State any sales contract to be passed”.

6. PROTECTION OF INFRASTRUCTURE, ENVIRONMENT AND REHABILITATION OF MINING SITES AND HYGIENE AND SECURITY IN MINES AND QUARRIES

6.1. Protection of infrastructure, environment and rehabilitation of mining sites

Article-27 (Mining agreement)

Development of any new deposits shall be subject to an environmental impact study pursuant to the environment legislation in force. Such study shall be part and parcel of the feasibility study.

The company and mining company commits to take the necessary steps to protect the environment while conducting mining operations including:

- Protection of natural sites;
- Preservation of health and safety of riparian communities as well as public sanitation, in general;
- Protection of indigenous natural fauna and flora;
- Protection of known natural resources.

Such measures taken must conform to requirements stipulated in the environmental legislation in force, or failing that, company with generally accepted practice in mining industry.

Commitments made by the company and the operation company include more specifically:

- Manage in an organized way soils and rocks handled so as to guarantee stability of mining sites and ensure that this does not adversely affect surface water flow regime and quality-sedimentation, unprotected water retention works or erosion;
- Avoid any discharge of solutions containing substances which are, due to their nature, likely to pollute soil, air and freshwater polluting substances;
- Manage water tables to prevent their pollution outside perimeters, during and after mining operations;
- Manage in a controlled and efficient manner industrial wastes generated by mining operations in active sites proposed by the company and approved by the public institution in charge of environmental protection, to avoid their dispersion in the environment;
- Rehabilitate sites as mining operations progress, if possible, and at the end of such operations. Rehabilitation refers to restoration of mined lands and their grading taken to account local climatic conditions to mitigate as much possible the potential impact of natural degradation;
- Establish a follow-up system to monitor the implementation and efficiency of measures taken, in conformity with the applicable environmental legislation which provides for the mitigation of residual impacts of rehabilitated sites and evolution of these impacts;
- Maintain the system in place for a period of five (5) years after completion of mining operations, however, the monitoring agency may decide to lessen or abandon monitoring activities before the end of that period

The company or the mining company shall be liable for any damage to the environment and to health and safety of riparian communities, resulting from non compliance with regulations.

6.2. Hygiene and security in mines and quarries

The article 121 of the Ordinance N° 93-16 of 2 March, 1993 related to the Mining Law stipulates that “any individuals or legal entities that carry out mineral substance, prospecting or mining activities, pursuant to this ordinance, must proceed in accordance with standard practice so as to guarantee the security and health of their employees and third parties.

Minimum health and safety rules applicable to prospecting and mining activities, provisions governing health hazards (silicosis risk, ionizing radiations, etc...) related to

mining or quarry operations as well as safety rules regarding transport, storage and use of explosives shall be provided for in rules and regulations.

6.3. Administrative control

Article-82:

The purpose of administrative control is to ensure preservation of deposits, safety of people and goods, protection of dwelling areas, buildings, communication routes and protection of water points and tables.

Authorized engineers and workers of the Direction of mines shall be responsible for technical and administrative control of mineral substances prospecting and mining activities and those conducted in their accessories and subsidiaries. To this effect, they are vested with powers of labour inspectors. They report to relevant labour inspectors any measures taken and/or notices given. Labour Inspectors may visit, at any time and together with agents of services of Ministry of Mines, companies and sites under their technical supervision.

7. CONCLUSION

Mining sector is one of strategic sectors of Niger Republic for the development of the country. In the mining politics, this sector is a way to fight against poverty, unemployment of young people and the economic development of the country. That's why, Niger Republic created a frame legislative encouraging investments in this sector to attain his objectives.

URANIUM STAKEHOLDER ENGAGEMENT IN NORTHERN AUSTRALIA

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Abstract

Uranium has been mined in the Northern Territory of Australia more or less continuously since 1949. Most of these mines have been located on Aboriginal land, although in many cases Native Title has only been recently established and the rights of the Traditional Owners finally acknowledged. In earlier days consultation with the Traditional Owners was generally unheard of and few sites were rehabilitated when mining ceased. However, leading practice in modern mining, including uranium mining, requires that these two issues are paid particular attention, whether it be for development and operation of current mines or the remediation of legacy sites. The paper presents two brief case studies in relation to stakeholder engagement developed in the Alligator Rivers Region uranium field of Australia's Northern Territory. The subject of the first case study, the South Alligator valley, was subject to intensive prospecting and exploration which resulted in the development of 13 small uranium mines between 1955 and 1964. The operations were abandoned and the area returned to being a cattle ranch. In 1987 the valley lay within an area that was incorporated into the World Heritage-listed Kakadu National Park. In 1996 the Gunlom Land Trust, an association of traditional owners, was granted native title to the area under the Commonwealth's *Northern Territory Land Rights Act (1976)*. The new owners immediately leased the land back to the Commonwealth Government for continued use as a National Park. A condition of that lease was that all former mine sites and associated workings would be rehabilitated by 2015. The paper describes the comprehensive consultation process involving all stakeholders that was developed for this programme; and goes on to describe the programme of remediation works to date and the situation as of 2009. The second case history deals with the consultation process developed by one Government agency as it works with Traditional Owners and other stakeholders in maintaining surveillance over the operating Ranger Uranium Mine. The Supervising Scientist Division of the Commonwealth Department of the Environment, Water, Heritage and the Arts is responsible for environmental oversight of the mining operations and has developed a number of systems for engaging stakeholders which have stood the test of time. These are described in the paper which ends with a brief overview of recent publications on this topic from IAEA, the uranium industry and others.

1. INTRODUCTION

After World War 2 modern uranium mining really became established. In northern Australia this began with the Rum Jungle operation in 1949 [1]. Aboriginal Traditional Owners (ATO) of the land were not consulted and the site was abandoned once mining was finished. Similarly for the 13 small mines of the South Alligator Valley, there was no consultation with the ATO of the area and no remediation when work finished [2]. At both these sites the land rights of the ATO and native title to the land have since been recognised through processes conducted under the Commonwealth Government's *Northern Territory Land Rights Act (1976)*. Following the establishment of native title, remediation of the sites was agreed to. In the case of the Rum Jungle site the first remediation was undertaken between 1982 and 1986. There was limited consultation with the ATO, but mainly through the Northern Land Council (NLC), an organisation set up under the Land Rights legislation to provide technical and legal services to the Aboriginal Traditional Owners. In the South Alligator Valley (SAV) the land grant did not occur until 1996 and thus the consultation process that is the subject of this paper was developed taking account of experiences from earlier efforts. The final phase of the remediation works programme is currently under way, and is due to be completed in late 2009.

2. THE NATURAL ENVIRONMENT

The Pine Creek geosyncline lies between approximately 13° and 14° south of the equator in the wet/dry tropics, a climate described as A_w in the Köppen [3] classification. The average annual rainfall is about 1 200 mm of which over 90% falls between 1 November and 30 April (the “Wet” season). The remainder of the year is referred to as the “Dry” season.

Temperatures average about 21°C annually with maxima often around 40°C and minima rarely below 14°C. The area hosts a savanna woodland with some sandstone escarpment country. The vegetation is dominated by eucalyptus species with some accacias and ironwoods in the drier locations and pandanus and melaleuca species in the wetter areas. The whole of the SAV lies within the boundaries of Kakadu National Park; the park has been world heritage listed for both natural and cultural attributes.

3. THE HUMAN ENVIRONMENT

The SAV area has no permanent population. Park rangers live in a small community about 30 minutes drive away. The SAV is cut off by road due to flooding in the wet season. Some ATOs visit the SAV and camp there for periods during the dry season. Elsewhere within Kakadu (apart from Jabiru town) there are a few outstations, one resort hotel (Cooinda) and some park ranger stations. Outside Kakadu the population is concentrated in a few small settlements, many of which owe their existence to mining operations. For example, the townships of Batchelor and Pine Creek have populations of barely a hundred, somewhat less than the days of the mining booms of the 50s, 60s and early 70s. There is an Aboriginal population elsewhere in the region living in outstations as well as in the townships. The eastern portion of the area is the Aboriginal Reserve of Arnhemland, where Aboriginal people live a mixture of traditional and western lifestyles; access for non-Aboriginals to Arnhemland is restricted to assist in the preservation of the Aboriginal culture. The town of Jabiru, built to service the uranium mine at Ranger has a permanent population of around one thousand persons and serves as a regional centre as well providing medical, administrative, police and educational facilities as well as a hotel, tourism camping sites, sporting clubs and some shops.

4. THE MINING HISTORY

The area has a long mining history starting with the Pine Creek gold rush of the late 1800s. Rum Jungle is perhaps the best known of the early uranium mines in the region. A copper mine since 1905, uranium was first identified at Rum Jungle in 1912 [4]. Following a ‘new’ discovery in 1949 uranium mining operated from 1954 until 1958 and copper mining continued until 1965, the mine finally closing in 1971. The local Aboriginal population had effectively no say in what happened at the operations and this situation remained unchanged until the granting of their land claim. Mining at Rum Jungle was followed by a group of smaller mines that were located in the upper reaches of the South Alligator valley. These locations are shown in Figure 1.

The valley was remote and the only acknowledged land use at the time was extensive cattle ranching in the bush land, which had begun around 1950. However, more than 50 radiological anomalies were located in the valley. Follow-up ground work identified economically viable uranium deposits and mining began in about 1954. Details of this early history of uranium mining are well documented [1, 2, 5, 6]. The operations were all small by modern standards, total production between 1955 and 1964 amounted to about 850 tonnes U_3O_8 [2]. Development of the mines was quick once deposits had been located, there being no

requirements for Environmental Impact Statements or consultation. The former was because there was no appropriate legislation in existence then; the latter because the local population was considered to be only the pastoralist, although Aboriginal people were present in the valley from time to time.

5. THE LEGISLATIVE BACKGROUND

The South Alligator Valley lies within the Alligator Rivers Region and is thus within the operational area of the Office of the Supervising Scientist (OSS). OSS is an agency of the Commonwealth (Federal) Government charged with ensuring that there should be no adverse environmental impacts arising from any aspect of uranium mining in the region. A part of the Commonwealth Department of Environment and Heritage, the OSS was set up in 1978 as an outcome of the Ranger Uranium Environmental Inquiry [7]. The OSS was not permitted to consult directly with traditional owners under the protocols in place at that time, but relied on communication through the NLC. This was obviously not the most effective means of communication as there was always a risk of misunderstanding or misinterpretation in either direction, but it was at least communication.

One function of the OSS was to provide the Secretariat for the Alligator Rivers Region (ARR) Coordinating Committee (CC). This was a body established under the same Act that created the OSS and was chaired by the Supervising Scientist. Membership included representation from all the departments involved in the governance of the uranium mines of the ARR from both the Commonwealth (Federal) and Northern Territory Governments, the NLC and the mining companies. In addition there were representatives of the major trade union for mineworkers, the National Parks Service and, eventually, a member of a national environmental organisation. The CC met twice per year under provisions of secrecy and did not include representatives of the ATO themselves as their interests were deemed to be managed by the NLC. Associated with the CC meetings schedule was a schedule of technical meetings for each mine site, the Periodic Surveillance Committees (PSC). Again there were only two meetings per year with no ATO representations and membership comprised the relevant mining company, the OSS, the NLC and the NT Government Mines Department. As the PSC were effectively sub-committees of the CC similar secrecy provisions applied.

From 1987 until 1991, there was a controversial exploration program at Coronation Hill, the site of a former uranium mine [8] in the South Alligator valley. Throughout the whole Coronation Hill saga the amount of consultation with Traditional Owners was increasing at each stage, although each side of the debate was possibly selective about whom they consulted and how the process outcomes were announced. But by modern standards the level and style of consultation was still very poor, and conflicts with the complexities of the legal situation over the involvement of the NLC only added to the tension. Eventually, in 1991, the Government made the decision to stop all future development at Coronation Hill and incorporate the area into Kakadu National Park. This was achieved later that year.

The local ATO, the Jawoyn people, began negotiating their land claim and options for the return of their traditional lands. The land claim was granted and in 1996 a lease was signed between the Gunlom Land Trust, the specific ATOs for the area, and the Director of National Parks. The area was immediately leased back as a Park for an initial period of 99 years. Amongst the clauses of the lease was a specific requirement that evidence of all former mining activity be rehabilitated. The lease specified that a Plan of Remediation be agreed by December 2000 and that work must be completed by December 2015.

6. CHANGES, COMMUNICATIONS AND PLANNING

By 2001, the need to modernise the system had become apparent. The OSS legislation was modified to dissolve the CC and replace it with two new independently chaired committees, the Alligator Rivers Region Advisory Committee (ARRACC) and the Alligator River region Technical Committee (ARRTC). In addition the PSC system, including the associated regular weekly ad-hoc inspections, was scrapped and replaced with a system of bi-annual audits and monthly inspections to check matters on the ground at the sites and a new Minesite Technical Committee (MTC) for each operating mine. The MTC meetings were set to happen a minimum of once per year but could be called at any time by any member to discuss relevant issues. The MTC membership was the same as for the PSC but with the additional provision that ATO representatives were invited and could bring technical experts as required.

This system has continued to the present time with a few modifications in terms of streamlining communications between members and optimising resources used in the field work, audit and inspection tasks. All inspections now include the NLC and are carried out monthly as a joint coordinated exercise to optimise the use of resources by all partners. A single report is written by each member organisation in rotation. The mining company ERA, operators of Ranger Mine, also arranges periodic tours of the mine site for ATO as well as regular public tours. Ranger is the only uranium mine operating in the region at the present time but MTC meetings are held for 3 facilities: Ranger (operating mine), Jabiluka (U deposit in care and maintenance); and Nabarlek (site under remediation and exploration).

ARRAC is a formal forum for information exchange and includes representation from both governments, uranium exploration and mining companies operating in the ARR, the mine work force, ATO, NLC, a local environmental group from the NT and the population of Jabiru. Meetings are held twice per year, one meeting always being held in Jabiru to ensure local stakeholders can have access to the members and members can have access to the sites. The scope of work for ARRAC includes uranium exploration operations in West Arnhem land and the remediation of the uranium legacy sites in the SAV.

ARRTC is a scientific committee mandated to look into the research needs of the region and to coordinate research and moderate applicability of research undertaken primarily by the Supervising Scientist's environmental research institute (eriss) but also by ERA and others such as the Parks Service etc. Members of the committee are all appointed by the Minister but must be acknowledged experts in their field, preferably at international and national level, and the ATO have a say in the nomination of an ARRTC member to express their concerns.

All the ARRAC meeting summaries and reports submitted for discussion may be viewed on a website after the meeting. Also other data such as environmental monitoring reports and incident investigation reports are also published for public use. During the wet season the OSS hosts a webpage which publishes monitoring data week by week or even daily if circumstances demand it. The OSS now also carries out monitoring at a strategic level in the principal waterways up- and down-stream of the Ranger mine in addition to programmes undertaken by the NT Government and the mining company.

7. A PRACTICAL CASE STUDY — THE SOUTH ALLIGATOR VALLEY

Once the lease had been signed in 1996 the clock began to count down for the preparation of the overall plan. By this time it had become accepted practice that Aboriginal

people had to be involved closely with every stage of works on their lands. Kakadu National Park is managed jointly by Parks Australia North (PAN) and the Traditional Owners. The Plan of Management is drawn up jointly and its implementation overseen by the Board of Management, which has Traditional Owners as the majority of members.

The initial information exchange meeting was held in October 1997. Many smaller Aboriginal groups needed to be brought together. Also representatives of several government agencies, both Commonwealth and NT, wanted to be present which created the risk of two groups developing, Aboriginal and non-aboriginal. The meeting was held in the former OSS field camp adjacent to Coronation Hill, now referred to by its local name of Guratba. The use of an open-air venue on the traditional lands of the people, with two days put aside for talking, relieved much of the stress for those unaccustomed to meetings. The format was made as informal as possible whilst maintaining a structure.

It transpired that whilst the Traditional Owners knew much about the sacred sites in the valley they were not familiar with the majority of the mining sites. Questions from the local people indicated they had little detailed knowledge of the former mining activity or the potential environmental impacts, apart from obvious visual impacts. For example, having to explain acid rock drainage was an interesting first challenge for the “experts”. It soon became apparent to the “experts” that communication was not happening as effectively as it might.

For many of the non-aboriginal people present this was their first experience of having to deal directly with the “clients” rather than through the NLC. The process was far from perfect and there was much to learn about cross-cultural communication. Some staff were sent for cultural awareness training to try and speed up the transition to a better system. The difficulties encountered by both sides included: inappropriate language with too many long and jargon words, representatives from different organisations wearing similar uniforms; and, unrealistic expectations amongst some of the non-Aboriginal people that decisions would be made soon after what seemed like complete and logical explanations had been delivered. This revealed a poor understanding of how Aboriginal communities make decisions by consensus rather than by majority. The rate of progress was too slow for some people. The problems continued after the meeting with the production of a summary record that was all words. Then staff changes at National Parks, the prime agency with carriage of the issue, resulted in the process virtually halting for several months.

Whilst this ‘pause’ was happening a helicopter trip was arranged, with a senior Aboriginal Traditional Owner present, to photograph sites from the air. These pictures were then used to show communities what the sites looked like. This operation was a great success and relationship building had begun. Time passed and progress was slow. It soon became apparent that at that rate it was not going to be possible to meet the deadlines set by the lease. The process was obviously wrong.

8. A REVISED PROCESS

As the need to start planning the SAV remediation had to happen it seemed an opportune time to try a new approach. So in 1999 it was decided, by OSS and others from government, to improve the consultation process through creation of a formal committee. A meeting was held at the permanent home of the majority of the Gunlom Trust members in a community near the town of Katherine, some 100 km away from Kakadu. The idea was to discuss, in an informal atmosphere, how to get the process back on track, especially how the concerns and aspirations of the ATOs could be addressed and would forming a committee

help move the process forward. After a slow start the various parties discussed the size and scope of the issue. The main agreement at the meeting was that ATOs would form the majority of the committee. Who else should be represented in the consultative process was a topic that was discussed at length. The final agreed composition of the group was:

- ATOs, selected by the community because they were custodians of sites and ceremonies within the affected areas and also some of them lived in the valley at times in the dry season. This group includes men and women from the various communities are the majority;
- National Parks -The lessees of the land, the holders of the radioactive residues of uranium mining in the eyes of the regulating authority and so the agency having responsibility to carry out the remediation under the terms of their lease;
- NLC-Representing the interests of the ATOs and providing them with specialist advice;
- OSS-Technical advisers to National Parks, as well as having responsibility for uranium mining environmental affairs in the region;
- NT Government Mining authority-The regulator of mining activity in the Northern Territory and so having some statutory obligations.

This group named itself the Consultative Committee, a title that was deemed to be the most expressive of their primary functions — consultation and information exchange. This Consultative Committee then agreed to set a timetable for meetings and activities to try and ensure that the program would be completed in accordance with the deadlines set in the lease. The idea was that the technical experts could meet as often as they wished, but at agreed intervals progress reports would be presented to the whole group and decisions made as to the next step.

The basic programme was agreed to be a major gathering every 6–8 weeks with any member of the Aboriginal communities concerned being welcome to attend. These meetings would hear presentations from the experts and then discuss the information. The style of the presentations was difficult to work out at first but great emphasis was put on the use of models, posters, pictures, diagrams and computer graphics. These techniques were very successful. For example, at times the use of small models was the best way to demonstrate options for earthmoving.

Also the choice of venue was important as people had to be comfortable with their surroundings to relax and discuss issues. Consequently conventional meeting rooms were not an option. However, this led to another problem. Having meetings in the open air at a shade house in the Ranger station or under trees at a campsite was fine in the dry season. But once the wet season approached it was essential to find venues that were sheltered and cool and where the group could be catered for easily.

A hotel resort at Katherine seemed like the ideal place with a suitable shelter in the gardens, but as the days got hotter and more humid it became more difficult for everyone to concentrate on the business in hand. For the next meeting, still during the wet, the Committee used a meeting room in a motel near the former Rum Jungle minesite. There was more acceptance of this format and venue by this time, but outdoor venues are still the first preference and so wet season meetings are minimised.

Whenever possible, meetings have been held in the SAV. This not only reinforces the links between the people and the land, but also enables site visits to be undertaken quickly

and easily to compare the presentation with the reality. Also the group members become more familiar with each other when camping in one location. Having discussions at meals and during site visits, as well as in more formal sessions, was seen as a very effective way to build up trust. This build up of mutual trust and respect within the group has been the most gratifying and satisfying part of the process to date for many of the participants.

Record keeping and minute-taking are an essential part of such a planning process. Clearly conventional processes with minutes written in “public service style” were not really applicable to this situation. Especially so when a number of the ATO did not count English as their first, or in some cases even second, language. Throughout the sessions all outcomes, questions raised and points agreed are now written up on a flip chart, preferably by a member of the community. Each page is photographed as it is completed and these photographs are compiled into the meeting record. In this way the community are confident that the record of what they wanted recorded is accurate. Also they remember more easily the context in which ideas were discussed and/or agreements reached. Occasionally the ATOs may ask to have a private discussion so they can debate a point amongst themselves in their own language. This activity is not discouraged as it is seen as an integral part of the development of mutual trust.

As the project developed and there were more meetings some previously “hidden” but significant issues came to light. In many cases these explained earlier an apparent reluctance to deal with some of the major problems. For example, cultural issues have been discussed more frequently and openly as the process has advanced. These have included the need to exclude women from discussions of sites sacred specifically to men. A further issue is that materials may not be brought into, or taken out of, the boundaries of some sites. This has obvious implications for what options are feasible at certain sites, e.g. when considering backfilling old mine pits and costeans.

There have been many concerns expressed about what constitutes an acceptable level of land disturbance during remediation activities. The basic requirement is that mechanical disturbance of land be minimised. Thus the smallest practicable machinery is selected for use in earthworks and agreed with the ATO. Equally no drilling or blasting is permitted in the valley for fear of arousing malevolent forces. This last point created a challenge as the original plans required a supply of clean rock to be used as capping material and erosion control works at several locations. One solution was found in the form of small outcrop of fractured material that met all the required criteria from a technical point of view yet was loose enough to be ripped up by an acceptably sized bull dozer. Eventually the material was not required as a better final design was adopted using a soil cover

Throughout the project it was often necessary to extend the original time schedule, a reflection of the time required to advance each stage. Communities will not be hurried and meetings needed to be spaced out to enable people to relax before the next round of discussions and actions. Also traditional activities would take precedence over the project meetings wherever there was a clash of dates. However, out-of-session work such as field investigations and intra-community discussions was encouraged to maintain progress. Fieldwork was tasked to provide the data needed for the remediation planning but also had to address issues raised at meetings. The questions raised most frequently in discussion usually related to the safety of foodstuffs and water sourced within the valley area during dry season camping trips. Consequently appropriate sampling programs (using traditional methods and ATOs as collectors) were often undertaken for food items and the results presented to the meetings. IN all cases the test results indicated that there were no radiological concerns in this regard for any samples of food collected in the valley.

Another part of the information transfer process was the organisation of a radiological protection seminar for the ATO to explain what radioactivity is and how it related to their everyday life. This was carried out by a independent specialist trainer and was very well received

9. OUTCOMES

The remediation works for the sites will be completed during the dry season of 2009. The site for the single disposal containment for all mining related contaminated waste in the SAV has been selected and characterised and the views of the ATO taken into account. The plan for the remedial work was accepted by the ATO in December 2001 after a community meeting accepted the technical aspects of having had various cultural issues addressed to their satisfaction. In the time since then the programme has had to wait for funding to be agreed, site investigations to be completed and final designs prepared and accepted by all stakeholders, especially the ATO and the regulatory authorities. Throughout this period the consultation process has continued and the emphasis is now on the post remedial works phase. This will involve setting up a long term monitoring and surveillance programme with the input and agreement of the ATO. The nature of their participation on that programme is still under discussion.

The ATO are now satisfied that they understand what is being done in the remediation process, and that they share ownership of the plan. In particular they are satisfied that the plan has been modified after consideration of their own ideas and aspirations. The Gunlom Land Trust members are looking forward to seeing their plan being implemented and participating fully in its implementation, as well as being main players in the long term stewardship these former mining areas. All these activities will also fit within the overall Plan of Management for Kakadu National Park.

10. IAEA DOCUMENTATION

The IAEA has long appreciated the need for, and advocated the use of, inclusive stakeholder consultation procedures as an integral part of leading practice. In recent years the IAEA has been involved in a number of projects aimed at improving the manner in which regulators and operators engage with their other stakeholders. Two examples are briefly discussed here.

The first example is the World Nuclear Association policy document “Sustaining Global Best Practices in Uranium Mining and Milling”, published in 2008 [9]. Sub-titled “Principles for Managing radiation, Health and Safety, Waste and the Environment” it represents the output from a meeting held by the IAEA in 2007 in Vienna at which the leading uranium producers and operators (mining companies) were asked to consider ways in which a joint industry/regulator approach to best practice could be developed to assist the many newcomers to the uranium production cycle, both producer countries and junior mining companies. A subsequent IAEA Technical Meeting in October 2008 discussed these issues further and it is hoped a further plan will be developed to include mentoring and possible development of guidance documentation.

In December 2007 the IAEA Laboratories at Seibersdorf, Austria published a report on the outcomes of a meeting held in October 2007 [10]. Entitled “Communication Strategies in Uranium Mining” this report contains the record of discussions amongst members of an expert group from all sides of the uranium mining industry. The experts group included members

from major uranium producing companies and their regulatory authorities and is a distillation of what was then considered best practice in stakeholder communications in the uranium production cycle.

11. CONCLUSION

Stakeholder communications have always been important as an integral part of the successful development of a modern mining project; never more so than when the mineral of interest is uranium. This paper has attempted to show how two approaches have been used with success for both on-going production sites and a specific legacy remediation project. The importance of good honest communications cannot be over emphasised and in both these cases there are now procedures in place that are a credit to all those who have worked to develop, maintain and improve the systems.

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URANIUM EXPLORATION AND GEOLOGY
(Session 3)

URANIUM EXPLORATION, RESOURCES AND PRODUCTION IN SOUTH AFRICA 2009

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Abstract

The paper gives a brief history of uranium mining in South Africa. The types of uranium deposits in South Africa are described and their distribution given. The majority of uranium is hosted as a by-product in the quartz-pebble conglomerates of the Witwatersrand Basin with lesser amounts in tabular sandstone and coal hosted deposits. The exploration activities of companies operating in South Africa are discussed and the reserves and resources identified are presented. A substantial increase in reserves has been recorded over the last two years because of intensive investigation of known deposits. Only a marginal increase in total resources was reported because of a lack of “greenfield” exploration. Production is far down from the levels achieved in the 1970s and 1980s. The surge in the uranium market resulted in a number of companies investigating their production options. The recent decline in the market has slowed down some of these activities and forced the closure of an operating mine. However a new mine has come into production and feasibility studies are being carried out on other deposits. The recently promulgated *Nuclear Energy Policy for the Republic of South Africa* defines Necsa’s role in nuclear fuel cycle and the uranium mining industry emphasizing security of supply. South African uranium resources will be able to supply all local needs for the foreseeable future.

1. INTRODUCTION

Investigators from the Manhattan Project visited South Africa in 1944 and 1946 to investigate the uranium potential of the country, particularly the Witwatersrand Basin where gold had already been mined for over 50 years [1]. The Atomic Energy Act was proclaimed in 1948 resulting in the formation of the Atomic Energy Board (AEB) to oversee nuclear related activities in South Africa. The Geology Department was one of the first departments created to assess and monitor the country’s uranium resources.

The first uranium was produced in 1952 at the West Rand Consolidated Mines. Uranium production grew rapidly as more and more uranium plants were commissioned.

In 1970, the Uranium Enrichment Corporation of South Africa (UCOR) was formed to develop uranium enrichment capabilities. The AEB became the Nuclear Development Corporation of South Africa (NUCOR) in 1983 and the Atomic Energy Corporation of South Africa (AEC) was created to control both UCOR and NUCOR. Both the AEB and the AEC participated in and reported to the Red Book until 1999.

The South African Nuclear Energy Corporation (Necsa) was formed in 1999 incorporating both UCOR and NUCOR [2]. At that time the Red Book activities were handed over to the Council for Geoscience who still report to the Red Book.

The nuclear renaissance in the mid 2000s prompted the national electricity utility to announce plans to increase their nuclear generating capacity to 20000 Mw by 2025. Necsa created the Nuclear Fuel Cycle Department (NFC) in 2007 to provide support for this initiative and to investigate the viability of re-establishing the nuclear fuel cycle in South Africa. The uranium Mining Section is responsible for assessing and monitoring the nation’s

uranium resources to determine their availability for the nuclear fuel cycle and the planned nuclear generation capacity.

2. URANIUM DEPOSIT TYPES IN SOUTH AFRICA

South Africa is well endowed with uranium resources and the 2007 Red Book [3] indicates that they are ranked 4th in the world in terms of Identified Resources recoverable at costs less than US\$130/kg U.

Uranium is found in South Africa in a number of deposit types, namely quartz-pebble conglomerates, tabular sandstones, coal-hosted, alkaline complexes, surficial, heavy mineral sands, alaskites and granites, and in marine phosphates. The distribution of these deposit types in South Africa is shown in Figure 1.

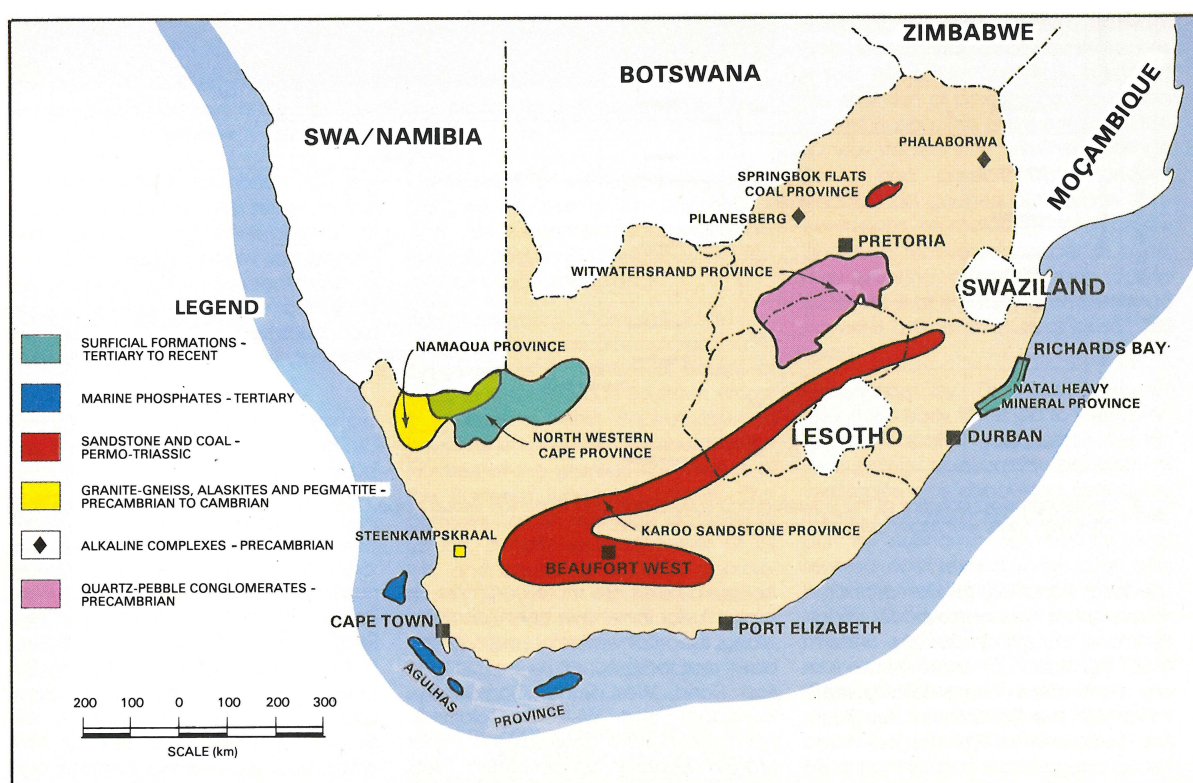


FIG. 1. Types and localities of uranium deposits in South Africa.

By far the majority (+70%) of uranium in South Africa occurs as a by-product is in the quartz-pebble conglomerate gold deposits of the Witwatersrand Basin (Figs 1–2). Figure 1 shows all the mines operating in 1986. Many of the gold mines are now defunct and only mine number 9 in the list, near Klerksdorp, now called the Vaal River Operation currently produces uranium. Mine number 7 is now the Dominion Reef Uranium Mine which produced uranium for a short time in 2008 before being placed on care and maintenance. Over one hundred years of mining for gold have resulted in large uranium resources in the tailings dams of the gold mines.

The next most significant uranium deposits are those hosted by sandstones and coal in the Karoo basins, each of which contain about 10% of the nation's resources.

FIG. 2. Mines of the Witwatersrand Basin.

Small amounts of uranium are found as a by-product to copper in the Phalaborwa Igneous Complex. The scale of copper mining was such that for many years it was economical to extract uranium from the heavy mineral concentrates generated during treatment of the ore [4].

Minor amounts of uranium occur in surficial deposits in the northwest of the country. They are calcrete or diatomaceous peat-hosted deposits. They tend to be small irregularly shaped bodies with low grades, but they are at or close to surface.

Alaskites and granites are known to be uranium bearing but they are too small and the grades too low to be of economic interest under current market conditions

The heavy mineral sands around the South African coastline are exploited for ilmenite, rutile, zircon and monazite. The monazite contains low grades of uranium but has never been extracted.

The marine phosphates occur as layers of nodules on the continental shelf off the southwest coast. They contain uranium which may be a useful by-product if these deposits are exploited in the future.

3. EXPLORATION

The 1970s saw companies very active in uranium exploration and many new deposits were discovered, particularly in the Karoo. The decline of the uranium market in the 1980s saw a marked reduction in exploration activities, which ceased totally outside the Witwatersrand Basin by the mid 1980s. Even the exploration in the Witwatersrand Basin was directed at gold with additional uranium resources being incidental.

The recent surge in the uranium spot market price has seen a large increase in the exploration for uranium in South Africa and also world-wide. There has been no “green fields” exploration in South Africa with all activities being directed at re-evaluating known deposits and looking for extensions to these deposits. The distribution of uranium resources have resulted in the major interest being placed on the Witwatersrand deposits, both underground and surface. However non-Witwatersrand deposits in sandstones, coal-hosted and surficial deposits are being investigated by various companies.

3.1. Witwatersrand exploration

AngloGold Ashanti at its Vaal River Operation is the only current uranium producer and it is examining possible extensions to its current mining operations and re-evaluating its tailings dams [5].

Uranium One has placed its Dominion Reef Uranium Mine on care and maintenance. Its exploration activities within its mining lease area have been terminated, pending an improvement in the uranium market [6].

First Uranium has commissioned its first uranium plant at its Ezulwini Mine and will be producing uranium. Current exploration activities are aimed at extensions to known underground resources at Ezulwini Mine and firming up resource and reserve estimates of the tailings dams there and at its Mine Waste Solutions operations near Klerksdorp [7].

Mintails has ground holdings over the old West Rand Consolidated Mine near Krugersdorp. This mine was the first to produce uranium in South Africa and Mintails is initiating a project to identify underground uranium resources there [8]. They also hold the rights to large tailings dams both on the West and East Rand that they are busy evaluating.

Rand Uranium is a company specifically formed by Pamodzi Resources (60%) and Harmony Gold (40%) to exploit the uranium resources of the old Randfontein Estates Gold Mine. This mine was a significant uranium producer in the past and has substantial resources both underground and in tailings dams. Current gold mining operations are continuing while a feasibility study of the uranium resources is being conducted. This should be completed by the end of 2009 and decisions be taken in the next year as to the future of these resources [9].

Harmony has other uranium resources in its mines in the Free State goldfield but has yet to make any public announcement in their regard.

Similarly Gold Fields is conducting a feasibility study on the economic viability of the uranium resources contained in the tailings dams on their mines on the West Wits Line. There are 14 tailings dams that are being evaluated and decisions will be made in the next year [10].

3.2 Non-Witwatersrand exploration

Most of the work is being conducted in the main Karoo Basin, but other companies are investigating the coal-hosted deposits on the Springbok Flats and surficial deposits [11] in the Northern Cape. Another company is exploring a quartz-pebble conglomerate deposit at the old Denny Dalton Mine in northern KwaZulu Natal [12]. All exploration activities have slowed recently because of the decline in the uranium market.

Uramin has the rights to the majority of the Rystkuil Channel which hosts a major portion of the larger known deposits in the Karoo Basin but has made no public announcement as to their progress or intentions.

Brinkley Mining [13] and Signet Mining [14] both have exploration licenses over a number of farms. The known mineralization is limited and a consolidation with other resource holders would probably be necessary to render their exploitation economically viable.

4. RESERVES AND RESOURCES

The reserves and resources tabled are compliant with South Africa's SAMREC code which defines how reserves and resources are quoted by publicly listed companies [15]. Resources are reported as *in situ* mineralization estimates based on geological evidence and knowledge. Reserves are a sub-set of resources which are economically mineable taking into account mining, metallurgical, economic, legal, environmental, social and all other relevant factors. Mines generally do not incur the cost of raising resources to reserves until necessary for exploitation in the near term.

AngloGold Ashanti has the largest identified underground resources at its Vaal River Operation. When total resources are considered then First Uranium and Uranium One have larger resources. It should however be noted that First Uranium resources are mostly in slimes dams. Uranium One's resources are almost all underground in a mine where uranium is the primary product with by-product gold. Resources for both First Uranium and Uranium One are largely in the Inferred category which is the lowest confidence category. First Uranium is currently carrying out investigations to raise the confidence of their resource estimates.

Mintails has the smallest published resources but their investigations of their assets are at an early stage and will no doubt grow as the investigations progress.

The published uranium reserves and resources in South Africa for 2007 are listed in Tables 1 and 2 contains the updated reserves and resources for 2009.

It can be seen that the reserves have increased by 69% but the resources have only increased by 7%. This is the result of intensive investigations of the known resources raising them to economically viable reserves but limited investigations aimed at identifying new resources. Uranium One have downgraded all their reserves because of the depressed market.

The completion of the feasibility studies being conducted by Rand Uranium and Gold Fields are likely to add tens of thousands of tonnes of extra resources to the total.

TABLE 1. SOUTH AFRICAN URANIUM RESERVES AND RESOURCES 2007

Category	Company				Totals × 1000 t U ₃ O ₈
	AngloGold Ashanti	Uranium One	First Uranium	Mintails	
Reserves × 1000 t U ₃ O ₈					
Proven	-	-	-	-	-
Probable	11.80	14.24	-	-	26.04
Total Reserves	11.80	14.24	-	-	26.04
Resources × 1000 t U ₃ O ₈					
Measured	1.40	-	8.54	-	9.94
Indicated	50.70	30.04	16.19	6.67	103.60
Inferred	6.00	83.47	105.60	7.07	202.14
Total Resources	58.10	113.51	130.33	13.74	315.68

TABLE 2. SOUTH AFRICAN URANIUM RESERVES AND RESOURCES 2009

Category	Company				Totals × 1000 t U ₃ O ₈
	AngloGold Ashanti	Uranium One	First Uranium	Mintails	
Reserves × 1000 t U ₃ O ₈					
Proven	-	-	8.31	-	8.31
Probable	19.20	-	16.52	-	35.72
Total Reserves	19.20	-	24.84	-	44.03
Resources × 1000 t U ₃ O ₈					
Measured	1.98	-	9.33	8.78	20.09
Indicated	67.80	30.04	19.20	4.65	121.69
Inferred	13.39	83.47	94.73	4.96	196.55
Total Resources	83.17	113.51	123.26	18.39	338.33

5. PRODUCTION

South Africa has always been a major uranium producer from the commissioning of the first uranium plant in 1952. Production increased rapidly to 4950 tU in 1960 to supply the Western World's military needs. Production rose to 6 140 tU in 1980, placing South Africa third after USA and Canada. There were 13 mines producing uranium in 1980. The decline in the market saw many mines cease uranium production in the 1980s and 1990s. By 2002 there was only one mine producing uranium and this reduced to a single plant producing 534 tU in 2006. This dropped South Africa down to 11th in the uranium producing nations.

The surge in the market had many companies announcing plans to increase or commence uranium production. These plans have slowed because of the depressed market. However a number of projects are progressing.

AngloGold Ashanti has refurbished its uranium plant and has announced that they will be constructing a second plant to double their capacity to over 1 000 tU₃O₈ per year. Dominion Reef Uranium Mine is on care and maintenance and negotiations for its sale are underway. If the market improves there is no reason to believe that it could not recommence production. First Uranium has commissioned its first uranium plant and it produced its first yellowcake in May 2009. A second uranium plant is under construction.

Mintails, Rand Uranium and Gold Fields are all undertaking further investigations and feasibility studies. Favourable market conditions could see Rand Uranium starting production late in 2012, but the other two companies are not that far advanced in their studies.

Table 3 shows a likely production scenario for the next four years. Obviously market conditions will have great influence over what transpires in the future. Many of the resources are marginal under current conditions, exacerbated by the worldwide financial meltdown. Any improvements in the financial and/or uranium markets could have a strong positive influence.

TABLE 3. FUTURE URANIUM PRODUCTION SCENARIO IN SOUTH AFRICA

Company	2008	2009	2010	2011	2012
AngloGold Ashanti	650	950	1 250	1 250	1 250
Uranium One	90	?	?	?	?
First Uranium		350	650	850	1 050
Rand Uranium					250
Total (t U ₃ O ₈)	740	1 300	1 900	2 100	2 550

6. NUCLEAR ENERGY POLICY FOR SOUTH AFRICA

This policy was promulgated late in 2008 and has an impact on uranium mining activities in South Africa [16]. The sections of relevance are as follows:

- Exercise control over un-processed uranium ore for export purposes for the benefit of the South African economy;

- South Africa shall endeavour to **use uranium resources in a sustainable manner**;
- Government shall be responsible for acquiring and managing strategic uranium stockpiles;
- Government shall ensure that the exploitation of our mineral resources and the securing of a long term supply of these resources is balanced in a sustainable fashion;
- The South African Nuclear Energy Corporation (Necsa) shall be encouraged to participate in the uranium value chain, beneficiation thereof and will be responsible for storing of uranium supplies acquired by the State.

7. CONCLUSIONS

The published uranium resources will be sufficient to meet South Africa's nuclear power generation needs for the foreseeable future. Further investigations are underway which will almost certainly increase these resources.

There are two areas of concern. A large proportion of the nation's uranium resources occur as by-product to gold and their exploitability is closely dependent on the continuation of gold mining. Studies are underway to assess the sustainability of the gold mining industry.

A second concern is that production levels will certainly increase well in excess of the national requirements and production will largely be exported, possibly resulting in a shortage at some time in the future. This will obviously be dependent on market conditions and the planned future increase in national nuclear generating capacity which has still to be formulated. The Nuclear Energy Policy specifically refers to strategic stockpiles and studies are underway to identify possible stockpiling strategies, assess them and the advisability of implementing them.

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AN OVERVIEW OF URANIUM EXPLORATION STRATEGY IN INDIA

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Abstract

Uranium exploration in India dates back from 1949 and the first mineralized area was located in the early 1950s in Singhbhum Shear Zone (SSZ), eastern India. Since then, a number of potential and promising uranium provinces have been established in India. The potential uranium provinces include SSZ, Dongargarh, Aravalli, Siwalik belt, Mahadek basin, south-western and northern parts of Cuddapah basin, North Delhi Fold Belt, Bhima and Kaladgi basins. The promising uranium provinces are Proterozoic Chhattisgarh, Indravati, Gwalior, Vindhyan, Shillong basins, Gondwana basins of Central India and semi-arid regions of western Rajasthan. With the establishment of large tonnage-high grade Lower-middle Proterozoic unconformity deposits in Canada and Australia, there was a paradigm shift in the exploration strategy towards the Proterozoic basins of India. The discovery of unconformity related uranium mineralisation in the northern part of Proterozoic Cuddapah basin in southern India in 1991 and discovery of few deposits in the province has opened the avenues for finding of similar deposits in Cuddapah and other 13 Proterozoic basins in India. As a sequel, Proterozoic Bhima basin in southern India has been recognized as a potential target for uranium mineralization, where a low tonnage-medium grade deposit has been established and mine development works are in progress. Sustained exploration efforts in other Proterozoic basins have yielded success in a few basins such as Deshnur area in Kaladgi Basin of southern India. Considerable uranium resources have been established in Proterozoic Cuddapah and Bhima basins. Apart from northern parts of Cuddapah and Bhima basins, areas in the southwestern part of Cuddapah basin for stratabound type, where a mine is under construction; Proterozoic Kaladgi basin for vein type; Cretaceous Mahadek basin for sandstone type and the North Delhi Fold belt for vein type of mineralization have been prioritized as potential areas for exploration. Airborne and ground geophysical techniques with adequate support of exploratory and evaluation drilling are expected to produce quicker results. The second priority is in the promising areas, where substantial ground radiometric and geochemical surveys have indicated the presence of uranium in the system. These comprise Proterozoic basins such as Chhattisgarh, Vindhyan, Gwalior, Bijawar, Indravati and Shillong basins for unconformity type; Gondwana sediments of central India for sandstone type; Central and Eastern Indian craton for iron oxide type; QPC type in parts of central and eastern India and surfacial type of uranium mineralization in the semi-arid regions of western Rajasthan. Uranium exploration in India is now geared up to face the challenges of fuel requirements for the rapidly growing domestic nuclear power industry. Exploration activities both in potential and promising uranium provinces have been planned for the next ten years. Comprehensive exploration strategy for every province is being executed to address specific exploration targets.

1. INTRODUCTION

Singhbhum Shear Zone (SSZ) discovered in the 1950's is a major uranium producing province in India and subsequently three other important geological environments viz.: 1) Fourteen Proterozoic basins for unconformity related and stratabound deposits, 2) Cretaceous Mahadek sediments of Meghalaya for sandstone type uranium mineralization and 3) North Delhi fold belt in the states of Rajasthan and Haryana for vein type mineralization have been established (Figure 1). The first major breakthrough in the Proterozoic basins was the discovery of an unconformity related uranium deposit in the middle Proterozoic sediments-crystalline basement unconformity in the northern part of the Proterozoic Cuddapah basin near Lambapur, Andhra Pradesh. Soon, the possibility of finding similar deposits in analogous geological environments all over the country was realised and huge exploration inputs have been deployed in seven of the fourteen Proterozoic basins in the country. The fourteen basins are dispersed in the Peninsular India and Meghalaya plateau and occupy an

area of 225 000 sq.km. With the advent and success of airborne geophysical surveys viz. Frequency Domain Electromagnetic and Time Domain Electromagnetic (TDEM) methods world over, India formulated a strategy to carry out nearly 400 000 line Km of airborne TDEM surveys (with radiometric and magnetic) in many of the potential areas in the country including the Proterozoic basins. There are also plans to infuse vast ground geophysical inputs in the exploration programme.

Since the early seventies, the Cretaceous Mahadek sedimentary basin in the southern parts of Meghalaya plateau has been recognized as a potential uranium province for sandstone type uranium mineralization. Extensive exploration in this province over a period of more than thirty years led to the discovery of six small to medium size deposits. The basin holds promise for more deposits in the adjoining areas.

The 320 km long NNE-SSW trending Kaliguman lineament in the states of Rajasthan and Haryana is recognized as a potential zone to host vein type of uranium mineralization. An integrated approach with litho-structural and ground geophysical inputs has resulted in the discovery of a fracture controlled vein type uranium deposit in the North Delhi fold belt near Rohil village, Sikar district, Rajasthan and the entire 320 km long Kaliguman lineament holds immense potential for additional uranium resources. Vast inputs of ground and airborne geophysical surveys and drilling is planned in this province.

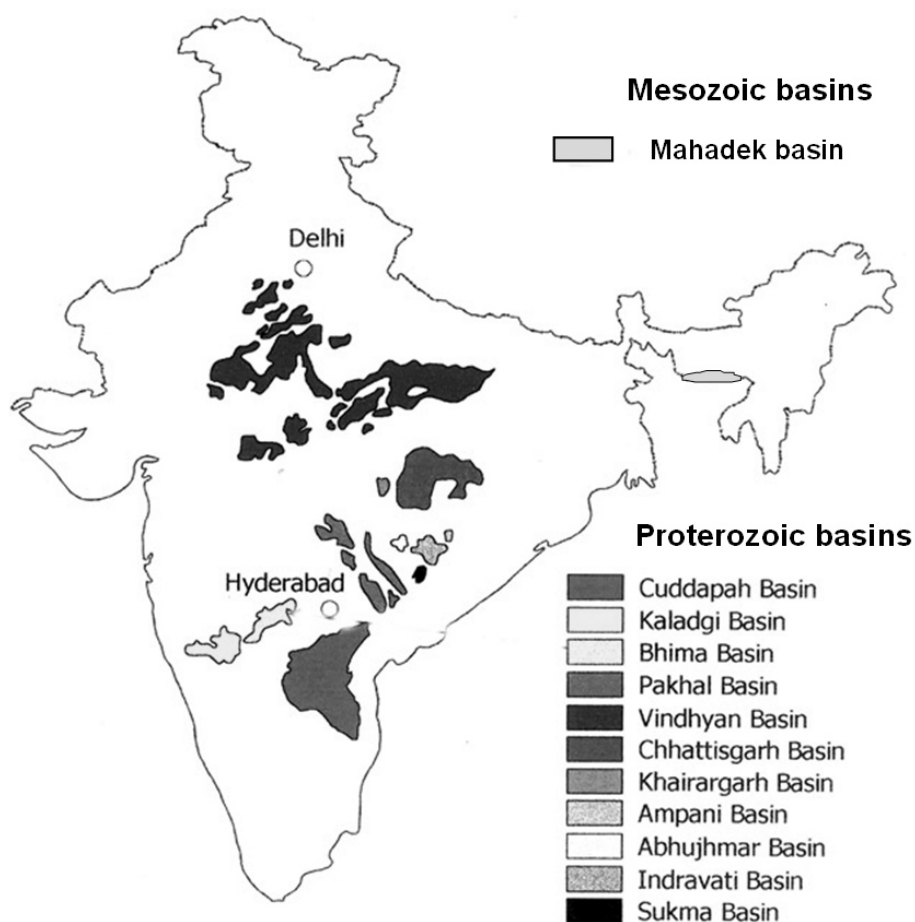


FIG. 1. Potential Proterozoic and Mesozoic basins of India.

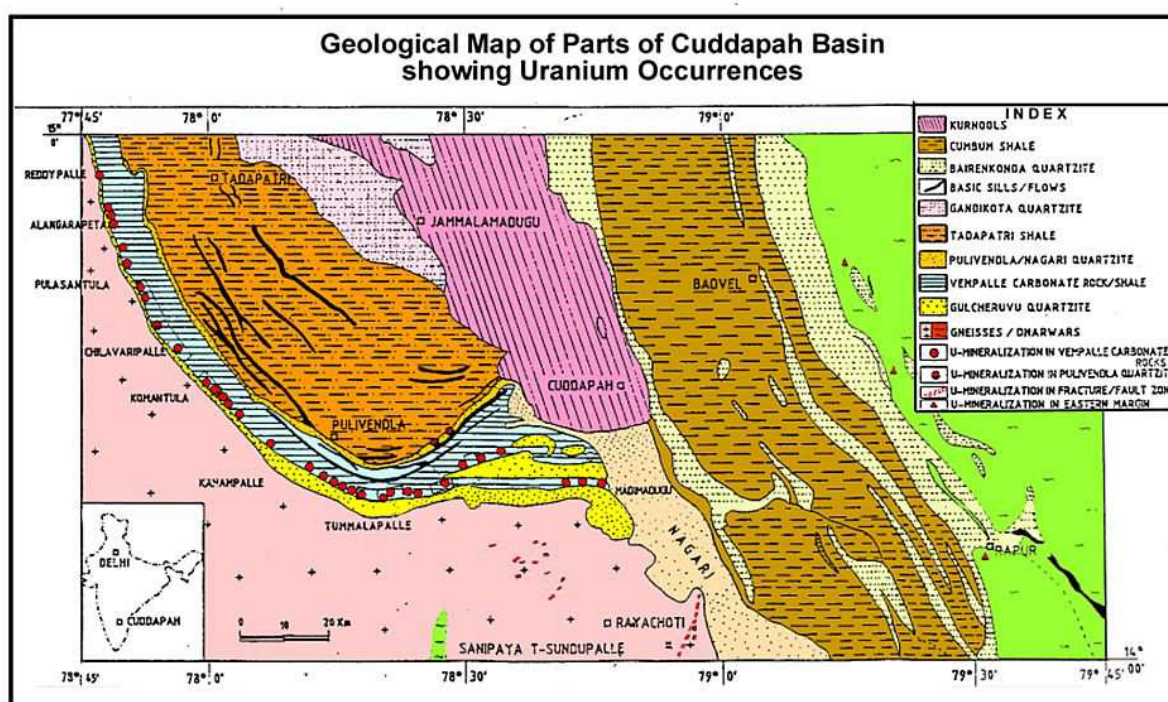
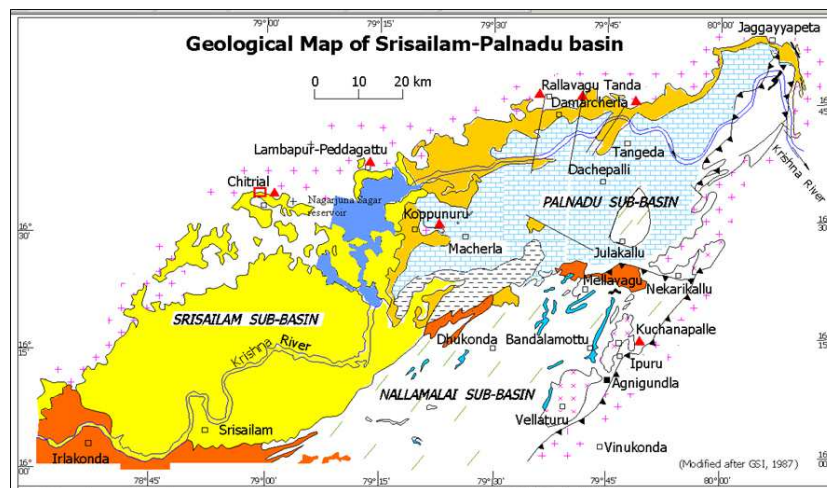
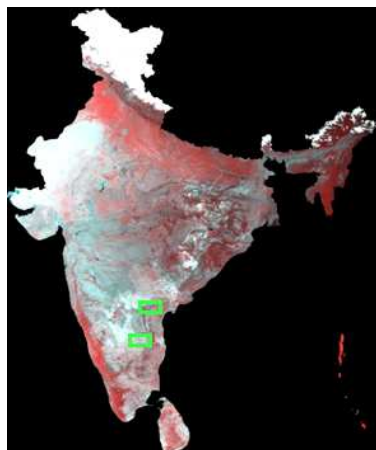


FIG. 2. Geological map of northern and southern Cuddapah basin.

2. CUDDAPAH BASIN

Cuddapah Basin in south India occupy an area of 44 500 sq km and contain over 12 km thick sequence of sedimentary and volcanic rocks belonging to Middle-Upper Proterozoic age. They are classified as an older Cuddapah Supergroup and younger Kurnool Group and holds rich mineral wealth, including uranium, hosted in a variety of lithostructural settings (Fig. 2).

As such three types of uranium mineralization have been established in Cuddapah basin. Dolostone hosted stratiform mineralisation and litho-structure controlled vein type in southern Cuddapah basin and unconformity related mineralization in the northern parts of the

Cuddapah basin has been established. The northern parts of the Cuddapah Basin comprising Srisailem and Palnad sub-basins (Fig. 2) are being explored for unconformity related uranium mineralization while the southwestern part of the basin is being explored for dolostone hosted stratiform type of mineralization.

Investigations carried out so far in Srisailem and Paldad sub-basins have resulted in establishing four low grade — low tonnage unconformity related uranium deposits at Lambapur, Peddagattu, Chitrial and Koppunuru in parts of Andhra Pradesh. Unconformity contact of the cover rocks with the basement rocks is the prime target for exploration. Coffinite and uranophane are major uranium minerals. Fluid inclusion studies of quartz occurring in mineralized granite indicate highly saline solutions of 100–200°C temperature could be responsible for deposition of uranium. Sm –Nd isochron dating of uraninite of Lambapur area indicate an age of $1\,327 \pm 170$ Ma, whereas U-Pb data yield radiogenic Pb ages of about 480–500 Ma [1].

In Lambapur, the first such uranium mineralization is noted in an outlier of Srisailem formation [2]. It is confined essentially to the basement granite and partly in the unconformably overlying basal pebbly/gritty quartzite of Srisailem Formation. The Peddagattu plateau forms a separate outlier of the Srisailem sub-basin south of Lambapur plateau. Peddagattu area has a geological setting similar to Lambapur uranium deposit. The sediments of Srisailem Formation include pebbly/gritty quartzite, shale with dolomitic limestone, intercalated sequence of shale — siltstone — quartzite and massive quartzite. Chitrial is yet another horse shoe shaped outlier of Srisailem Formation resting unconformably over the basement granitoids. Chitrial outlier covers an area of more than 60 sq.km. and the surface indication reveals widespread uranium mineralisation in this area. A part of the outlier has been explored for uranium resources and a low grade low tonnage deposit has already been established. With more than 50 sq km of mineralized area to be explored, the Chitrial outlier is likely to emerge as a low-medium grade high tonnage unconformity related uranium deposit in the province. Exploration in the remaining part of Chitrial outlier is likely to be initiated in the near future. In Koppunuru, to the SE of Lambapur-Peddagattu, mineralization occur at the unconformity contact between the basement granitoids and the overlying Banganapalle quartzites and within the quartzites. Uranium exploration activities in the northern part of Cuddapah basin have so far been restricted mostly in the outliers and shallower parts of the basin.

Radiometric and geological mapping would continue to be the basic data generation method in this area. Groundwater tubewells drilled by private and government agencies are radiometrically logged for presence of mineralized intercepts. Studies are underway to characterise the ore body and host rocks through geochemical and petro-minerological studies. With the help of huge volume of data generated in this area, efforts are on to model the signatures of uranium mineralisation with reference to host rocks and a variety of geological, geochemical, geophysical and radiometric attributes. It is proposed to undertake hyper-spectral remote sensing studies for delineation of possible alteration zones. Drillhole cores are to be routinely scanned by hyper-spectral scanners for identification of alteration features, especially clay minerals. The northern part of Cuddapah basin is proposed to be covered by closely spaced airborne geophysical surveys including radiometric, magnetic, gravity and TDEM techniques. TDEM surveys are especially expected to provide insights on the extent of alteration haloes, thickness of palaeosol horizon, concealed basement fractures and conducting bodies, if any, associated with uranium mineralization.

The dolostone hosted stratiform uranium mineralization in southwestern part of the Cuddapah basin is probably only one of its kind in the world. The host Vempalle formation, an older stratigraphic unit of the Cuddapah supergroup comprise a sequence of stromatolitic dolomite, dolomite, mudstone, chert and basic sills. A 160 km long belt of Vempalle limestone with a dip of 12° towards the basin is established to host low grade mineralization [3]. The ore horizon is stromatolitic-siliceous dolostones occurring between two limestone beds. Uranium occur as ultrafine granules of pitchblende associated with pyrite, molybdenite, covellite and chalcopyrite [4].

The mineralized dolostone horizon is represented by 1–7 m thick, alternating bands of light and dark gray layers. Uranium mineralization occurs along the bedding planes, carbonate-phosphate contact, microstylolites and grain boundaries of clasts. Phosphate, silica and organic matter in the impure dolomitic limestone are the main controlling factors for uranium mineralization. Mineralisation is tabular, stratabound, non-transgressive and homogenous. Limited variations are noticed in grade and thickness along strike as well as dip directions. Mineralisation occur in two ore lodes which are separated by an average of 3 m lean zone.

Strata bound, syn-sedimentary nature of uranium mineralization and isotropic character of ore body facilitates predictive sub-surface exploration both along the strike and dip. Uranium mineralization has been established along 160 km long belt along the strike and holds promise for few hundred thousand tonnes of low grade uranium resources. Efforts are being carried out for sedimentary facies mapping of massive/cherty limestones of Vempalle Formation to identify pockets of higher grade mineralization. Geochemical characterisation and genetic modeling for U, Mo and other elements in the orebody and provenance rocks is also underway to understand the genesis of mineralization.

3. BHIMA BASIN

The Neoproterozoic Bhima basin is exposed over an area of 5 200 sq km in parts of Gulbarga district of northern Karnataka and Mahboobnagar and Ranga Reddy districts of western Andhra Pradesh state. The northern extension of this basin is concealed under the Late Cretaceous — Paleocene Deccan Trap volcanic province while the southern boundary exposes the Precambrian granite — greenstone terrain of Eastern Dharwar craton. Limestone and shale are the predominant litho units with a thin arenite and conglomerate at the base of the sequence exposed at several places. The sedimentary sequence lie unconformably over the basement crystalline rocks. The average stratigraphic thickness of the Bhima sediments in this area is about 300 m as observed from surface and sub-surface data.

E-W and NW-SE trending faults are the most prominent structural features observed in Bhima Group, which are deep seated and continue into the basement. In addition, a number of smaller cross faults with NS and NE-SW trends have been identified. The most prominent among the major faults are the E-W Gogi — Kurlagere reverse fault and NW-SE Wadi fault, E-W Tirath-Tintini fault and the other important minor faults are, Wajjal and Farhatabad fault. A small, medium grade deposit has been already established near Gogi town in Bhima basin. The deposit occurs along the east west trending Gogi — Kurlagere fault. A number of such faults that cut across the basement and Bhima sediments have been identified as favourable settings for mineralization [5]. Coffinite and pitchblende are major uranium minerals.

Borewells dug to tap groundwater are being radiometrically logged for mineralized intercepts. Radiometric and geological mapping would continue to play a major role for basic

exploration inputs. Hydrogeochemical surveys have been launched on a big scale in the area to identify areas of anomalous uranium concentration. It has been planned to systematically scan the drillhole cores by Hyper-spectral core logger for alteration minerals. Vast inputs of airborne geophysical surveys including TDEM, Magnetic and Radiometrics and ground based geophysical surveys have been deployed. Efforts are underway to model the parameters of uranium mineralisation for specific signatures so that similar settings could be targeted for exploration in other areas of the basin.

4. NORTH DELHI FOLD BELT

The metasediments of North Delhi Fold Belt (NDFB) comprising Khetri, Alwar and Bayana-Lalsot sub-basins in the states of Rajasthan and Haryana are the host for more than 200 uranium occurrences (Fig. 3). Most of the radioactive anomalies are falling in the Khetri sub-basin. Khetri sub-basin (KSB) hosts both polymetallic (Cu, Mo, Zn, Pb, U) and non-metallic fluorite and calcite mineralization. In KSB, radioactivity is associated with altered metasediments (with or without albitisation) and intrusives. The host metasediments are represented by quartzite, quartz-biotite schist, phyllite, carbonaceous phyllite, calc-silicate rocks and impure marble. The intrusive host rocks comprise granite, basic rocks, albitite/aplite and quartzo-feldspathic rocks. The albitites and albitised rocks have formed due to alkali metasomatism, post-dating the major acidic magmatic episodes in the NDFB [6] [7]. Apart from the NDFB, intermittent uranium mineralisation is established for 320 km along the NNE-SSW trending Kaliguman lineament which has also witnessed widespread soda metasomatism (Fig. 3).

A low grade low tonnage uranium deposit has already been established in NDFB near Rohil. Scope for similar mineralisation in the NDFB and all along the 320 km long lineament in other sectors is very bright. Geological and radiometric study of scanty outcrops along with hydro-geochemical surveys have brought to light anomalous uraniferous areas. Radiometric logging is carried out on a regular basis in the pre-existing groundwater tube wells for mineralized intercepts. Vast exploration inputs have been deployed in this province in areas along the Kaliguman lineament. The signatures for mineralization in this sector are albitisation, linear low magnetic zones as a result of hydrothermal activity leading to alteration of high magnetic susceptible minerals, association of buried conducting bodies as a manifestation of sulphide minerals associated with uranium mineralization and association of shear/fracture zone and axial planes of folds. Efforts are being made to create a mathematical model using vast geological, radiometric and geophysical datasets to establish quantitative parameters for the uranium mineralization in NDFB. Exploration programme is expedited by vast inputs of airborne geophysical surveys and a matching drilling campaign.

5. MAHADEK BASIN

Mahadek Basin, in the state of Meghalaya, northeast India is of upper Cretaceous age and occurs in the southern fringes of Meghalaya plateau (Fig. 4). It extends over 180 km length from Lumshong of Jaintia Hills in the east to Balphakram of South Garo Hills in the west with average width of 10 km, over an area 1 800 sq km. However, the Lower Mahadek sediments are exposed only in an area of about 470 sq km. The remaining part of the Lr. Mahadek sediments are concealed below the Tertiary sediments.

Meghalaya Plateau is a prominent geomorphic upland feature bounded on all sides by major tectonic elements like Brahmaputra graben in north, Dauki Fault in south, Haflong Fault in east and Jamuna Fault in Rajmahal Garo gap in the west. It comprises of Archaean

granite — gneisses, overlain by Lower and Middle Proterozoic Shillong Group of meta-sedimentary rocks and occupies central and eastern parts of the Plateau. Neoproterozoic granites namely Myllem (607 Ma), Nongpoh (550 Ma), Kyrדם (479 Ma) and South Khasi batholith (690 Ma) intrude these rock units. In southern part of the plateau, Sylhet Traps of Jurassic age are emplaced as extrusive rocks along the Raibah Fault and served as the basement for younger sedimentary column in the south of the fault. During the Upper Cretaceous period, the alkaline complex were also emplaced in the northeastern part of the Meghalaya Plateau and Assam, namely Sung Valley, Jasra, Samchampi (Assam) alkaline complexes.

The Mahadek Formation is divided into Lower Mahadek and Upper Mahadek members based on their characteristic depositional and sedimentological features. The Lower Mahadek sediments are deposited in fluvial regime by alluvial fan proximal facies and are characterized by grey to dark grey coloured, coarse to very coarse grained, poorly sorted, immature, feldspathic arenite wacke with abundant organic matter and pyrite. The Upper Mahadek sediments are deposited in oxidizing environment by fluvial to marginal marine system [9]. Granite and granite gneisses with high intrinsic uranium content of 8–59 ppm formed the fertile provenance for Mahadek sediments and uranium mineralisation. Urano-organic complex with or without discernible pitchblende is the predominant uranium phase observed. In addition, minor phases like coffinite, uraninite, brannerite, U-Si-C complex are also noticed. The associated trace elements include V, As, Co, Mo and Se with varied concentration levels. Uranium mineralization occurs mainly along the palaeo-channels or palaeo-basement lows and preferentially confined to near the basement rocks. The flood plain sediments are massive and silty with beds of pyrites.

In the nearly 1 300 sq.km of the Mahadek basin, the target horizon, the fluvial Lower Mahadek sandstones, are covered by a sequence of Upper Cretaceous and Tertiary sediments ranging in thickness up to 300 m. Also most of the basin is under thick forest cover and wild life sanctuary. Ground magnetic and resistivity surveys are being carried out for the delineation of palaeo channels and basement lows. Micro-geomorphological studies using aerial photos and high resolution satellite images have been successfully used for the delineation of channel sediments and flood plain sediments among the exposed parts of Lower Mahadeks. Extensive inputs of TDEM for delineation of palaeo channels, where the target horizon is covered by a thick pile of Tertiary sediments, gamma-ray spectrometer survey for radiometry, magnetic and resistivity surveys for basement topography are proposed to be carried out in this sector.

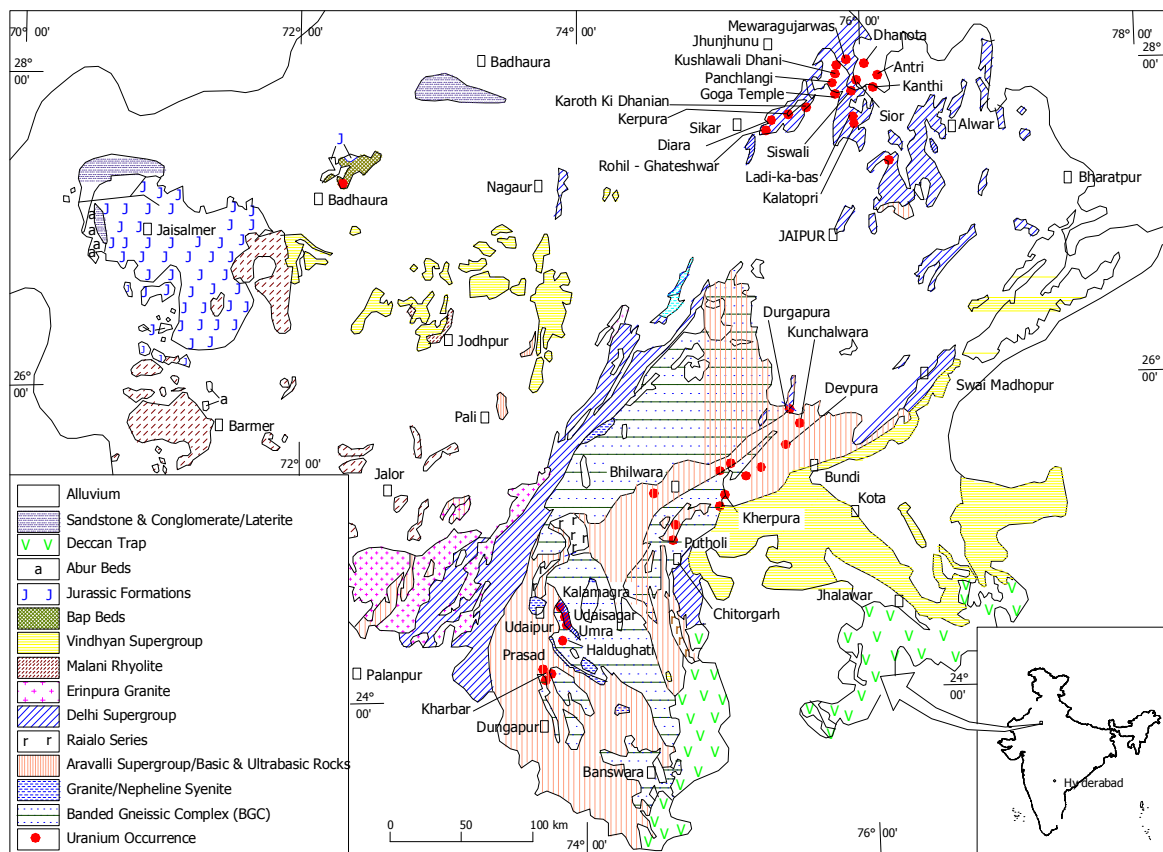


FIG. 3. Geological map of North Delhi Fold Belt.

6. KALADGI BASIN

Kaladgi Basin is a peri-cratonic Meso to Neo Proterozoic basin located on the north-western fringe of the Western Dharwar Craton covering an area of approx. 8 000 sq km in the states of parts of Karnataka, Maharashtra and Goa. The north and western extensions of the basin are covered by Cretaceous — Eocene Deccan Traps. Several outliers of the Kaladgi Supergroup occur along the southern and south-eastern margin of the basin. A number of basement faults, fractures and shears trending E-W, WNW-ESE, NE-SW and NW-SE direction, cut across both the basement and the overlying sediments, particularly along the peripheral parts of the basin.

Radiometric surveys have brought to light a number of radioactive occurrences in Kaladgi Super Group of rocks and its environs [9]. The most promising one is located at Deshnur. Uranium mineralization occurs within quartz arenite of Badami sediments near the unconformity contact between the Basement Chitradurga Group of metasediments and the overlying flat Badami Group. Sub-surface drilling indicated the presence of high grade uranium mineralization of the order of $0.13\% \text{ eU}_3\text{O}_8 \times 63.20 \text{ m}$ associated with sulphide bearing lower conglomerate and the basal arenite, just above the unconformity. Primary uranium minerals like pitchblende, uraninite, coffinite and brannerite are identified.

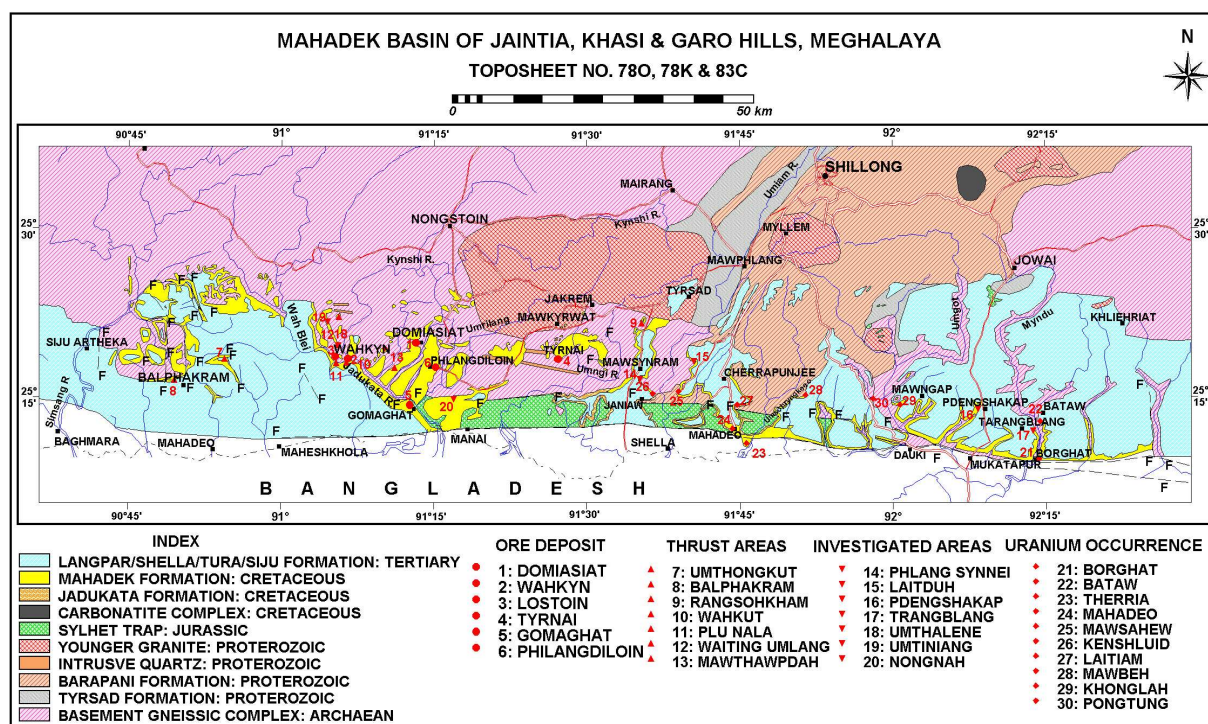


FIG. 4. Geological map of Mahadek basin.

7. OTHER PROMISING PROVINCES

A number of geological provinces which hold potential for uranium have been identified. Important among them are (a) Western Rajasthan for Calcrete type of uranium mineralization; (b) Bundelkhand craton, Madhya Pradesh and Uttar Pradesh and Chotta Nagpur Granite Gneissic Complex, Jharkhand for Iron oxide breccia type uranium mineralization; (c) Iron Ore basins in the states of Chhattisgarh and Orissa for QPC type of mineralisation.

8. CONCLUSION

India is pursuing a robust uranium exploration programme to identify uranium resources for the country's nuclear power programme. More than 130 000 tonnes of U_3O_8 contained in 26 deposits have been established so far. Most of the resources are low grade and many are of low tonnage in nature. During the past ten years the focus has been shifted towards the exploration of the fourteen Proterozoic basins for unconformity related, dolostone hosted and vein type of mineralization. The strategy was rewarded with immediate success that uranium shows have been discovered in almost all the basins and four low grade — low tonnage deposits and a medium grade low tonnage deposit have been identified in two of the basins. The southwestern part of the Cuddapah basin is the host for dolostone hosted uranium mineralization and preserve a potential for few hundred thousand tonnes of low grade mineralisation. Vast exploration inputs have been deployed in the provinces discussed above and in all likelihood a number of new areas with high grade mineralization would be discovered in some of the Proterozoic basins in the near future.

ACKNOWLEDGEMENTS

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URANIUM EXPLORATION IN PAIPA AND IZA AREA, COLOMBIA: A PRELIMINARY REPORT OF NEW CONTRIBUTIONS

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Abstract

This paper shows the preliminary results from uranium exploration of the Boyacá Department, for the first survey conducted by the Colombian state after 26 years. The exploration was carried out this year and the zone covers an area of 460 square kilometers divided into three sectors, located in the municipalities of Sogamoso Paipa, Iza, Tota and Pesca, Chivata and Tuta. The area is dominated by Cretaceous-Tertiary sedimentary rocks Quaternary sediments. Paipa and Iza exposes outcrops volcanic and sedimentary rocks; and the major structural features are Arcabuco anticline, Los Medios syncline and Boyaca and Soapaga faults. The sedimentary formations from the oldest to most recent in the area are: Tibasosa Formation; Une Formation, Conejo Formation; Plaeners Formation; Los Pinos Formation; Labor y Tierna Formation, Guaduas Formation Socha Formation; Picacho Formation an Concentration Formation; in the area outcrops also, volcanic rocks (rhyolites porphyrites and andesites); and explosive (pumices). In the Paipa Area, three anomalous sites (Durazno, Quebrada Honda and Casa Blanca) were found with values ranging between 440 and 7 500 counts/s, the highest values were reported in the Durazno area. The host rocks are volcanic rocks (tophus) and tectonic breccias with thin strips of coal from the Guaduas Formation. In 1979 the studies by ENUSA (Spain) reported values up to 3 800 counts/s. In Iza, five anomalous zones (El Crucero, San Miguel, Cuitiva — Iza, Erika and Tota — Pesca) was found with values ranging between 480 and 4 480 counts/s. Host rocks are igneous rocks in Erika sector; and phosphates in El Crucero sector with a maximum value of 2 100 counts/s. In shot holes made in Iza the values went up from 1 200 counts/s in surface to 4 480 counts/s in depth (1.60 m). In Paipa, the values increased from 4 500 in surface to 7 500 counts/s at 1.50 meters. Chemical analysis, of samples from “El Durazno” records values between 200 and 5 345 ppm so that this year (2009), A few boreholes in the area are proposed to learn more about the behavior of mineralisation in depth and the geometry of the potential deposits.

1. INTRODUCTION

The study area covers 460 km², distributed into three sectors of interest. These sectors are located in the municipalities of Sogamoso Paipa, Iza, Tota, pesca, Tuta and Chivata, in the Department of Boyacá (Figure 1).

2. OBJECTIVES

- Identify, characterize and classify the radioactive anomalies in Paipa and Iza and to know the source of radioactivity in these anomalies;
- Identify trends in mineralization;
- Explore the phosphate (Guadalupe Group) in the areas selected for mineral exploration;
- Identify uranium mineralization in rocks (shale, siltstones, sandstones, conglomerates and volcanic rocks); and
- Identify mineralization relates to fault zones, tectonic and breccias seen in the study area.

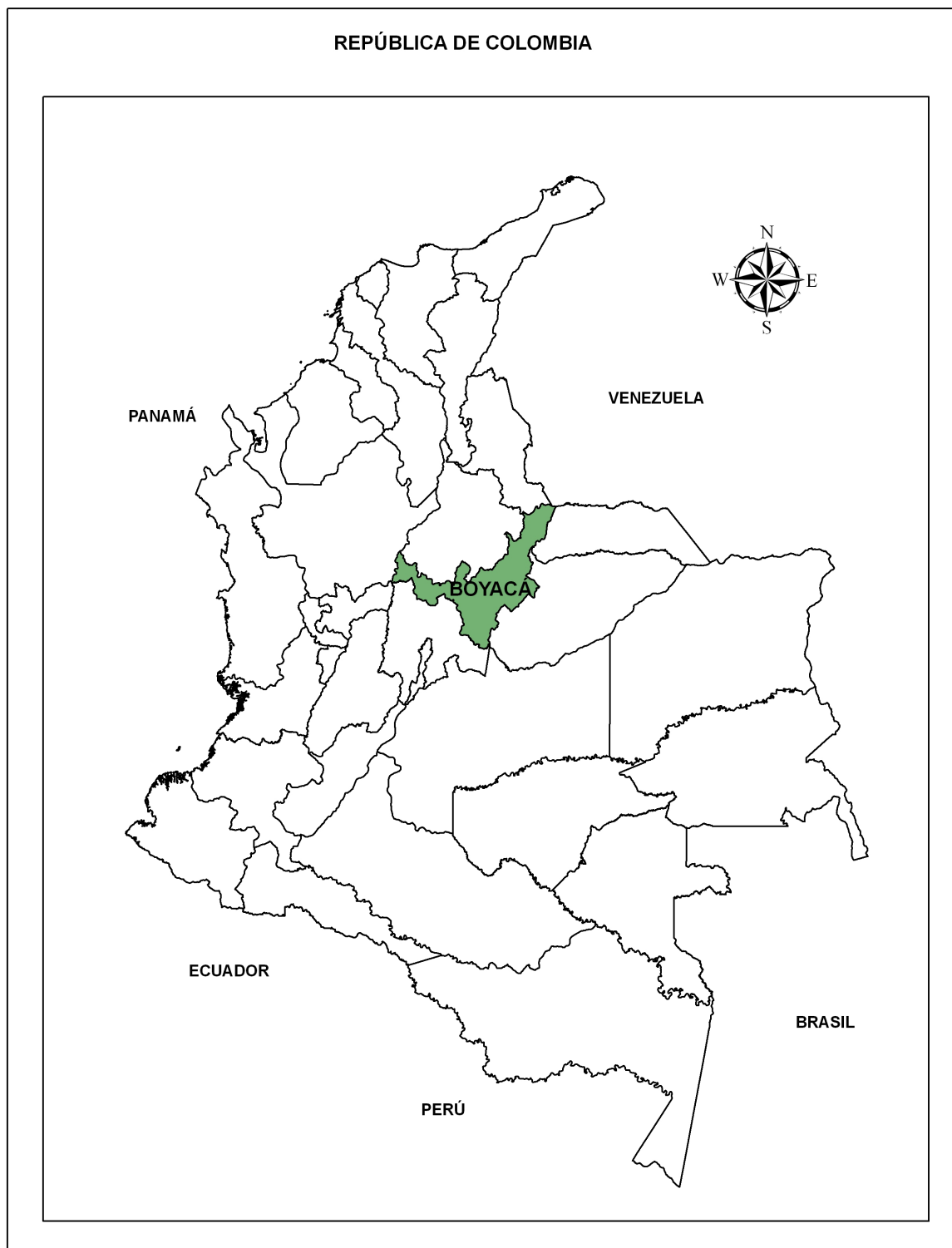


FIG. 1. Location map — Colombia.

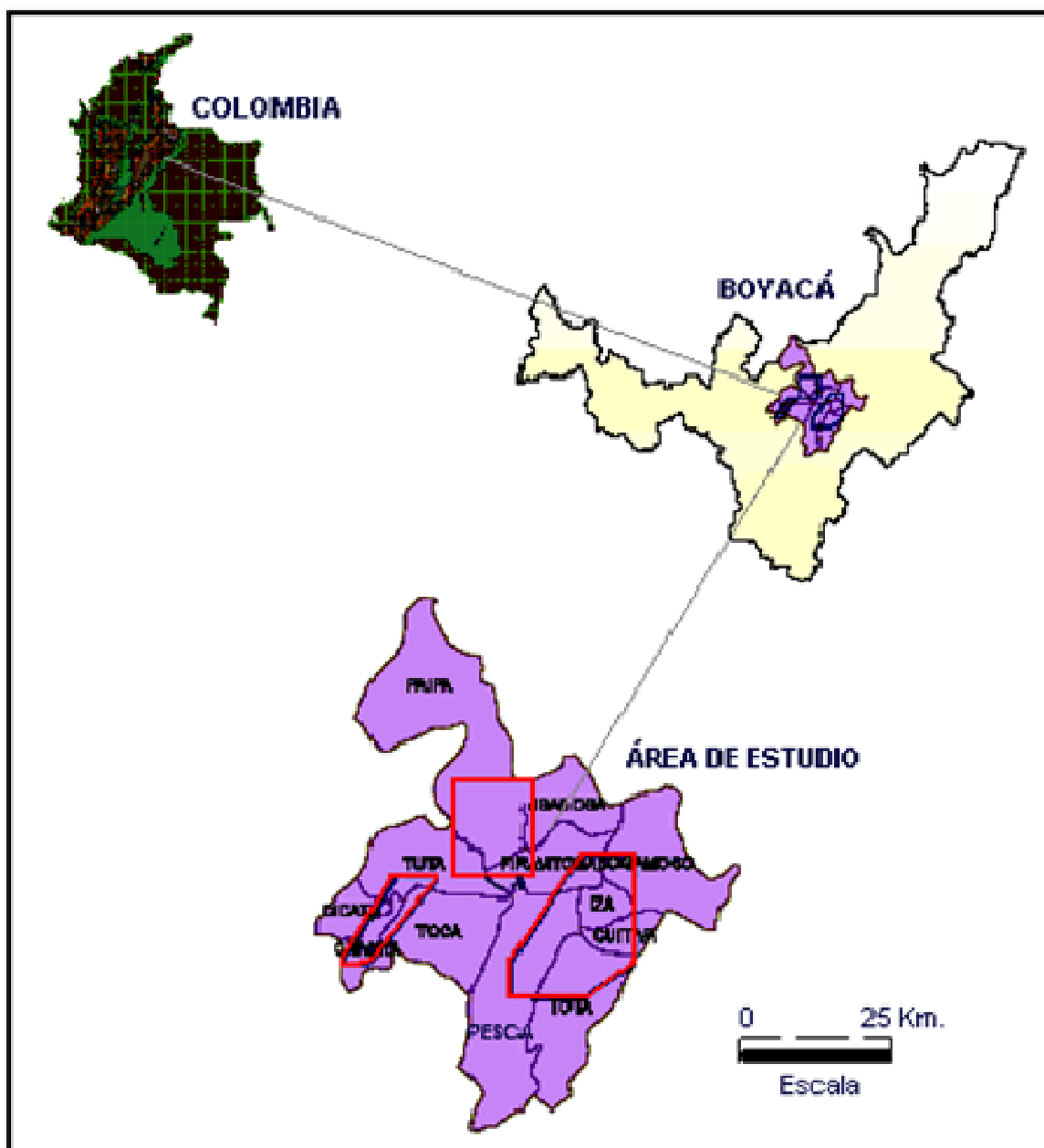


FIG. 2. Location of study area.

3. BACKGROUND

In Colombia a number of geochemical anomalies and radioactive minerals have been identified between 1978 and 1982, in Zapatoca, California, Concentration (Santander), Santa Helena (Norte de Santander), Berlin (Caldas), Paipa and Iza (Boyaca). The present work was carried out in the last two locations, by INGEOMINAS.

4. GEOLOGY

In the area is dominated by Cretaceous age to Tertiary sedimentary rock and Quaternary sediments. Paipa and Iza exposes outcrops of volcanic and sedimentary rocks; the major structural features are Arcabuco anticline, Los Medios syncline and Boyaca and Soapaga faults. The sedimentary formations from the oldest to most recent in the area are: Tibasosa

Formation; Une Formation, Conejo Formation; Plaeners Formation; Los Pinos Formation; Labor y Tierna Formation, Guaduas Formation Socha Formation; Picacho Formation an Concentration Formation. Outcrops of volcanic rocks (rhyolites porphyrites and andesites); and explosive pumices are also found (Figs 2, 3, 4).

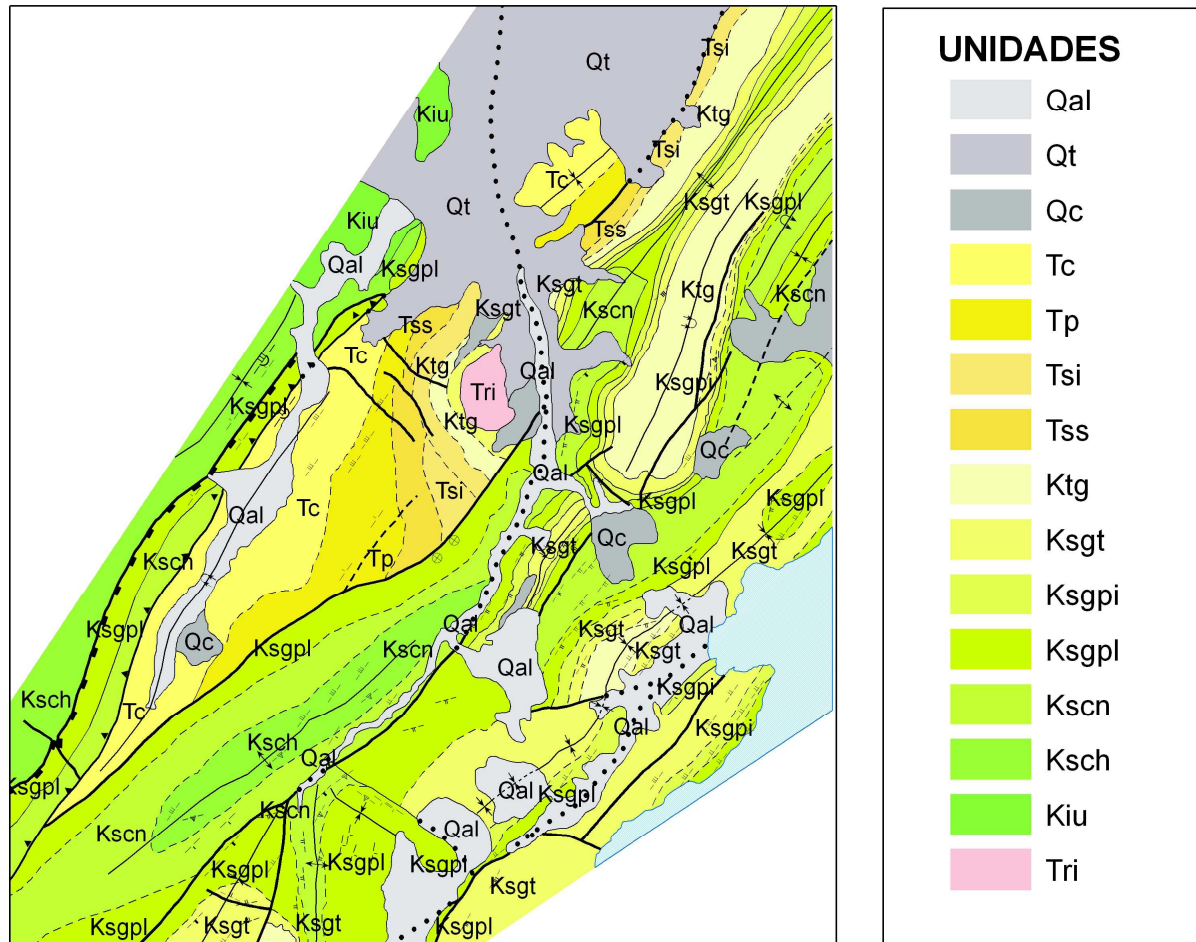


FIG. 3. Geology of Iza area, scale 1:25 000 (From 191 y 192 maps of INGEOMINAS modified by photogeologic control and field observations).

Description of the geological units from oldest to youngest, in the areas of study:

- Tibasosa Formation (Kt): Characterized by limestones, sandstones, and shales;
- Une Formation (Kiu): It consists of white to yellow sandstone, quartz, iron with a siliceous cement, medium to coarse grained, locally conglomerates and dark and shale seen;
- Churuvita (Ksch) Group: Consisting of basal quartz sandstones alternating with black shale, sandstones, siliceous limestone and siltstones;
- Conejo Formation (Kscn): Characterized by black shale and sandstones with thin intercalations of siliceous limonite;
- Plaeners Formation (Ksgpl): Formed by layers of sandstones, chert, phosphorite levels intercalated with clay and light grey to white sandstone;

- Los Pinos Formation (Ksgpi): Formed by claystones, dark *grey* sandstones with intercalated fine-grained quartz and limestone in thin layers (biomicrites);
- Labor y Tierna Formation (Ksgt): It is composed of fine-grained quartz sandstones medium shales;
- Guaduas Formation (KPgg) (Ktg): Grey clay, friable sandstones and occasional coal beds (Fig. 4);
- Socha Inferior Formation (Pgars), (Tsi): Composed of quartz sandstone and *grey* claystones;
- Socha Superior Formation (Pgass), (Tss): Composed of clay and *grey* quartz sandstone with coal beds in the upper half of the Tertiary;
- Picacho Formation (Pgp), (Tp): Sandstones and conglomerates, chert and quartz from the upper Tertiary;
- Concentration Formation (pgc), (Tc): Conglomerates quartz sandstone, quartz sandstone and *grey* clays of the Tertiary Upper;
- Cacho Formation (pgc): Yellowish white quartz sandstone, coarse-grained to conglomeratic, friable, stratified and cross-intercalation of quartz lenses, sandstone and *grey* clay;
- Bogota Formation (Tb): Friable sandstones of medium to coarse grained, ferruginous, with cross-stratification, interspersed with yellow clay;
- Tilata Formation (Net): Composed of layers of gravel, clay and sand;
- Volcanic Bodies (NgQv): Outcrops in Paipa that have intense hydrothermal alteration, cutting Conejo and Churuvita formations and underlying the Tilata Formation (Fig. 4). The color of the weathered rock is light *grey* to white, porphyritic texture with phenocrysts of plagioclase and amphibole. The volcano in Paipa has generated several pyroclastic products (dust, ash, sand and pumice and lapilli). In Iza area rhyolitic rocks are exposed.

5. STRUCTURAL GEOLOGY

The area presents several tectonic structures. The dominant fault system are related to the reactivation of ancient tectonic structures and the generation of a new family of faults, due to the compressive regime of the Andean orogeny in the Paleogene and Neogene. The major structural features are Arcabuco anticline, Los Medios syncline and Boyaca and Soapaga faults.

The Boyacá fault is perhaps the most characteristic ancient structure, formed in the Paleozoic. The fault has a NE direction, with a reverse dip to the west. The fault system of Tunja and Chivata with direction NE — NNE parallel to the Boyaca fault is seen between Boyacá (starts around the locality of El Manzano and moves to the NE) and Sóapaga. Other fault are El Bizcocho, El Batán, Rancho Grande, Buenavista, Agua Tibia, Cerro Plateado.

In the El Durazno Sector the following structures are observed:

Weak zones in NE direction and fault in NS direction, has created a center of convergence and contributed to the emplacement of volcanic rocks in the area, which in turn generated fracturing in sedimentary rocks through which volcanic emplacement have taken place. This led to enrichment of siliceous material in sandstones of the area. This process is related to a recent tectonic shift that has contributed to a morphological structure of the region (Fig. 5).

- Los Lazos Fault, located along Canoe Creek – SE margin, is a normal fault with direction N20°E, which uplifted Labor and Tierna formation and juxtaposes them with the Guaduas Formation;
- The Planada Fault, located on the creek of the same name, in EW direction, which separates the two main volcanic bodies in Paipa;
- La Cantera Fault, with NS direction, which intersects the Guaduas Formation and has contributed to the mixing and interaction of volcanic rocks within a shear and uplifting the volcanic body.

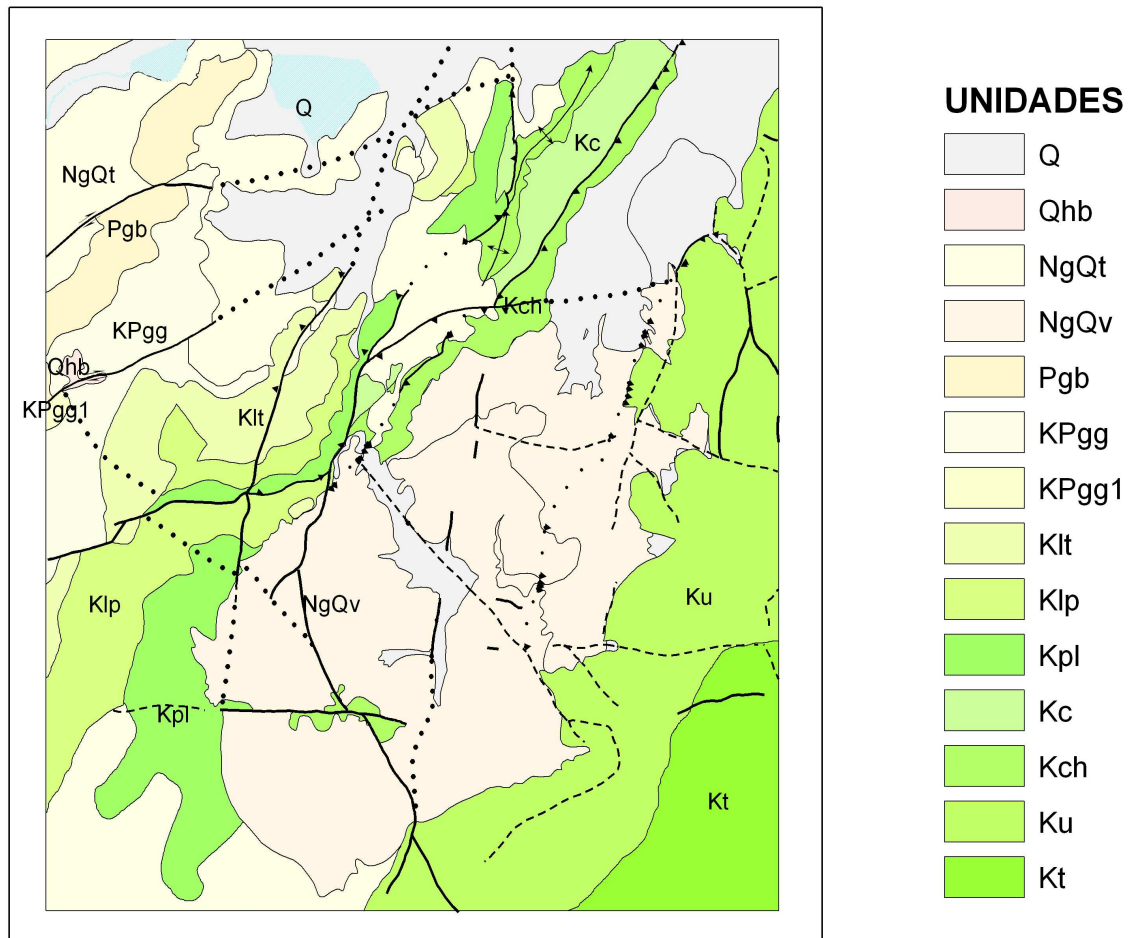


FIG. 4. Geological map — Paipa area.

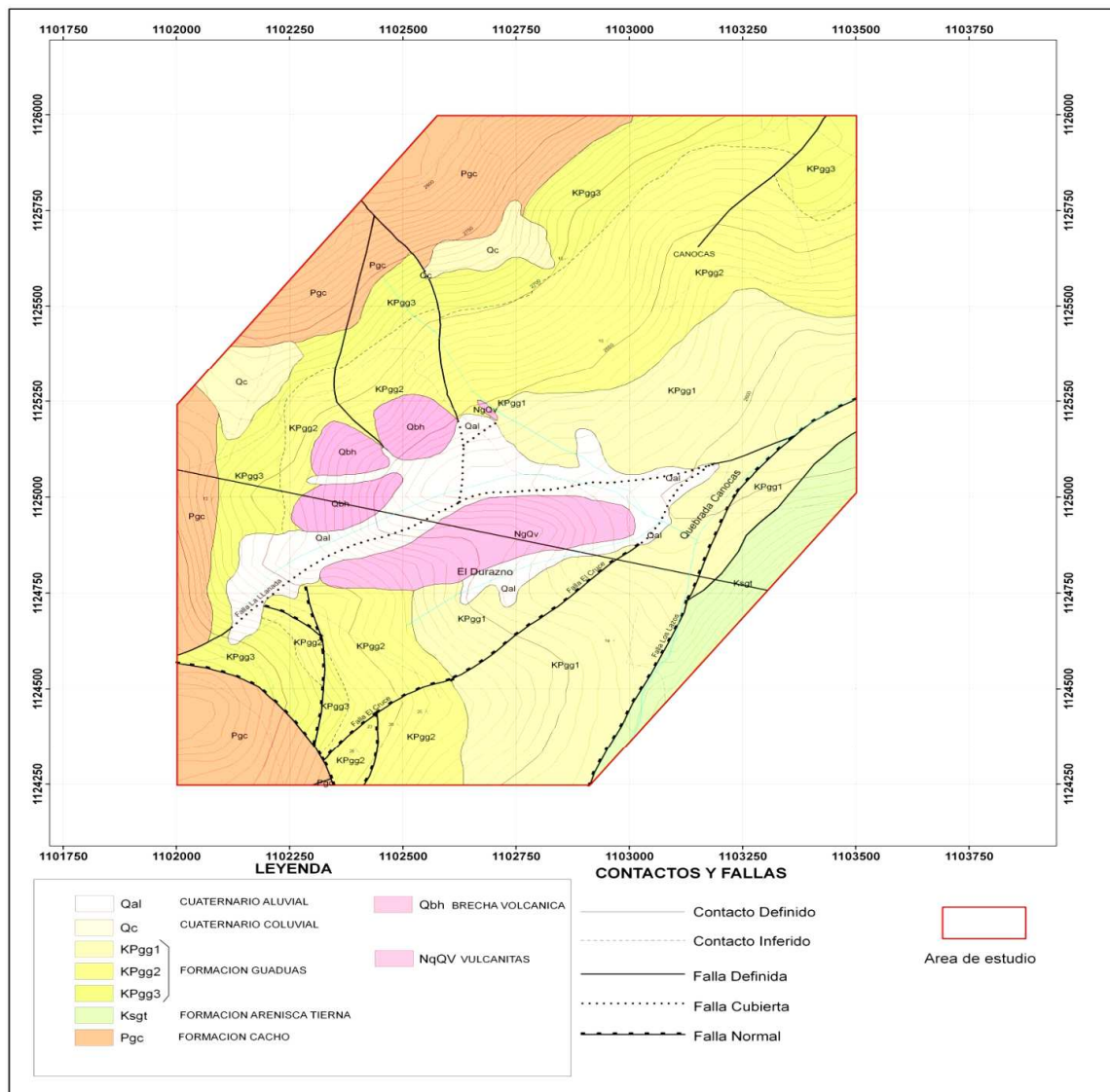


FIG. 5. Geology of El Durazno sector.

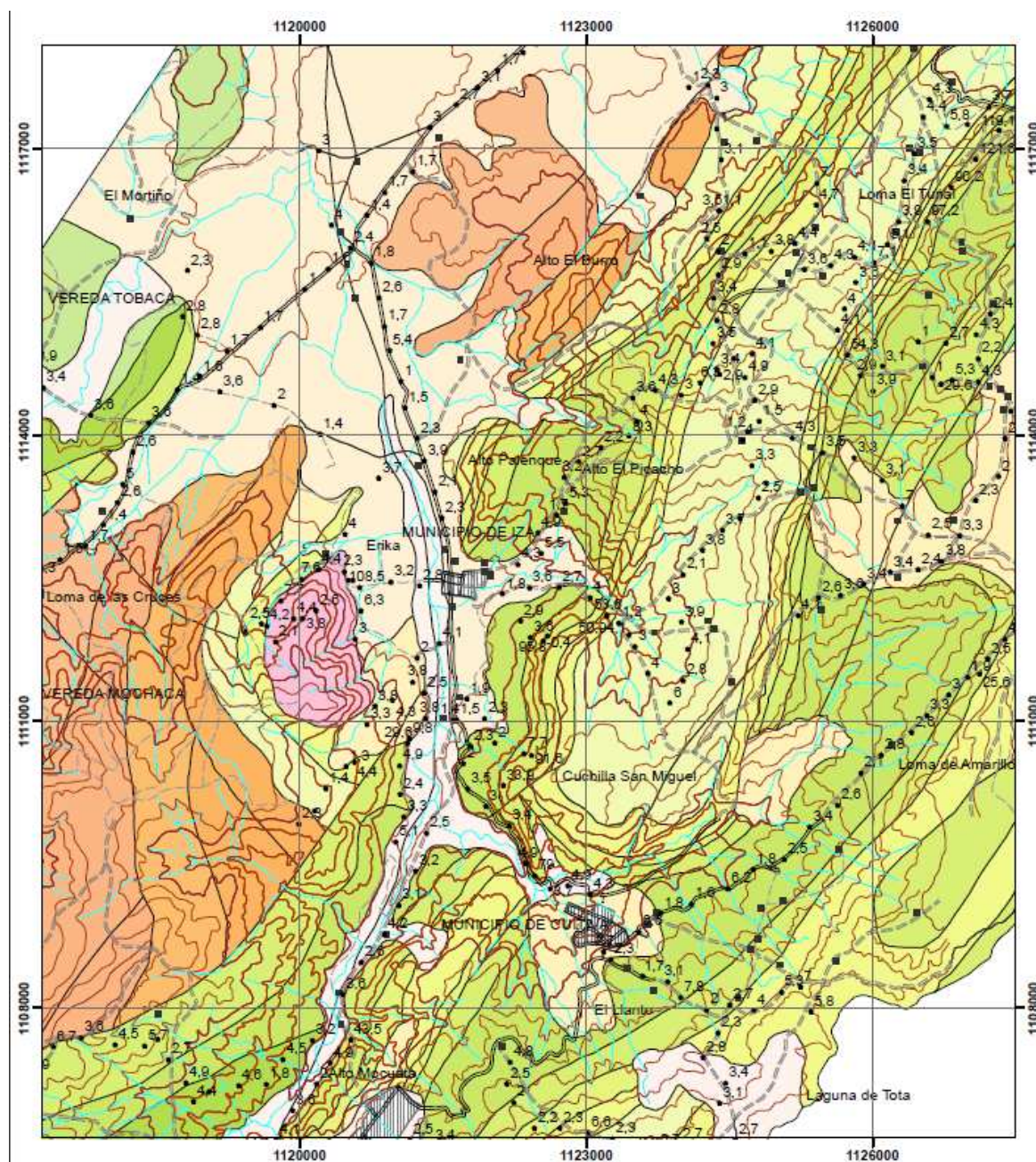
6. METHODOLOGY

The methodology included collection of geological information of radioactive minerals in the anomalies in Paipa and Iza Areas (Figs. 6–8).

Sampling: The regional geophysical and geochemical exploration was conducted, using the geological maps produced by INGEOMINAS as guides. The measurement of gamma radiation with a Gamma Spectrometer GS512 (512 channels), to directly correlate the measurements of K, U and Th and the total counts obtained with the Exploranium GR 130 (256 channels).

Geochemical exploration included sampling of sediments (mesh No. 15), and rock chips in the anomalous sites and in locations where high levels of radioactivity ; Soils were sampled at different horizons.

Laboratory work – Statistical and geostatistical work in a GIS platform for the interpretation of data.



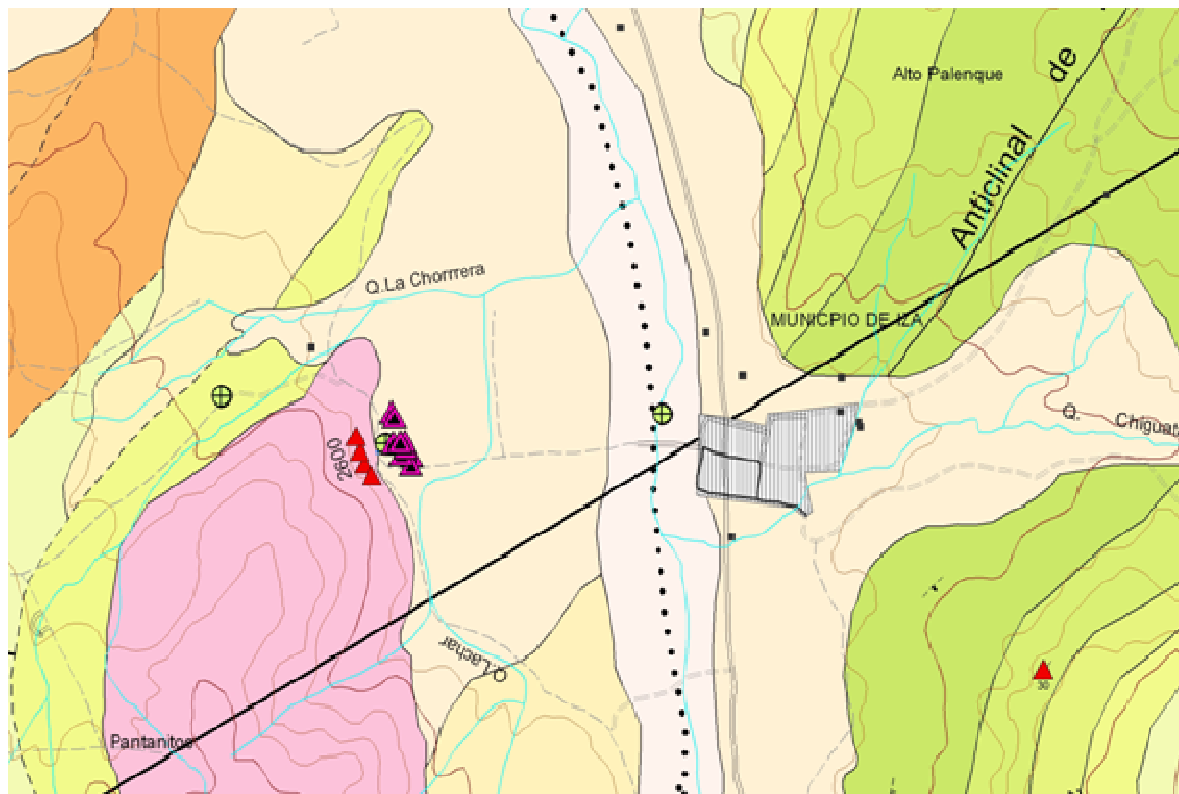


FIG. 7. Erika Sector, geological map.

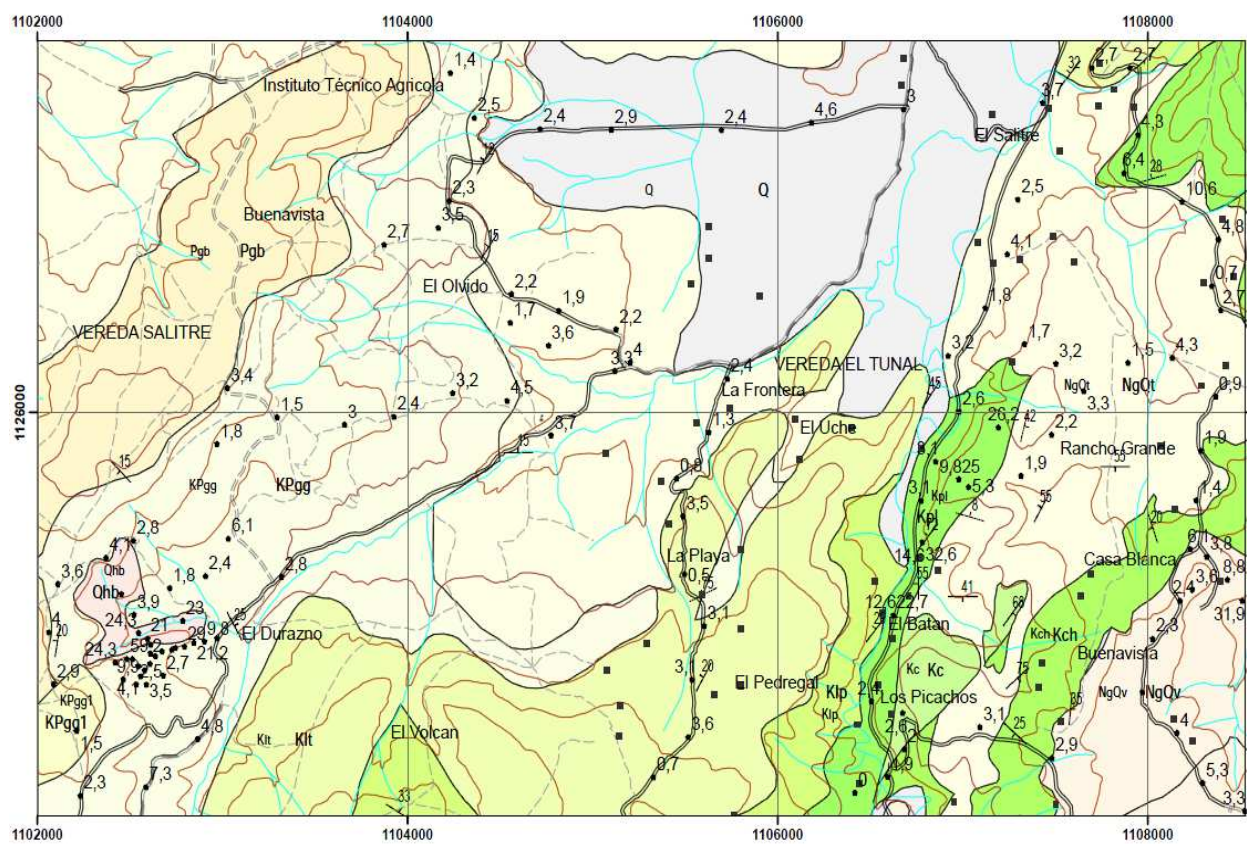


FIG. 8. Paipa Area geophysical stations.

7. RESULTS

In Paipa area uranium values less than 10 ppm are associated with sandstones of the Plaeners, Labor y Tierna Formation, and claystones; and 2 and 10 ppm in Los Pinos Formation; the volcanic deposits (between 4 and 10 ppm) and unconsolidated Quaternary deposits (0 and 3 ppm).

Fourteen anomalous uranium values up to 100 ppm were found, but the highest values within the volcanic rocks is in the El Manzano Sector with 5 400 ppm of U in the contact zone between volcanic deposits and claystones of the Guaduas Formation, adjacent to the Canocas fault. Other abnormal areas are located in El Batan and Olitas, with higher values associated with volcanic rocks, south of Silver Hill, in La Laguna, south of Pan de Azucar, in Cruz de Murcia village. This anomalies are associated with the Batan fault with values between of 33 ppm, 26.6 ppm

In Iza sector, the highest value is in the area adjacent to the thermal spring (Erika), with values between 90 ppm and 273 ppm U and 1 000–1 100 counts/s by Exploranium. It is located near the contact zone between the volcanic rocks and Quaternary unconsolidated deposits.

Other anomalies are related to the phosphate rocks in the eastern and north-eastern town of Iza, with values from 30–245 ppm. Total Count Readings ranged from 500–1 600 counts/s, respectively. Other anomalous values include 75 ppm of Th, at south of Iza and 35 ppm Th in the Northeast of the same population, all are related to the phosphate rocks.

8. DISCUSSION

In Iza and Paipa the following criteria for radioactive ore mineralization are recognized:

Presence of high levels of radioactivity (between 2 000 counts/s and 7 500 counts/s) measured with Exploranium in the contact zone between organic matter — coal (from Guaduas Formation volcanic rocks and pyroclastic rocks) in the El Durazno Sector. The mineralization is due to uranium seen as films or crusts on the rocks (+6 oxidation state), being transported and reduced and precipitated, or absorbed by clay minerals and organic matter, in sandstones and shales .

Geothermal fluids also favored the migration of uranium (due to its solubility in water) to adjacent wells. Chemical processes has contributed to the remobilization of radioactive minerals.

Fluids are also transport radon [1–2], and an understanding of the gradients of pressure, inferred from the physical and geological characteristics of the soil, rock type is important. Faults or fractures as pathways for radon transport in a volcanic environment ofetn related to geothermal activity

Previous gamma radiation surveys in Paipa southern sectors of El Durazno and other sites, indicated that radioactivity associated with thorium and potassium [1].

Higher radioactivity is also be related to the presence of adularia (feldspar) where radioactive potassium is the contributor. Adularia is precipitated directly from the geothermal fluids in the fractures.

The presence of kaolin (very common around the volcanic edifice) is related to weathering and alteration of the potassium feldspar — plagioclase present in the rhyolitic lavas and is possibly due to steam discharges caused by the geothermal system [3]. Another source of radioactivity are the phosphates. This may be the explanation for the presence of high levels of radioactive minerals in the fossil strata in Plaeners Iza and Tota localities .

9. CONCLUSIONS

In the study area is dominated by sedimentary rock formations of the Cretaceous to the Neogene and Quaternary. Chemical results record significant values in Paipa in the El Durazno Site (200 ppm to 5 435 ppm U). The anomalous values are associated with volcanic rocks (ryolites) and tectonic breccias in the presence of thin strips of coal from the Guaduas Formation. Other sites are in El Batán and El Molino, with values between 440–1200 counts/s in Plaeners Formation. Values recorded in Erika are up to 273 ppm in contact of volcanic rocks and quaternary; El Crucero 210–270 ppm and Cuitiva 245 ppm in sedimentary rocks — phosphates sands in Plaeners Formation

In Iza area, radiometric surveys have identified anomalous zones in the El Crucero, San Miguel, Cuitiva — Iza, Erika and Tota — Pesca, with values between 480 and 4480 counts/s; The highest values as associated with igneous rocks is in Erika sector — 4 480 counts/s. and the highest values in phosphates was found in El Crucero sector — 2 100 counts/s. In Paipa around El Durazno radioactivity is between 450–7 500 counts/s, El Batán 440 counts/s and El Molino 450 counts/s.

The potassium concentrations, of the volcanic rocks are from 1–3% of K, and in the claystones from 1–1.5% mainly in Guaduas Formation. It is less than 1% in sandstones, siltstones and unconsolidated deposits. There are anomalous values of K reaching values up to 10% in areas of volcanic rocks with uranium anomalies. There is only one place with a high content of thorium (47 ppm) related to the presence of clays in the Guaduas Formation in the Chivata Sector.

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LEVELLING AIRBORNE AND GROUND GAMMA-RAY SPECTROMETRIC DATA TO ASSIST URANIUM EXPLORATION

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Abstract

Geophysical methods can be used for mapping in both 2 and 3 dimensions, as well as the direct detection of ore bodies. The gamma-ray spectrometric method is an efficient method for the regional assessment of uranium potential and the detection of surface mineralization. However, the full potential of the method can only be realized when the data are adequately standardized. Examples of this standardization at both regional and local scales are dealt in this paper. At a regional scale, it is shown how the levelling of airborne gamma-ray spectrometry data over Australia increases the value of the resulting data, and on a local scale a geometrical correction for ground gamma-ray spectrometry in shallow holes that improves the accuracy of measurements is introduced.

1. INTRODUCTION

As a result of the radioactive property of uranium, gamma-ray spectrometry remains a fundamental technique for the detection of uranium minerals. More than half the area of the earth's continents is now covered by gamma-ray spectrometric survey data. These data were collected over the past 40 years using a variety of detection instruments. Consequently, the results of these surveys are often not compatible.

A significant advance for the mapping of radioactive materials was the introduction, by the International Atomic Energy Agency (IAEA), of reference materials for the calibration of radiation detection instruments [1]. These reference materials effectively constitute a radioelement datum. They are used for the calibration of laboratory spectrometers which, in turn, are used to assign radioelement grades to the calibration pads used for the calibration of airborne and ground radiometric instruments. This ensures that the radioelement concentration estimates derived from these surveys are consistent with the IAEA datum. The concept of a global radioelement baseline [2] and its application to the standardization of gamma-ray spectrometric data ensures that the full benefit of these data for use in uranium exploration and environmental mapping are captured. In the following section we show an example from Australia where the levelling of airborne gamma-ray spectrometric surveys to the IAEA datum has greatly increased the value of the survey data.

Ground gamma-ray spectrometry is another area where standardization can improve the value of radioelement data. For uranium exploration, ground gamma-ray spectrometry is typically applied on a local scale for the mapping of discreet radiometric anomalies. In these situations the source-detector geometry of individual field measurements can often be different from the source-detector geometry used during the calibration of the portable spectrometer. Where these source-detector geometries are different, the corresponding measurements will not be directly comparable. We show how geometry corrections can be estimated and, once applied, allow the compilation of radiometric maps that can be used for

the quantitative comparison of anomalies from ground measurements taken under a variety of source-detector geometries.

2. LEVELLING AIRBORNE GAMMA-RAY SPECTROMETRIC DATA

In Australia, over 80% of the continent is covered by gamma-ray spectrometric surveys flown by Australian governments over the past 40 years (Figure 1). These data are used to map the concentrations of potassium (K), equivalent uranium (eU) and equivalent thorium (eTh) at the earth's surface. However, a common problem with national gamma-ray spectrometric survey coverage is that the surveys are often not registered to the same radioelement datum. This is particularly the case with older surveys where results were typically presented in units of counts/sec. These results thus depend on factors such as survey flying height, detector volume and energy window widths. Thus, where early surveys used different instrumentation and survey parameters, the results are not directly comparable. Modern surveys conform to standards set by the IAEA [3] [4]. However, recent surveys can still have significant mismatches along their common borders. This could be due to limitations in spectrometer calibration, but are most likely due to environmental effects (for example changes in soil moisture) that result in temporal changes in the gamma-radiation fluence rate at the earth's surface. These problems limit the usefulness of gamma-ray spectrometric data as it is difficult to compare radiometric signatures observed in different surveys. The solution to this problem is to systematically back-calibrate all surveys to the same datum.

Geoscience Australia has recently undertaken an Australia-Wide Airborne Geophysical Survey (AWAGS), funded under the Australian Government's Onshore Energy Security Program, to serve as a radioelement baseline for all current and future airborne gamma-ray spectrometric surveys in Australia. The survey data were acquired at a nominal survey height of 80 m above ground level along north-south flight lines spaced 75 km apart and east-west tie lines spaced 400 km apart (Fig. 2). The survey data were acquired and processed according to the standards specified by the IAEA [3]. The survey was also back-calibrated at 47 field sites located beneath sections of selected flight lines using a well-calibrated portable gamma-ray spectrometer [5]. The final estimates of radioelement concentrations along the AWAGS lines are thus consistent with the International Atomic Energy Agency's radio-element datum [2] [5].

The AWAGS survey was then used to adjust the 540 airborne gamma-ray spectrometric surveys that comprise Australia's national radioelement database to a common datum. This was achieved using an enhancement of the method described by [6]. For each survey in the national database, both a level shift and a scaling factor are estimated which, once applied, minimize both the differences in radioelement estimates between surveys (where these surveys overlap) and the differences between the surveys and the AWAGS traverses. This procedure effectively levels the surveys to the IAEA datum to produce a consistent and coherent national gamma-ray spectrometric coverage of the Australian continent [5].

The levelled database has been used to produce the first "Radiometric Map of Australia" — levelled and merged composite potassium (% K), uranium (ppm eU) and thorium (ppm eTh) grids over Australia at 100 m resolution. A ternary image (K-red, eU-blue, eTh-green) derived from this database is shown in Fig. 3. The normalized K, U and Th radioelement grids can be used to produce a range of derivative grids such as dose rate (Fig. 4) and ratios between the radio-elements.

Interpreters can now use the normalized database to reliably relate geochemical patterns observed in one area to similar patterns observed elsewhere, and better appreciate the significance of broad-scale variations in radioelement concentrations. This enhances the value of the data for uranium and thorium exploration, in particular, through the ability to make quantitative comparisons between radiometric signatures in different survey areas. The dose rate data also serves as an accurate baseline for environmental contamination studies.

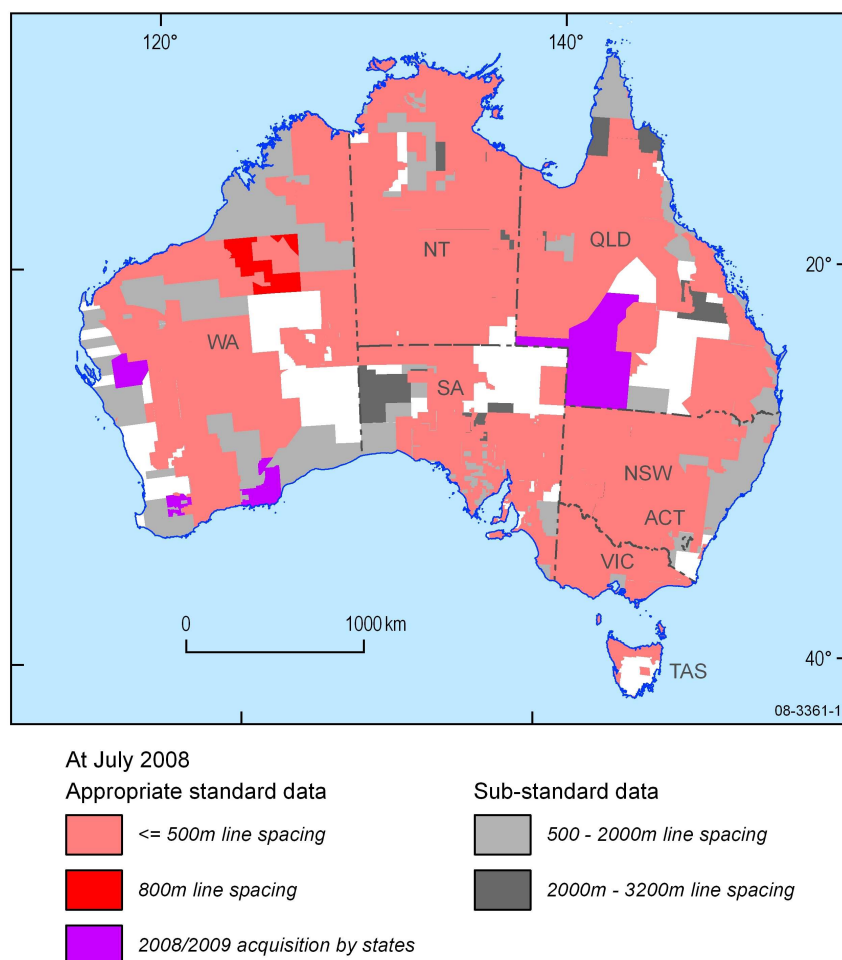


FIG. 1. Digital airborne gamma-ray spectrometric survey coverage of Australia (1970–2008).

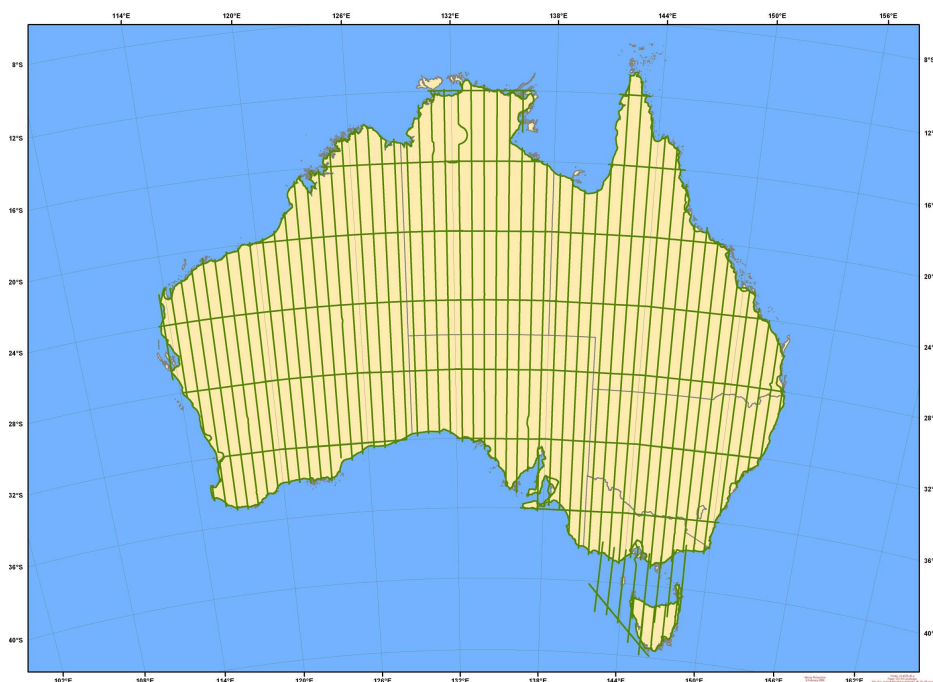


FIG. 2. Locations of the AWAGS survey flight lines.



FIG. 3. Ternary image (K-red, eU-blue, eTh-green) of Australia derived from the new levelled National Radioelement Database.

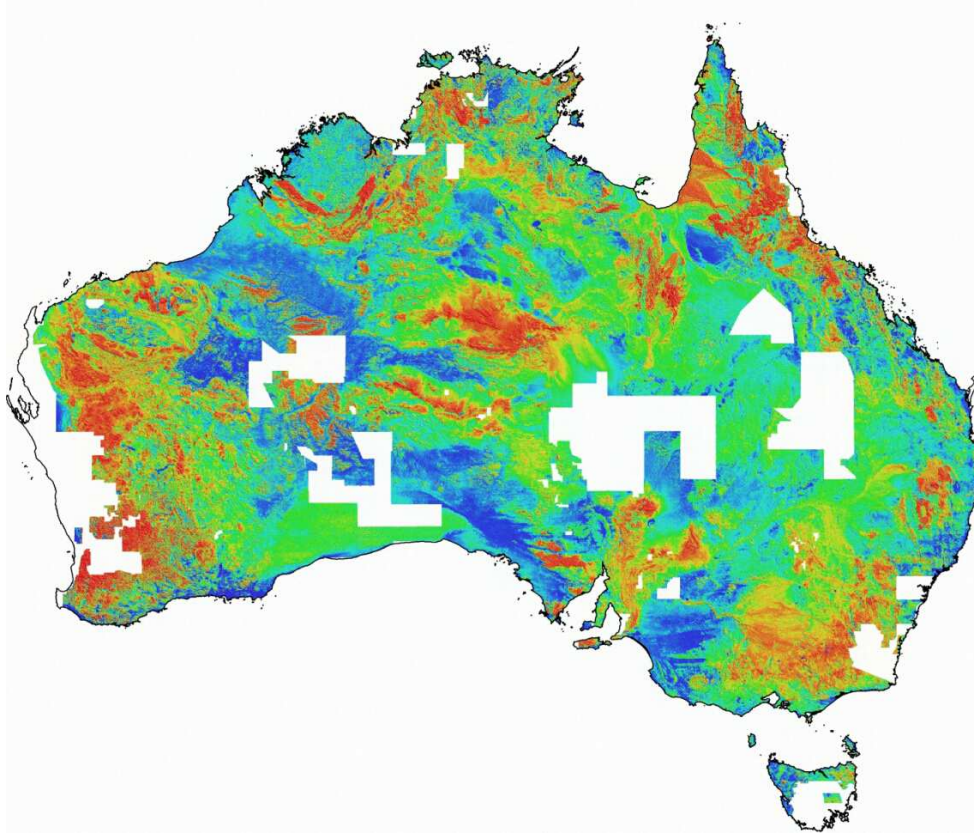


FIG. 4. Pseudo-colour image of air-absorbed dose rate (nGy/h) over the Australian continent.

3. LEVELLING GROUND GAMMA-RAY SPECTROMETRIC DATA

Ground gamma-ray measurements with portable gamma-ray spectrometers are made using specific source-detector geometries that are defined by the solid angle, ω (sr), subtended by the source at the detector. Examples include a flat earth ($\omega = 2\pi$ sr), in shallow holes ($\omega > 2\pi$ sr), or at low altitudes above the surface of the earth. The latter is often the case with dynamic measurements. Since portable gamma-ray spectrometers are calibrated for an infinite half-space source-detector geometry ($\omega = 2\pi$ sr), K, U, and Th radioelement estimates derived from portable spectrometer measurements with other source-detector geometries will be either positively or negatively biased. To gain an insight into this bias, we have undertaken field measurements of the K, U and Th response of a portable multichannel gamma-ray spectrometer to variations in the height of the detector above the earth's surface to a height of 3 m. We have also measured the detector response in shallow holes to a depth of 0.4 m. The measurements were taken in an area of crystalline rocks of medium radioactivity in 2008 near Vrazna, 70 km south of Prague, Czech Republic.

The decrease in gamma radiation with height above the earth surface was investigated for each of total count (TC) (0.84–3.06 MeV), K (1.46 MeV), U (1.76 MeV), and Th (2.62 MeV) using a calibrated GS-256 gamma-ray spectrometer with a 76×76 mm NaI(Tl) scintillation detector. Measurements were made for a range of detector heights between 0.06 m and 3 m in increments of 0.2 m, with the heights measured from the surface of the earth to the centre of the scintillation crystal. Static measurements with 240 s sample times were taken at each height as the detector was raised from ground level to 3 m. The

measurements were then repeated at each successive height as the detector was lowered back to ground level (Table 1).

TABLE 1. TOTAL COUNT (TC) AND CONCENTRATIONS OF K, U, AND TH ESTIMATED FROM MEASUREMENT AT A RANGE OF HEIGHTS BETWEEN 0.06 AND 3 M ABOVE THE EARTH'S SURFACE. S IS THE STANDARD DEVIATION OF REPEAT MEASUREMENTS, AND V IS THE COEFFICIENT OF VARIATION

Height m	TC ppm Ueq	K % K	U ppm eU	Th ppm eTh	TC ppm Ueq	K % K	U ppm eU	Th ppm eTh
0.06	18.3	2.4	4.1	8.2	18.0	2.4	3.7	8.5
0.20	17.7	2.4	2.9	9.0	18.0	2.4	3.0	10.7
0.40	17.8	2.5	3.2	9.5	17.6	2.4	3.2	8.9
0.60	17.4	2.4	3.7	8.1	17.6	2.3	4.0	8.5
0.80	16.8	2.2	3.5	7.6	17.3	2.3	3.5	7.6
1.00	16.7	2.1	3.6	7.8	17.0	2.2	3.7	8.4
1.20	16.7	2.2	3.6	7.8	16.6	2.2	3.6	7.3
1.40	16.1	2.0	3.8	6.7	16.6	2.2	3.9	7.1
1.60	16.1	2.0	3.5	7.2	16.2	2.1	3.8	7.0
1.80	16.4	2.1	3.6	7.8	16.2	2.0	4.9	5.9
2.00	16.4	2.1	4.2	7.3	16.1	2.0	3.5	7.3
2.20	15.8	1.9	4.7	7.0	16.6	2.0	4.5	6.2
2.40	15.9	2.1	3.7	6.7	15.8	2.0	3.8	6.8
2.60	15.8	1.8	4.3	7.4	15.3	2.0	3.2	7.3
2.80	15.6	2.0	4.0	6.1	15.7	1.9	4.1	6.4
3.00	15.0	1.9	3.3	6.8	15.1	1.9	3.4	7.2
s	0.240	0.075	0.346	0.525				
V %	<1.6	<3.9	<11.9	<8.6				

The exponential integral of the second kind, $E_2(\mu h)$, describes the decrease of gamma radiation over an infinite source with increasing height, h (m), due to attenuation of gamma rays in the air, where μ (m^{-1}) is the linear attenuation coefficient for gamma rays of a particular energy in air [3].

$$I_h = I_0 E_2(\mu h) \quad (1)$$

Table 2 shows the percentage reduction in gamma radiation at a height of 1 m above the earth surface relative to ground level for the Vrazna experiment. Also shown are: linear attenuation coefficients calculated from mass attenuation coefficients [7]; linear attenuation coefficients calculated from the Vrazna experimental data using equation (1) and the measurements at 0 and 3 m height; and a range of experimentally determined linear attenuation coefficients derived from airborne gamma-ray spectrometric data.

Table 2 shows that there is a significant difference between the rate of attenuation of gamma rays at low altitudes above the earth surface (ground measurements) compared to that at higher altitudes (airborne measurements). There is a greater rate of attenuation of the gamma rays at low altitudes which should be considered for ground data levelling.

The data in Table 2 are consistent with both the fall-off of radiation with height described by Equation (1) [3], and a decrease in the attenuation coefficient, μ , with increasing airborne altitudes [8]. Measurements on the ground (ground static measurements), at low altitudes above the surface (ground dynamic measurements), and at altitudes of 1–2 m (car-borne measurements) will be affected by this phenomenon. The same effect on gamma radiation at very low altitudes has been observed at similar observation sites.

TABLE 2. THE DECREASE OF GAMMA RADIATION WITH INCREASING HEIGHT ABOVE THE EARTH SURFACE AND LINEAR ATTENUATION COEFFICIENTS, M , FOR GAMMA RAYS AT SPECIFIC GAMMA-RAY ENERGIES

Parameter Energy (keV)	TC	K 1461	U 1765	Th 2615	Reference
Decrease gamma (%)	7.2	10.4	6.4	5.4	Vrazna, h 0 – 1 m
μ (m ⁻¹) ground	0.0168	0.0222	0.0129	0.0156	Vrazna, h 0 – 3 m
μ (m ⁻¹) μ/ρ theory		0.0068	0.0062	0.0051	[7]
μ (m ⁻¹) airborne		0.0060	0.0066	0.0040	[9]
μ (m ⁻¹) airborne	0.0067	0.0082	0.0084	0.0066	[10]
μ (m ⁻¹) airborne	0.0070	0.0095	0.0085	0.0075	[8]
μ (m ⁻¹) airborne	0.0080	0.0099	0.0093	0.0085	[11]

Portable gamma-ray spectrometric measurements in shallow holes (up to 0.6 m deep) are affected by an increase in the solid angle of the source that is subtended by the detector. Such measurements provide better counting statistics and are also not affected by uneven surface terrain and by organic components in the top layer of soil.

Since the response of a gamma-ray spectrometer is proportional to the solid angle, ω , subtended by the source at the detector, an instrument calibrated for $\omega = 2\pi$ sr overestimates radioelement concentrations from measurements made in shallow holes. Correction factors for levelling data measured in shallow holes were derived experimentally at the Vrazna test site and compared with theoretical values. Table 3 lists the response of a GS-256 portable gamma-ray spectrometer in a shallow hole with horizontal section 0.3×0.3 m. The hole was gradually excavated with measurements taken every 0.04 m depth up to a final depth of 0.4 m. Two measurements were taken at each depth using a sample time of 240 seconds.

TABLE 3. DATA ON TOTAL COUNT TC AND APPARENT CONCENTRATIONS OF K, U, AND TH FROM MEASUREMENTS AT THE DEPTH D IN A SHALLOW HOLE AT THE LOCALITY VRAZNA

Depth m	TC ppm Ueq	K % K	U ppm eU	Th ppm eTh	TC ppm Ueq	K % K	U ppm eU	Th ppm eTh
0.00	18.0	2.4	3.7	8.5	18.3	2.4	4.1	8.2
0.04	19.8	2.7	4.2	8.8				
0.08	21.8	3.0	3.9	10.2				
0.12	23.3	3.2	4.6	11.0	23.0	3.1	4.0	11.1
0.16	27.1	3.8	5.5	12.5	27.2	3.9	4.7	14.0
0.20	30.3	4.5	4.9	14.8	30.2	4.5	5.1	13.4
0.24	33.2	4.9	5.1	15.9	32.7	4.9	5.0	15.7
0.28	35.2	5.1	6.2	16.9	36.0	5.3	6.3	16.2
0.32	38.6	5.6	6.5	18.5	38.9	5.8	6.9	16.0
0.36	41.1	6.0	6.7	17.9	40.3	5.8	6.3	19.6
0.40	42.4	6.2	6.4	19.9	43.1	6.3	6.8	20.5
s	0.358	0.088	0.307	0.893				
V %	<2.0	<3.7	<8.3	<10.8				

The gamma radiation detected from a source is related to both the distribution of radionuclides in the source, and the source-detector geometry. If a detector is placed above the centre of a circular source, then the solid angle subtended by the source at the detector is given by $\omega = 2\pi (1 - \cos \varphi)$, where 2φ is the plane angle at which the circular source is seen from the point of detection. Using this relationship, we calculated the solid angles ω for the various depths d used in the Vrazna shallow hole test. These are used to calculate, as a first approximation, the geometrical correction factors for measurements in shallow holes shown in Table 4 (geometrical model).

$d = 0.0$ m	$\varphi = 90.00^\circ$	$\omega = 2\pi$ (sr)
$d = 0.2$ m	$\varphi = 133.02^\circ$	$\omega = 2\pi \cdot 1.6823$ (sr)
$d = 0.4$ m	$\varphi = 156.19^\circ$	$\omega = 2\pi \cdot 1.9149$ (sr)

TABLE 4. ESTIMATES OF MULTIPLICATION CONSTANTS FOR THE CONVERSION OF APPARENT K, U, AND TH CONCENTRATIONS DETERMINED IN A SHALLOW HOLE TO CONCENTRATIONS MEASURED AT THE SURFACE. THE VALUES BASED ON EXPERIMENTAL DATA ARE DERIVED FROM THE DATA GIVEN IN TABLE 3. THE GEOMETRICAL MODEL VALUES WERE DERIVED AS DESCRIBED IN THE TEXT

Depth (m)	TC	K	U	Th	Based on
0.0	1.00	1.00	1.00	1.00	
0.2	0.60	0.53	0.76	0.59	Experiment
	0.59	0.59	0.59	0.59	Geometrical model
0.4	0.42	0.39	0.59	0.41	Experiment
	0.52	0.52	0.52	0.52	Geometrical model

Deviations between the experimental and theoretical correction factors shown in Table 4 are probably due to a vertical inhomogeneity of the natural radionuclides in the soil at the Vrazna test site.

4. CONCLUSIONS

The standardization of airborne and ground gamma-ray spectrometric data using a global radioelement baseline established by the IAEA can add significant value to existing gamma-ray spectrometric data. We have shown how well-calibrated measurements tied to the global datum have been used to back-calibrate over 540 airborne gamma-ray spectrometric surveys in Australia in order to produce the first radiometric map of the Australian continent. The map can be used to make quantitative comparisons between radioelement measurements across the continent and will be of great benefit to uranium explorers in Australia.

On a local scale, an experimental study of the absorption of gamma rays at low altitudes above the earth's surface and in shallow holes has been used to estimate correction factors for ground gamma-ray spectrometric measurement with distinct source-detector geometries. The correction factors enable the compilation of radioelement maps and the comparison of anomalies from ground measurements taken under a variety of source-detector geometries.

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THE APPLICATION OF BOREHOLE SEISMIC TECHNIQUES IN MINE DEVELOPMENT AT THE MILLENNIUM URANIUM DEPOSIT, NORTHERN SASKATCHEWAN, CANADA

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Abstract

The Millennium uranium deposit is located within the Athabasca Basin of northern Saskatchewan, Canada. The deposit is situated in metasedimentary rocks, is controlled by multiple sub-vertical faults, and cross-faults and is overlain by over 500 m of intensely altered, porous Manitou Falls group sandstones. The rock quality directly surrounding the deposit is greatly reduced because of alteration and post-Athabasca sandstone structures, which provide conduits for the migration of basinal and meteoric fluids. This leads to significant risk for mine development and shaft sinking, because of the increased potential for water inflow into mine workings. To mitigate the risk involved with mining in such complex geology several projects were proposed as part of a pre-feasibility study. Of these, seismic methods were identified as the best tool to potentially identify alteration and structurally compromised zones. Subsequently, a comprehensive surface and borehole seismic program was completed in an attempt to delineate these engineering hazards and to provide assurance of success of the shaft sinking and mine development. This was the first time a seismic program of this scale was undertaken for geotechnical studies during mine development in the Athabasca Basin.

1. INTRODUCTION

The Millennium uranium deposit (indicated resource of 18 000 t U) is located within the Athabasca Basin of northern Saskatchewan, Canada (Fig. 1). The Millennium project is a joint venture between Cameco Corporation (42%), JCU Exploration (Canada) Co. Ltd. (30.1%) and AREVA Resources Canada Inc. (27.9%). The deposit is hosted within Wollaston Domain basement, in steeply dipping gneisses of Paleoproterozoic age, in fault contact with Archean granitoid gneisses (Fig. 2). These basement rocks are unconformably overlain by 500 m to 625 m of flat lying Mesoproterozoic to Paleoproterozoic Athabasca Group sandstones. Uranium deposits in the Athabasca Basin are typically associated with reactivated basement graphitic faults which formed initially as ductile to ductile-brittle deformation events predating the deposition of the Athabasca Group [1]. The deposit is associated with multiple north-south trending graphitic and non-graphitic faults and cross-faults that have resulted in over 100 m of unconformity relief above the deposit. The mineralization process is associated with intense hydrothermal alteration of the basement rocks, and to a lesser extent the sandstone units located above the mineralization. The alteration and associated structure results in a breakdown of the rock quality, raising concerns of ground failure and associated water incursions during development and mining. The mitigation of potential water in-flow events, such as the flooding that occurred at the McArthur River mine in 2002 and the more recent incidents at Cigar Lake, is one of the major engineering concerns that needs to be addressed in the mine development plan.

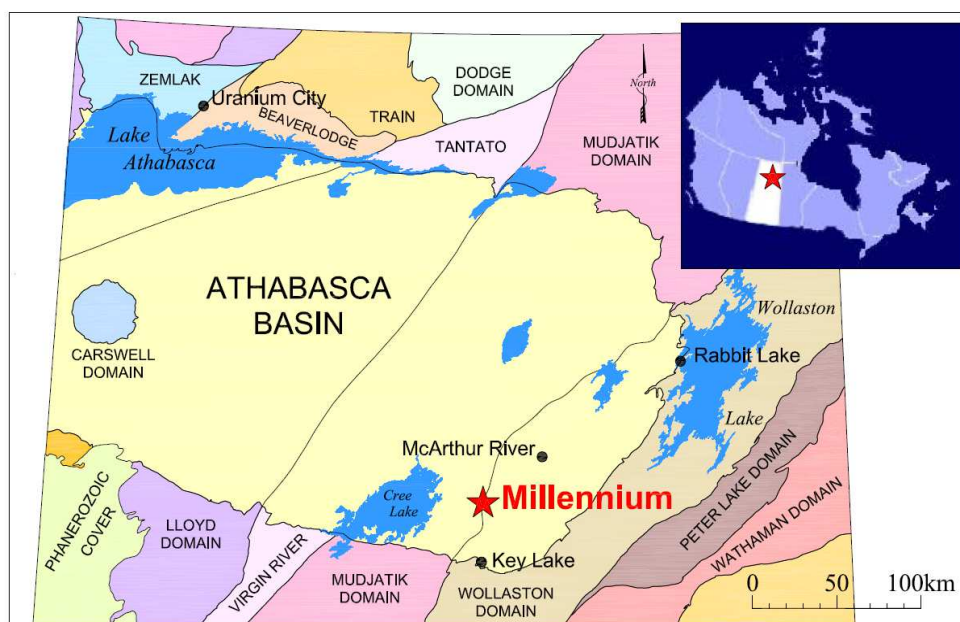


FIG. 1. Location of the Millennium deposit.

The Millennium deposit was discovered in 2000, with subsequent exploration programs defining sufficient uranium resources to warrant a pre-feasibility study for mine planning in 2007. Exploration drilling was focused in a small area directly above the deposit, and along the north-south striking B₁ conductive corridor. As part of the pre-feasibility study, multiple types of seismic surveys were undertaken to map: a) the depth to the unconformity hanging wall and footwall to the deposit, b) post-Athabasca structure and c) the extent of the hydrothermal alteration encompassing the deposit. The seismic program consisted of a surface 3D seismic survey and multiple borehole seismic surveys, including vertical seismic profiling (VSP), moving source profiling (MSP) surveys in drill hole CX-061 and single hole, multi-azimuth (Side-scan) surveys in the shaft pilot holes CX-062 and CX-063.

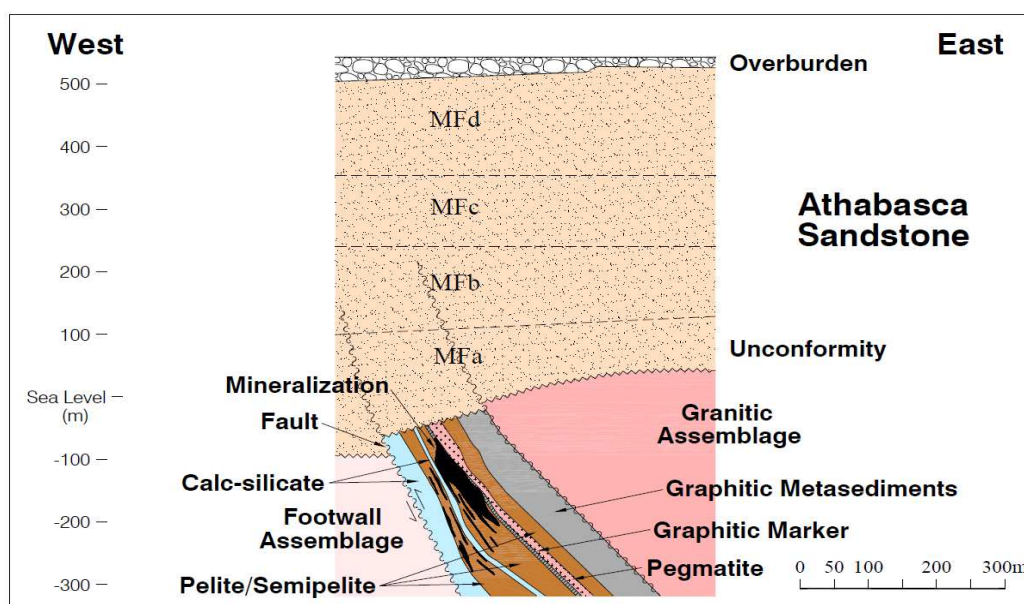


FIG. 2. Generalized geologic cross-section of the Millennium uranium deposit.

2. SEISMIC TECHNIQUES

The various seismic survey techniques used during the study provide different resolution with respect to the targets of interest due to the different frequency content and coupling with the geology (Fig. 3). The 3D surface survey provides the best areal extent and depth of investigation, but preferentially couples with horizontal to sub-horizontal strata. The 3D surface survey also has limited resolution compared to the borehole seismic results because of the wider geophone spacing and lower frequency content present in the recovered dataset. The borehole seismic techniques, VSP, MSP, and Side-scan, utilized the vertical shaft pilot holes. These surveys optimally couple with the vertical to sub-vertical structures within the area of interest. These features present the greatest hazard to sinking a mine shaft because they are difficult to intersect with a vertical drill hole. The piezoelectric seismic source used in the Side-scan borehole survey provides the highest frequency content, and therefore has the best resolution (± 2 m), but is limited in its radius of investigation (150 m) because of signal attenuation. The VSP survey, which is a hybrid survey that uses a surface seismic source and hydrophones located in the borehole, provides a reasonable resolution (± 5 m), has the advantage of coupling with reflectors oriented both vertically and horizontally, and has enough energy to image features within the area of planned mine development (500 m radius of investigation). For this reason the VSP survey is considered to be the most effective imaging tool for obtaining the intermediate scale geotechnical information required for mine development.

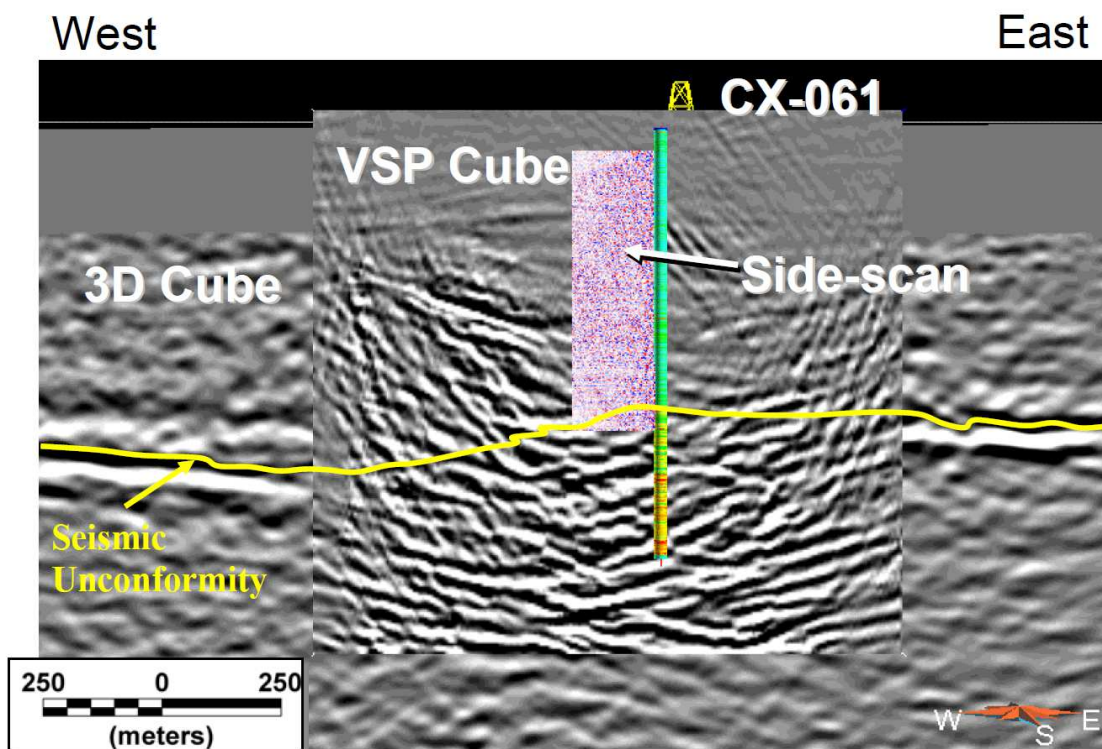


FIG.3. Seismic Amplitudes illustrating the different resolution of the seismic survey techniques applied at Millennium.

The processing of VSP data is complex and time consuming. Normally data from each source point has to be migrated in different directions in order to correctly image reflectors of

interest. Given that the survey at Millennium was comprised of 31 shot points on surface, this would have amounted to a significant number of 2D sections to independently review and interpret in 3D in order to arrive at a consistent interpretation. To overcome this problem, a novel approach of integrating all of the VSP data into a single 3D VSP cube, after migration using the Image Point Transform (IPT) migration technique, was developed and applied to these data [2]. This processing allows for the stacking of data from all the shot points in 3D space. The resulting cube also retains the original seismic amplitudes and directional information from all shot points. The 3D VSP cube also allows for additional data manipulation (filtering) to highlight features dipping at various angles.

The interpretation of the 3D VSP cube at Millennium has resulted in the definition of a complex system of post-Athabasca faulting located in proximity of the deposit and mine infrastructure. The majority of these faults parallel the strike of the drill-defined basement stratigraphy, but conjugate faults and numerous cross faults, trending at various azimuths and at different scales, have also been interpreted from these data (Fig. 4). The majority of the interpreted faults extend up into the overlying sandstone units, an indication of post-Athabasca movement. Coupled with the existing drill hole information and other seismic datasets, the 3D VSP cube has resulted in an improvement in the understanding of the structural setting around the deposit.

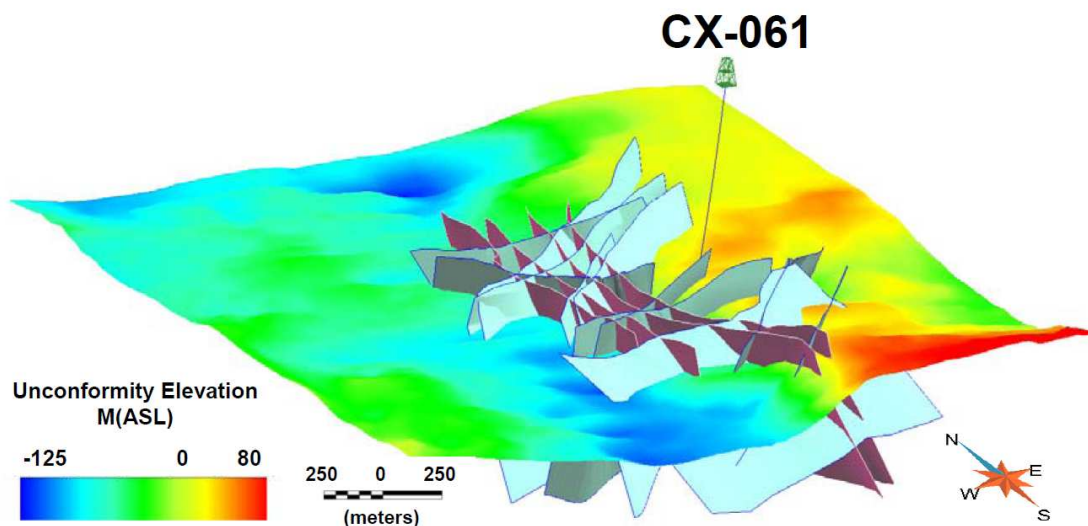


FIG. 4. Interpreted depth to unconformity (3D surface seismic cube) with interpreted post-Athabasca structure (3D VSP cube).

3. CONCLUSIONS

The comprehensive seismic program completed as part of the pre-feasibility study at Millennium was the first of its kind completed within the uranium industry. It has added insight into the structural setting and the location of the unconformity around the planned mine infrastructure. Coupled with additional drill hole information, the datasets resulting from the study provide detailed geotechnical information that will be used in mine development, and in subsequent mining, to avoid a costly water inflow event over the life of the mine. The datasets described above are dynamic and will be reinterpreted in more detail as more seismic

data or drill results become available. Based on these results and Cameco's experience with the Shaft 2 flood at Cigar Lake, borehole seismic surveys have now been accepted as one of the discriminatory tools for shaft site selection prior to mine development.

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X-RAY AND RADIOMETRICS IN GEO-ECOLOGICAL AND GEOCHEMICAL MAPPING

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Abstract

Monitoring of tailing pits of uranium ore conversion products and reserve supplies of low-grade ores stored in dumps is traditionally based on radiation environment on these sites and adjacent territories. The results of gamma-ray spectrometry of solid fractions and radon concentration measurement in liquid and gas phases of technogenic formations are used in radiation hazard evaluation. Radiometric testing practice of low-activity field formations in loose and lump masses shows that due to high emanating ability it is necessary to use dual-channel radiometer for ionizing radiation background record and compensation. Thus gamma-radiometry is not the direct method of uranium content determination and alfa- and beta-radiometry can be correctly used only for sample analysis in laboratory environment. Consequently, distant express testing with the help of X-ray radiometric (XRM) instruments (on calcium, iron, manganese, titanium, copper, arsenic, lead, strontium, selenium, molybdenum, uranium, etc.) is recommended for additional introduction in field observations of radio-ecological environment in mining and processing production tailing and dumps of low-grade ore reserve supplies. Thanks to preliminary areal schemes of geochemical zonality as per XRM data XRM application allows to use the sample limit, given for a wide range of laboratory analyses rationally. Sampling places and their number as well as kinds of laboratory analyses are chosen based on XRM data. It is rather effective to use laboratory variant of atomic absorptive analysis on mercury and stibium in gases (GA), generated in the process of grated samples calcination in muffle furnaces. During the presentation of the report In order to prove the effectiveness of XRM and GA presentation graphics with the results of areal mapping using the above methods and geochemical testing on the territories of Tashkent (Uzbekistan) and Chimkent (Kazakhstan) regions within the framework of the geological and ecological mapping project on the above specified territories.

1. INTRODUCTION

Profitability of mining and processing production is defined by the difference between the price of a commodity product in the world mineral market and unit cost of its production and sale, which depend both on geological factors, and processing factors, and also depends on the infrastructure developed. With regard to uranium manufacture three cost categories (per kg of uranium concentrate) are defined: less than US\$130, less than US\$80 and less than US\$40.

According to the long-term forecast of IAEA experts [1], the increase in uranium demand on the average is expected to be 1–2% annually, and the world requirements will be about 75 thousand tonnes a year by 2020. The shortage of uranium in the world market has resulted in a steady growth of its price, but only to the extent that now only deposits of ores easy for mining with relatively cheap methods of uranium extraction are of the greatest interest. Low-grade ores, piled in dumps of uranium mining operations should also be included to this category. The working of such is possible in case of selective extraction with acceptable uranium content.

Such ores, as a rule, are located in immediate proximity to transport and power lines (railways, motorways and electric power lines). Costs for capital construction, mining works (overburden, extraction, stockpiling) and incidental costs (transportation) are repaid by product sale.

2. RESULTS

Monitoring of low-grade uranium ores has shown that radiometric surface survey of dumps (gamma-survey and radon survey) are indirect methods in relation to uranium and give too average values. For example, comparison of results of areal radiometric survey and geological testing made in early 1990s by Integrated geological-ecological expedition No. 1 of State Geological Enterprise "Kiziltepageology" [2] has shown the following.

The uranium mineralization is distributed along certain zones on the dumps. Surface radiometric survey (gammaray-survey) in comparison with blast holes gamma-ray logging gave good results for uranium content in layers up to thickness to 1 m (Figure 1) and Table 1.

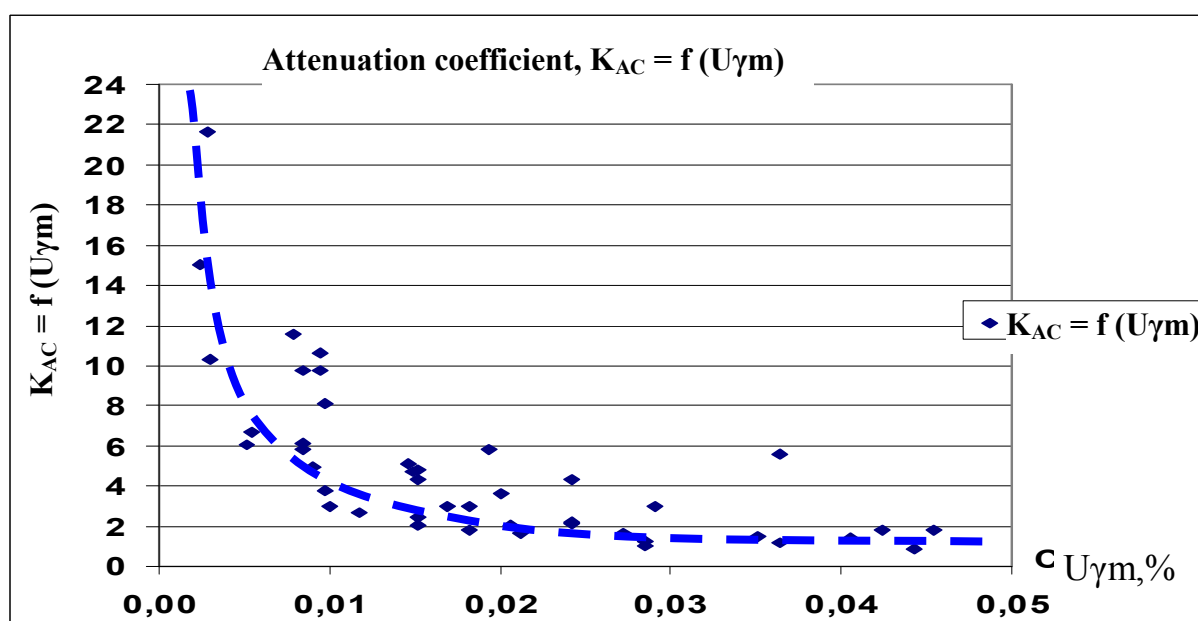


FIG. 1 The histogram of functional relation of coefficient of gamma-radiation attenuation (K_{AC}) registered at surface sampling of dumps, with uranium content ($C_{U\gamma m}$) in the tested layer, calculated according to quantitative interpretation of gamma-ray logging of blast holes.

TABLE 1. COMPARISON OF RESULTS OF QUANTITATIVE INTERPRETATION OF SURFACE GAMMA-SURVEY (GS) AND GAMMA-RAY LOGGING (GL) OF CONFIRMATORY BLAST HOLES WITH 1 M DEPTH WITHIN THE FRAME OF OUT OF BALANCE ORES OF DEPOSIT

Uranium content		Attenuation coefficient	Number of points	Outcome, %
As per GS %	As per GL %			
0.003	0.011	3.38	44	20.37
0.007	0.016	2.15	86	39.81
0.013	0.025	1.94	61	28.24
0.029	0.047	1.59	25	11.57
Average	0.011	0.021	1.91	216
Standard deviation	0.008	0.022		

It can be seen from the table that total uranium content in dumps can exceed approximately by a factor of 2 from the values of areal gamma-survey data. The following correction factors are used:

- Correction for attenuation of gamma-radiation with activity up to 330 $\mu\text{R/h}$ — 2.0;
- Correction for attenuation of gamma radiation with activity of more than 330 $\mu\text{R/h}$ — 1.6.

Low-grade ores of deposit are represented by sandy-argillaceous material. In arid climatic conditions of Central Kizilkums they are not subject to influence of meteoric (rain) waters and atmospheric oxygen. Therefore the radiation effect on environment is insignificant.

Another picture is observed in the ores located on the territory of Tashkent region. Here ore mass is hosted by rocks which are actively subject to oxidizing influence of an atmospheric precipitation. Accordingly natural heap leaching and alteration of minerals redistributed of some mobile elements including toxic ones.

Due to radioactive disbalance due to radium disequilibrium and radon exhalation, the uranium is difficult to estimate by means of radiometric and radon surveys as these methods are indirect in relation to uranium. Therefore it is recommended to include X-ray radiometric testing by means of field (portable) X-ray radiometric analyzers in multidiscipline study of ore raw materials.

The advantages of XRT application is based on the following:

- (1) This method is direct (in-situ) for determination of a wide spectrum of chemical elements including uranium (Fig. 2);

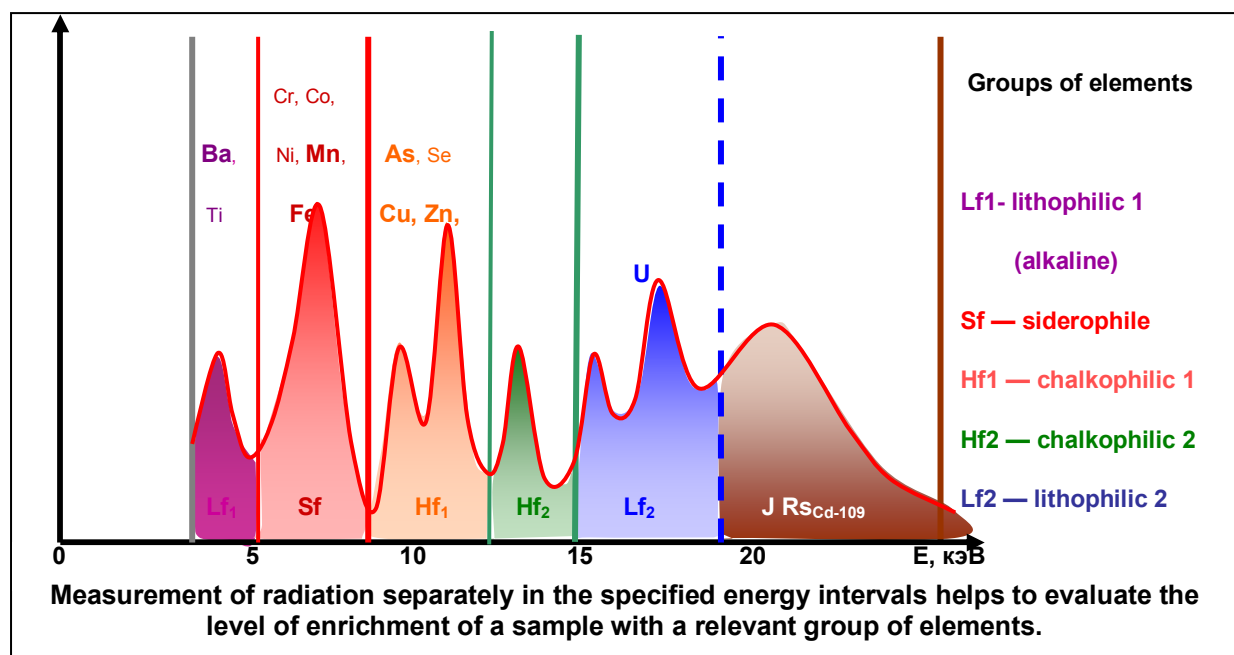


FIG. 2. Formalized spectrum of X-ray radiation from ore samples of complex deposits.

- (2) In estimation of technological impact of mining and metallurgical enterprises on ecosystem and, in particular, on the environment, it is necessary to select a big number of bulk soil samples and to estimate the content for a wide spectrum of ore and toxic chemical elements in them with various laboratory methods. Preparation of such samples for laboratory analyses (drying, crushing, degradation, bucking, reduction, sampling of lots and their duplicates) and sample analysis itself require a lot of efforts, time, materials and reagents. Thus the percent of samples with abnormal content of ore and toxic elements does not exceed 10–15 %;
- (3) The investigator receives the results of laboratory analyses, basically, after the end of field work when it is found out that detailed analyses of the estimated anomalies could have been made on some sites, whereas there was no necessity for a wide spectrum laboratory analyses of samples on other sites.

3. CONCLUSIONS

- (1) Dumps of anomalous uraniferous ores are characterised by radiological disequilibrium, therefore for their estimation, along with ΓC and ΓK , it is recommended to use PPM, as a direct method;
- (2) Sampling and their preparation for laboratory analyses are essentially reduced with reduction of material expenses and time with higher reliability of geologo-ecological studies of natural landscapes and the ore dumps.

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URANIUM MINING AND PROCESSING
(Session 4)

LICENSING STATUS OF NEW AND EXPANDING IN-SITU RECOVERY URANIUM PROJECTS IN THE UNITED STATES

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Abstract

The authors investigated the licensing status of new in-situ recovery (“ISR”) uranium projects, as well as the expansion of existing projects, within the United States (“US”). Specific emphasis and analysis is placed on those projects within the states of Texas and Wyoming. Of note, information used to prepare this paper was obtained from public sources that included company web sites, the US Securities and Exchange Commission, the US Nuclear Regulatory Commission (“NRC”), the US Energy Information Agency (“EIA”), and the relevant state regulatory agencies. The renewed interest in the production of natural uranium has been motivated, in part, by the increased sale price of yellowcake beginning around 2003 resulting in numerous new and existing natural resources companies acquiring mineral rights in the United States. Because of the economic favorability in terms of both operating and capital costs of ISR mines versus conventional mines in the US (with its relatively low grade of uranium ore), the model for most companies was to acquire mineral properties that had the potential for being mined using the ISR method. There were, however, exceptions to this model. The Uravan mineral district in southwest Colorado and southeast Utah, where relatively high-grade, shallow uranium deposits have the potential to be mined using underground methods, is one such exception. However, the focus of this paper will be on ISR projects. In Wyoming, which has been the top producer of natural uranium among the 50 states for the past seven years, there is one producing ISR mine (Bill Smith — Highland), one ISR mine on standby (Christensen Ranch), and two ISR uranium projects licensed but not yet built (Gas Hills and North Butte). Cameco Resources is planning to develop two ISR projects in Wyoming that have been licensed but not yet constructed. Additionally, three new uranium companies (Ur-Energy, Uranerz and Uranium One) have filed applications with the federal and state agencies to construct and operate commercial uranium ISR mines on their respective properties in Wyoming. The only other states that have had, and currently have, commercial ISR uranium production are Nebraska and Texas. According to the EIA, in 2008 there was production from one ISR mine in Nebraska and from four ISR mines in Texas. Applications are pending for expansion of the Crow Butte mine in Nebraska, and applications are also pending for both a new ISR mine and expansion of at least one existing mine in Texas. Nebraska, like Wyoming, is a non-agreement state requiring both state and federal operating licenses for an ISR uranium mine while Texas is an agreement state requiring only a state license for operating an ISR mine. In addition to the aforementioned states, ISR development plans and licensing status of projects in Colorado, New Mexico and South Dakota will also be covered in this paper.

1. BACKGROUND

The mining of uranium in the United States (US) using the in-situ recovery (ISR) method started on a commercial basis in the mid 1970s. This method is sometimes referred to as solution mining. A limited amount of test mining using the ISR method took place as early as the late 1960s. Today, the majority of the production of natural uranium in the US comes from ISR mining and world wide, approximately twenty-eight percent (28%) of annual uranium production comes from this same method. Historically, only three states in the US have had commercial ISR mining of uranium. These states are Nebraska, Texas and Wyoming. Two other states, Colorado and New Mexico, have had ISR test mining but no commercial mining using this method.

According to the US Energy Information Agency (EIA), production of natural uranium in the US in 2008 amounted to 3 902 383 pounds as U_3O_8 (~1 500 tU). Approximately 3 million pounds as U_3O_8 (77%) of last year's US production came from ISR production. The three states in the US that currently have commercial production of natural uranium using the ISR mining method are the same three states mentioned above; Nebraska, Texas and Wyoming. A table showing the approximate production of uranium from these three states in 2008 using ISR mining is presented below (Table 1).

TABLE 1. 2008 US ISR URANIUM PRODUCTION (APPROXIMATE)

	Nebraska	Texas	Wyoming	Total*
As Pounds U_3O_8	600 000	1 200 000	1 200 000	3 000 000
As tU	231	462	462	1 155

The renewed interest in the production of natural uranium has been motivated, in part, by the increased sale price of yellowcake beginning in 2002–2003 resulting in numerous new and existing natural resources companies acquiring mineral rights in the United States. The intent of these companies was to either sell their mineral rights to another company or to develop their mineral interests into operational uranium mines. Because of the economic favorability in terms of both operating and capital costs of ISR mines versus conventional mines in the US (with its relatively low grade of uranium ore), the model for many companies was to acquire mineral properties that had the potential for being mined using the ISR method. There were, however, exceptions to this model. The Uravan mineral district in southwest Colorado and southeast Utah, where relatively high-grade, shallow uranium deposits have the potential to be mined using underground methods, is one such exception. However, the focus of this paper will be on ISR projects. Almost all of the newly acquired federal mining claims, and state and private mineral leases, are on lands where uranium mineralization or oxidized-reduced (geochemical) fronts had been identified during exploration activities in the 1960s, 1970s and 1980s.

2. DISCUSSION

2.1 Licensing Process in the US for ISR Uranium Mines

In the US the federal regulation and oversight of ISR uranium mining is the responsibility of the US Nuclear Regulatory Commission (NRC). On the individual state level, a particular state may be an “agreement state” or a “non-agreement state.” In an agreement state, the NRC, at the request of the state, has delegated its regulatory oversight to the state. In this situation, the state must demonstrate to the satisfaction of the NRC that the state program is at least as protective of the environment, and worker and public safety (including radiation protection) as the NRC program. In a non-agreement state, both the NRC and state independently regulate ISR mining (dual jurisdiction) and a mining operation must have both an NRC license and a state license. The states of Texas and Colorado are examples of an agreement state where Wyoming and Nebraska are examples of non-agreement states. The state of Utah is an example of a third situation in which that state is an agreement state

with the NRC but not for uranium milling or ISR projects in which case there is oversight by both the state and the federal government.

Recently, the NRC announced that the three applications that have been submitted to that agency for review and approval on new ISR projects in the state of Wyoming will have to go through the Supplemental Environmental Impact Statement (SEIS) process. Prior to that announcement, the companies that submitted these applications, Uranerz Energy Corporation, Uranium One Americas and Ur Energy were anticipating that since the NRC had recently issued the Generic Environmental Impact State for ISR mining that only an Environmental Assessment (EA) would be necessary. An EA is typically a shorter process. The NRC informed the three companies that requiring that an SEIS be prepared by an independent third party on each of the applications will not cause a significant delay in the issuance of the source material licenses. The NRC also stated that for now, any applications for new ISR projects in non-agreement states will have to go through the SEIS process while applications to expand or modify existing ISR operations will most likely have to go through the simpler EA process.

2.2 Licensing Status of New and Expanding ISR Uranium Projects in the US

Before presenting the current status of license applications for new ISR projects in the US or the amendment to existing licenses, the present status of existing ISR operations and projects fully licensed but not yet built is presented in the table below (Table 2):

TABLE 2. STATUS OF EXISTING ISR OPERATIONS IN THE US

Project Name	State	Owner	Status
Crow Butte	Nebraska	Cameco	Producing
Alta Mesa	Texas	Mestena Uranium	Producing
Hobson	Texas	South Texas Mining Venture	Licensed, not operating
Kingsville Dome	Texas	URI	Producing, now shutdown
Rosita	Texas	URI	Standby
Vasquez	Texas	URI	Shutdown
Smith Ranch-Highland	Wyoming	Cameco	Producing
Christensen Ranch	Wyoming	Cogema Mining	Standby

Source: US Energy Information Agency (1st Quarter 2009)

Not listed in the above table are three Cameco projects in Wyoming that are not yet built but have the NRC Source Material License and state permit to mine. These three projects are named North Butte, Ruth, and Gas Hills — Peach. Also, the US Energy Information Agency lists HRI, Inc. as having two ISR projects not yet constructed in New Mexico, Church Rock and Crownpoint, as partially permitted and licensed.

2.3 License Applications Submitted and Under Review for New and Expanding ISR Projects

License Applications that have been submitted to the appropriate agencies for new ISR projects in the US are broken down by state in the following Table 3.

TABLE 3. LIST OF ISR LICENSE APPLICATIONS SUBMITTED IN THE US

State	Company	Project Name/Location	NRC Submittal Date*
New Mexico	HRI, Inc.	Church Rock	(see note above)
New Mexico	HRI, Inc.	Crown Point	(see note above)
South Dakota	Powertech Uranium Corp.	Dewey — Burdock Project (new) Black Hills	NRC — February 2009
Texas	Uranium Energy Corp.	Goliad ISR Uranium Project (new) South Texas	Agreement State - Submitted to State
Texas	Uranium One Americas	Palangana South Texas	Agreement State - Submitted to State
Wyoming	Uranerz Energy Corp.	Nichols Ranch ISR Project (new) Powder River Basin	NRC — December 2007
Wyoming	Uranium One Inc. (Energy Metals Corp.)	Moore Ranch ISR Project (new) Powder River Basin	NRC — October 2007
Wyoming	Ur-Energy Inc.	Lost Creek ISR Project (new) Great Divide Basin	NRC — March 2008
Wyoming	Uranium One Americas (Energy Metals Corp.)	Jab-Antelope Project (new) Great Divide Basin	NRC — September 2008
Wyoming	Cogema	Christensen Ranch ISR Mine — Restart	NRC — April 2007
Nebraska	Cameco	Crow Butte ISR Mine — Expansion (north trend)	NRC — June 2007
Nebraska	Cameco	Crow Butte ISR Mine — Expansion (plant upgrade)	NRC — October 2006

* The authors of this paper have not provided an expected license approval date for the listed projects as the regulatory agencies are under no mandate to issue a license within a set time period.

2.4 License Applications for Planned New ISR Projects or Expansion to Existing ISR Projects

According to NRC documents, a number of companies have submitted letters of intent to build new ISR projects or expand existing ISR operations in non-agreement states. The following table summarizes these letters of intent (Table 4).

TABLE 4. LICENSE APPLICATIONS FOR PLANNED NEW ISR PROJECTS OR EXPANSION TO EXISTING ISR PROJECTS IN NON-AGREEMENT STATES

State	Company	Project Name/Action	Estimate Application Date
Nebraska	Cameco Resources	Three Crow, Crow Butte Expansion	March 2010
Nebraska	Cameco Resources	Marsland, Crow Butte Expansion	September 2012
Wyoming	Ur-Energy Inc.	Lost Creek, Expansion	November 2009
Wyoming	Ur-Energy Inc.	Lost Soldier, Expansion (Lost Creek)	November 2009
Wyoming	Uranium One Inc. (Energy Metals)	Allemand-Ross, Expansion (Moore Ranch)	December 2009
Wyoming	Uranium One (Energy Metals)	Ludeman, Expansion (Moore Ranch)	August 2009 (revised)
Wyoming	Cameco Resources	Smith Ranch-Highland, Plant Expansion	To Be Determined
Wyoming	Strathmore	Reno Creek, New Project	March 2011
Wyoming	Wildhorse Energy	West Alkali Creek, New Project	December 2010
Wyoming	Wildhorse Energy	Sweetwater, ISR and Conventional	May 2011
Wyoming	Cameco Resources	Ruby Ranch, Expansion (Smith Ranch.)	October 2011

3. SUMMARY

In the United States, as of June 2009, ten applications for mining licenses for new ISR projects, or expansion or restart of existing ISR projects have been filed with the appropriate government agencies. Seven of these applications are for new projects and the remainders are for expansion of existing projects or requesting authorization to restart. As for eleven planned new ISR projects or planned expansions of existing ISR projects (applications not yet submitted), nine are located in Wyoming and two in Nebraska. If all of the projects discussed mentioned in this paper were to be in operation at one time, the total US ISR production could be in the range of 20–25 million pounds (7 700–10 000 tU) of natural uranium per year as U_3O_8 .

As a perspective on the licensing of new ISR uranium projects in the US as compared to twenty years ago, a lot has changed within the licensing agencies that have resulted in longer time periods for the applications to be processed and approved. At both the federal and state levels, one major factor contributing to the longer application processing time is that the agencies lack adequate staff in terms of both size and experience. This is not a criticism of the agencies per se as the rapid growth in the uranium sector since 2003 caught both the government and industry off-guard. In general, the agencies that regulate ISR mining have been working to fix this problem; however, it is not just hiring the needed professionals but it also getting them trained and up-to-speed which takes time. The recent slow down in the US economy is amplifying the staffing problem as many of the relevant agencies are cutting staff to meet shrinking annual budgets.

On the federal level, another issue is that the NRC offices in Washington DC are a long distance geographically from where most of the ISR projects are located in the western US. Twenty to twenty-five years ago the NRC had a field office in Denver that handled the bulk of the review of new ISR license applications and the review of amendments to existing applications. The NRC staff in Denver at that time became very experienced and efficient at processing uranium mining applications. The proximity of their offices to the applicants' offices made for easy accessibility to discuss and resolve any contentious issues. When the uranium mining industry in the US all but disappeared twenty years ago, the NRC closed their Denver office and transferred the regulation of the industry back to Washington.

To highlight how the licensing timeframe for commercial ISR uranium mining projects has change in the intervening twenty years, Uranerz USA, Inc. took about a year to collect the required baseline data, and to prepare the NRC source material license application and the state DEQ permit to mine application for the North Butte ISR project (now owned by Cameco) located in the Powder River Basin of Wyoming. The NRC reviewed and approved the North Butte application in about one year and the state of Wyoming reviewed and approved the application in six months. At that time the NRC considered an EA acceptable for North Butte since there was an existing environmentally compliant commercial ISR mining operation nearby and two successfully completed ISR test mines. Today, the NRC requires an SEIS for any new ISR uranium mining project regardless of location which dictates a lengthier review process. For the three new ISR projects in Wyoming that have applications submitted to the NRC and the state, the review and approval process is going to take over two years to complete.

URANIUM POTENTIAL AND SOCIO-POLITICAL ENVIRONMENT FOR URANIUM MINING IN THE EASTERN UNITED STATES OF AMERICA WITH EMPHASIS ON THE COLES HILL URANIUM DEPOSIT

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Abstract

Virginia Uranium, Inc. (“VUI”) is an exploration and development company that holds exclusive rights to the world class Coles Hill uranium project in Pittsylvania County, Virginia. This project has the potential to supply significant uranium to the market. Since the 1980s over US\$60 million has been expended to advance the project. The Coles Hill uranium deposit is located in south central Virginia and is probably the largest undeveloped uranium deposit in the United States. It has a measured and indicated resource of 119 million pounds of $U_3O_8^{(A)(B)}$ at a cut-off grade of 0.025% U_3O_8 based on a National Instrument 43-101 technical report prepared for Santoy Resources Ltd. and Virginia Uranium, Inc. by Behre Dolbear and Company, Ltd., Marshall Miller and Associates, Inc., and PAC Geological Consulting Inc. dated February 2, 2009 and revised April, 2009. The whole rock analyses of the deposit indicate a relatively monomineralic ore that does not contain quantities of heavy metals that are typical of uranium ores of the southwestern United States. The Colorado School of Mines Research Institute conducted mill mineral processing tests in the 1980s. Project pre-feasibility studies and other plans completed in the 1980s will be updated over the next 12 months. Mining and support personnel can reasonably be recruited from the local area, as the skill sets needed for miners exist already among people and companies who are comfortable with farming and heavy equipment. Virginia currently requires that uranium mining regulations and permitting be adopted by law prior to approving a mining operation at Coles Hill. Virginia has regulated and permitted many similar mining industries. In fact, lead has been mined in the state from 1750–1981 and heavy metal sands have been mined since 1991 in Dinwiddie County that is over 90 miles/144 kilometers east of Coles Hill. A process to evaluate uranium mining through the Virginia Coal and Energy Commission began in November 2008. On the 21st of May 2009, the final scope of the study to evaluate uranium mining was issued and the study is expected to begin shortly. The results of that study may help form the basis for statutes, regulations and ultimately for allowing uranium mining to proceed in Virginia. VUI intends to support legislation for uranium mining regulations in the January 2011 state legislative session. In contrast, the mill and tailings management permits are the responsibility of the federal government. These federal permit applications could begin immediately.

1. US URANIUM MARKET

The United States of America (“US”) is the world’s largest consumer of nuclear power with 104 operating stations that produce almost 20% of the US power supply (Table 1). In 2007, the US nuclear power plants generated 806.5 billion kWh. In 2007, according to the US Department of Energy (“DOE”), the United States purchased 51 million pounds (19 615 mtU) of U_3O_8 of which only 8% (4 million pounds/1 538 mtU) was US origin and the remaining 92% (47 million pounds/ 18 076 mtU) from foreign sources. The US dependency on foreign uranium is far greater than its dependence on foreign oil.

The DOE projects that US electricity demand will rise 25 percent by 2030. That means the US will need over a hundred new power plants to provide electricity for our homes and continued economic growth. Maintaining nuclear energy's current 20% share of generation would require building three reactors every two years starting in 2016, based on DOE forecasts.

TABLE 1. US HISTORICAL SUPPLY AND DEMAND

	2003	2004	2005	2006	2007	5-year avg
Total US Purchases (1)	56 552	64 102	65 749	66 539	50 983	60 785
US Mine Production (2)	2 200	2 452	3 045	4 692	4 541	3 386
% Purchases	4%	4%	5%	7%	9%	6%

Notes1. Total Purchases and US Origin from: <http://www.eia.doe.gov/cneaf/nuclear/umar/table2.pdf>2. US Uranium Mine Production from: <http://www.eia.doe.gov/cneaf/nuclear/dupr/umine.pdf>

2. VIRGINIA URANIUM, INC. AND COLES HILL URANIUM DEPOSIT

Virginia Uranium, Inc. (“VUI”) is focused on the exploration and development of the Coles Hill Uranium Property, in Pittsylvania County, Virginia which contains two significant deposits of uranium (Figs 1 and 2). This area of the US was targeted by Marline in 1977 for uranium exploration because of the belt of Proterozoic terrain and “the fact that on a worldwide basis most of the prominent uranium provinces are associated directly or indirectly with Precambrian terrain” per uranium expert, Franz Dahlkamp. The area was also favorable due to the existence of boundary Triassic basins in contact with local high background granites [1].

The Coles Hill deposits were discovered using conventional reconnaissance vehicle-borne scintillometer surveys. The property was drilled from 1979 until 1984 with 182 rotary-percussion holes (totaling 124 799 feet/38 038 meters) and 74 NQ core holes (totaling 65 082 feet/19 837 meters), totaling 256 holes and 189 881 feet/57 875 metres. In 2007, Virginia Uranium re-drilled seven rotary-percussion holes totaling 9 137 feet (2 784 metres) and three new NQ core holes totaling (4 510 feet/1 374 meters). The results of the new drilling verified the Marline estimates and provided the following current resource estimate in a NI 43-101 [2].

The deposits consist of continuous high grade zones (greater than 0.25%) within and along a central axis with decreasing grade outward. The defined deposit comes to the surface and is amenable to open pit mining. The mineralization is restricted to uraninite, pitchblende, and coffinite. The deposit contains hydrothermal zones within the hematitic rich amphibolite, which has intruded the mylonite, and with hematite rich mylonite of the Leatherwood granite. Ore is found in the footwall in the western Piedmont and is bounded by the Chatham fault zone and Triassic basin to the southeast. There is considerable potential to both extend the high-grade sections within the overall deposit and extend the deposit at depth. In addition, a number of exploration targets have been identified in the surrounding land package controlled by VUI. At this time, the project is ready for the pre-feasibility stage and will need a state-regulatory framework to upgrade the deposit to a reserve and a full feasibility stage. The resource estimate is summarized in Table 2.

TABLE 2. COLES HILL RESOURCES

Millions of Tons and Pounds In-Place									
Cutoff %U ₃ O ₈	Measured ¹			Indicated ¹			Total ¹		
	Tons ²	% U ₃ O ₈ ³	Lbs. U ₃ O ₈	Tons ²	% U ₃ O ₈ ³	Lbs. U ₃ O ₈	Tons ²	% U ₃ O ₈ ³	Lbs. U ₃ O ₈
Project Total (South and North Coles Hill Deposits)									
0.100	0.75	0.228	3.45	6.27	0.215	26.9	7.03	0.216	30.4
0.075	1.35	0.164	4.44	24.0	0.116	55.9	25.4	0.119	60.4
0.050	2.28	0.124	5.65	35.4	0.101	71.7	37.7	0.103	77.4
0.025	6.62	0.064	8.42	92.1	0.060	111.0	98.7	0.060	119.0

¹ Total tonnage above cutoff grade and average weight % U₃O₈ of that tonnage

² Short tons based on a rock density of 2.56 g/cc

³ Average weight %

The "Qualified Persons" (as defined in NI 43-101) who prepared the resource estimate were Betty L. Gibbs for Behre Dolbear and K. Scott Keim for Marshall Miller and Associates, Inc.

Mineral resources which are not mineral reserves do not have demonstrated economic viability. The estimate of mineral resources may be materially affected by environmental, permitting, legal, marketing, or other relevant issues.

3. POLITICAL BACKGROUND

In 1980, the project contained sufficient "reserve" estimates for the Commonwealth of Virginia to hold hearings and take notice that a new mining industry was in the state. Although Virginia has a well-established mining tradition and regulatory framework the general public perceived that uranium mining was different and as such should be treated differently. Marline recognized that public perception and worked closely with and supported the various studies that were proposed and completed [3].

In 1981, the Virginia General Assembly directed the Virginia Coal and Energy Commission to undertake a study of uranium development in Virginia. This resulted in the creation of the Uranium Subcommittee that:

- (1) Received testimony from numerous sources;
- (2) Held hearings on the advisability of uranium development in the commonwealth;
- (3) Took a fact-finding trip to Texas to visit operating uranium mines and mills;
- (4) Met with Texas state legislators on the issue of uranium mining;
- (5) Recommended that Virginia regulate the exploration for uranium ore, and
- (6) Met with regulatory agencies from New Mexico, Colorado, and Wyoming.

These hearings, fact-finding sessions, and presentations mainly focused on generic issues related to the uranium industry and did not focus on a specific site. As a result of this study the General Assembly of Virginia found that it **"has not identified any environmental or public health concern that could preclude uranium development in Virginia"**.

As this study was only of a general nature, the Virginia General Assembly, in 1983, established a legislative committee, the Uranium Administrative Group (“UAG”) to examine the issue of uranium development “at specific sites in Pittsylvania County”. Specifically the study looked at the costs and benefits of such activity in Pittsylvania County which was based in part on information submitted by the proponents. Marline submitted to the UAG its best judgment at the time of the contemplated design and operation of the mine, mill, and tailings management complex and prepared an analysis of the suitability of the site for the proposed project. This analysis included a description of:

- (1) Geologic characteristics;
- (2) Hydrological characteristics;
- (3) Hydrogeological characteristics;
- (4) Seismological characteristics;
- (5) Biological and meteorological characteristics;
- (6) Demography, and
- (7) Current uses of the land in the vicinity of the site.

The suitability studies were site-specific and were conducted in accordance with accepted environmental assessment and engineering practices. In addition to environmental work associated with the above studies, a complete Nuclear Regulatory Commission (“NRC”) Regulatory Guide 4.14 one-year baseline study was completed.

As a result of this scientific study of the site, the UAG concluded: **“that the moratorium on uranium development can be lifted”**. Seventeen of the nineteen members of the UAG supported the development of regulations for uranium mining.

Both the general study and the site specific study completed by various independent groups within the Commonwealth concluded that the uranium industry could proceed and that the environment and health and the safety of the workers and general public would be protected.

As a result of the drop in uranium prices, Marline lost interest in the project in 1985 and the politicians saw no need at the time to pass uranium mining legislation directing the state agencies to develop uranium mining regulations.

The Virginia Code § 45.1-283 explicitly states “Notwithstanding any other provision of law, permit applications for uranium mining shall not be accepted by any agency of the Commonwealth prior to July 1, 1984, and until a program for permitting uranium mining is established by statute.” The intended purpose of the law was not to exclude the industry from Virginia but to develop an appropriate regulatory framework based on Virginia’s natural environment. In fact the Virginia Code §45.1-274 explicitly permits uranium exploration.

In September 2007, the Virginia Governor’s office released the Virginia Energy Plan. This plan mentioned the Coles Hill deposits numerous times and stated in part “Virginia should assess the potential value of and regulatory needs for uranium production in Pittsylvania County.” The report also stated “there are sufficient resources to support a uranium mining industry in Pittsylvania County with enough to meet the fuel needs of Virginia’s current generation” (p. 101) Virginia Uranium supported the statements in the Virginia Energy Plan and supported a new study. On November 6, 2008, the Coal and Energy Commission, the same group that studied the uranium mining issue in the 1980s, in following

up on the recommendations of the Virginia Energy Plan appointed a Uranium Sub Committee to again study the uranium mining issue.

On the 21st of May 2009, the Uranium Mining Sub-Committee of the Virginia Coal and Energy Commission approved a scope of study. This study is expected to start during the summer of 2009 by the National Academy of Science (or equivalent). The results of that study should form the basis for regulations and ultimately for uranium mining to proceed in Virginia [4].

4. VIRGINIA — A NUCLEAR FRIENDLY STATE

The Commonwealth of Virginia has a large nuclear presence. Dominion Resources, the largest electric utility has four nuclear power plants, with a 5th plant proposed, providing 35% of Virginia's electricity supply. In Lynchburg, just 50 miles North of the Coles Hill Deposits Areva, the French nuclear conglomerate, and Babcock and Wilcox manufacture nuclear fuel assemblies. And in the Hampton Roads area Areva has a nuclear heavy equipment manufacturing partnership with Northrop Grumman Corporation. In addition, one of the largest naval bases in the world, and home to nuclear powered aircraft carriers and submarines, is located in the Hampton Roads area Virginia's nuclear heritage is extensive and the Virginia Energy Plan states **“Virginia should increase activities to further develop the state's nuclear industry cluster” (p 169).**

5. MINING INDUSTRIES IN VIRGINIA

Mineral resources have played a significant role in Virginia's growth and development since the settlement of Jamestown when English colonists began mining and smelting iron in 1609.

The first commercial coal mining in the United States occurred in 1748 near Richmond, the state capitol. Thomas Jefferson, in his essay "Notes on the State of Virginia," mentioned the discovery of gold, coal, lead, copper, iron, graphite, marble, limestone and other minerals and rocks.

Today, over 400 different minerals have been found and more than 30 different mineral resources are produced in Virginia at a combined annual value of nearly US\$2 billion.

Virginia is the nation's 10th largest producer of coal, ranks 5th in the production of crushed stone and has experienced a dramatic increase in the production of natural gas, driven by the development of coal-bed methane reserves.

Virginia is home to many prominent mining companies such as Alpha Natural Resources and Massey Energy. Virginia Tech (the colloquial name of Virginia Polytechnic Institute and State University in Blacksburg) hosts one of the largest Mining Engineering and Geosciences university departments in the US. Also, the US Geologic Survey main offices are based in northern Virginia.

Virginia has the nuclear and mining history to support and compliment the development of a uranium extraction industry.

6. SOCIAL SITUATION

In regards to the uranium issue in Pittsylvania County the population can in general be divided into four groups: those that strongly support the industry, those that support the industry but want to see the results of the new study, those that have real environmental concerns, and those that will use any tactic to stop the industry [5]. Our studies show that the majority of the people fall within the first three groups. They see the positive impact that this project would mean for the County, the Commonwealth, and the Nation. The fourth group that just wants to stop the project will say and do anything to advance their cause.

Our challenge at Virginia Uranium is to present the scientific facts and work with all groups to further their education and understanding of uranium mining and milling. We are confident that uranium mining and milling can take place in Virginia such that the environment and the safety and health of the workers and general population are protected.

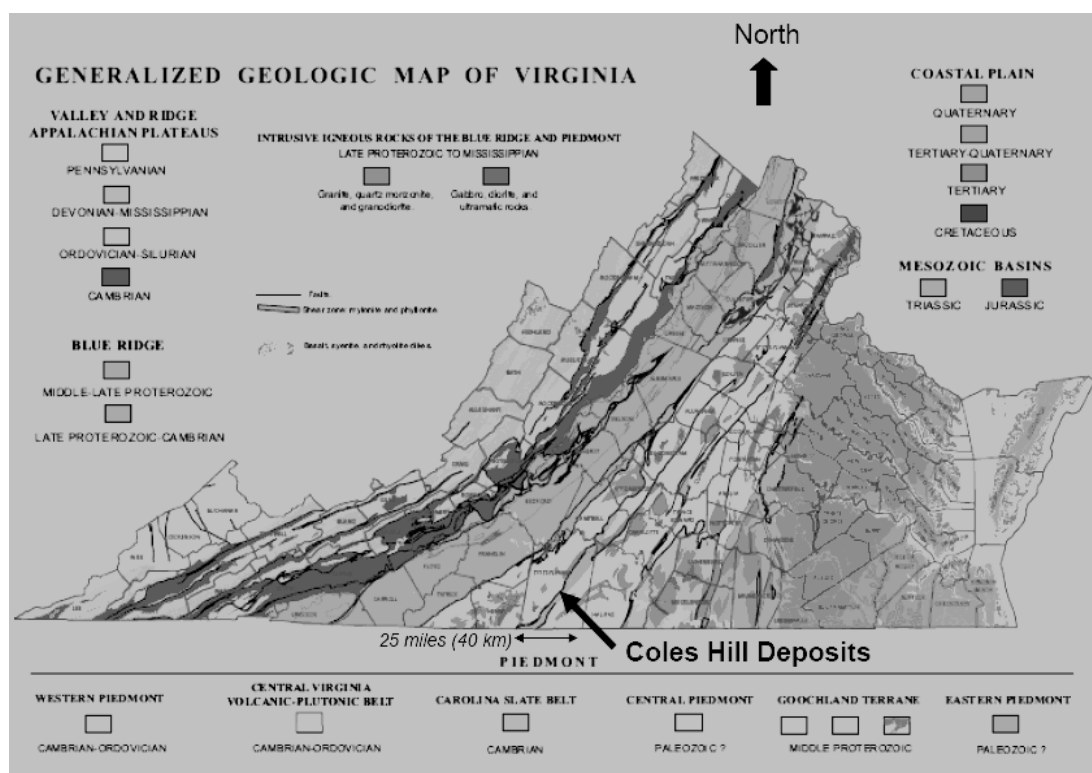
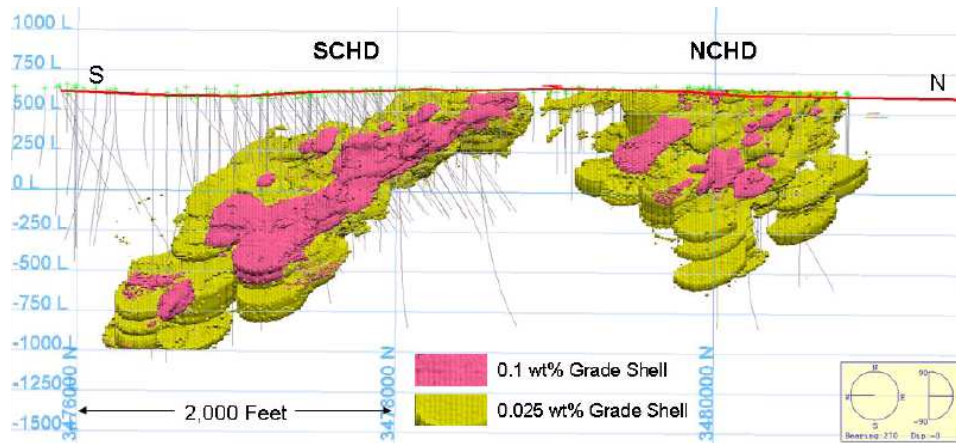


FIG. 1. Location and geologic setting of deposit (Source: Virginia DMME).



Coles Hill Uranium Deposit, Pittsylvania County, Virginia. Vertical Cross-section with 3-D View of the 0.025 wt% U_3O_8 Grade Shell with the 0.1 wt% U_3O_8 Grade Shell Superimposed, Looking West.

FIG. 2. Deposit three dimensional view (Source: Marshall Miller and Associates and Virginia Uranum, Inc.).

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UNDERGROUND MILLING OF HIGH-GRADE URANIUM ORE

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Abstract

There are many safety and technical issues involved in the mining and processing of high grade uranium ores such as those exploited in Northern Canada at present. With more of this type of mine due to commence production in the near future, operators have been looking at ways to better manage the situation. The paper describes underground milling of high-grade uranium ore as a means of optimising production costs and managing safety issues. In addition the paper presents some examples of possible process flowsheets and plant layouts that could be applicable to such operations. Finally an assessment of potential benefits from underground milling from a variety of viewpoints is provided.

1. INTRODUCTION

This paper presents and analyzes the new concept of underground milling of high-grade uranium ore. Compared to conventional milling on surface, the underground milling scheme appears to offer significant cost savings and a lower environmental impact. The paper describes the underground milling scheme, presents process flowsheets and plant layouts, and provides an assessment of potential benefits from underground milling.

2. NUCLEAR RENAISSANCE AND URANIUM PRODUCTION

2.1. Global uranium production requirements

The world is experiencing a nuclear renaissance. Global population growth in combination with industrial development will lead to a near doubling of electricity consumption by 2030. Governments in many parts of the world have accepted the need for nuclear power as an essential part of the policy mix capable of delivering a low-carbon-emissions electricity generating sector. Nuclear electricity is already being generated in nations comprising nearly two-thirds of humanity. In the last two years, the US Nuclear Regulatory Commission has received 17 applications for 26 nuclear reactors, with proposals for 6 additional reactors pending. Nuclear power is under serious consideration in over 30 countries which do not currently have it. Worldwide, there are now 45 reactors under construction with a net electrical capacity of 40 GW(e).

Currently, production from the world's uranium mines satisfies only 55% of nuclear power plant consumption. The nuclear renaissance will translate into a substantial increase in uranium demand, likely exceeding expected production from current global operations, planned expansions and new development projects. World mine production needs to expand significantly. Thus other as yet unspecified uranium deposits must be brought into production.

2.2. Observed and potential effects in Northern Saskatchewan

In response to the supply/demand considerations noted above, there has been, for the past few years, a “uranium rush” in many parts of the world, including the resource-rich Athabasca Basin in northern Saskatchewan. In a recent count, there were 72 mineral exploration disposition holders exploring for uranium in this region. Positive results from any of these exploration activities could, depending on their location, potentially provide a source of additional feedstock for any of the existing milling centres in northern Saskatchewan and/or result in the establishment of additional new milling capacity. Underground milling would be considered in the latter instance.

3. A URANIUM MILLING PRIMER

3.1. Unit operations

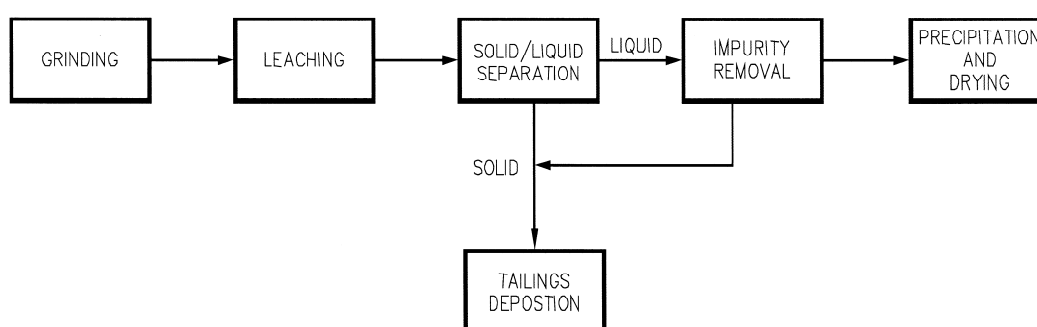


FIG. 1. Uranium milling operations.

Figure 1 summarizes the basic steps in uranium milling. The uranium mills in northern Saskatchewan operate as follows:

- Grinding — Semi-autogenous grinding (SAG);
- Leaching — Sulphuric acid, oxidation by sodium chlorate, oxygen or hydrogen peroxide;
- Solid/liquid Separation — Counter-current decantation (CCD);
- Impurity Removal — Solvent extraction (SX) with ammonia or strong acid stripping;
- Precipitation and Drying — Ammonia with calcining, or hydrogen peroxide with drying;
- Tailings Deposition — In-pit tailings management facility;

Further details on uranium milling [1] [2] and uranium tailings management [3] [4] are available.

3.2. Current high-grade ore mining and milling scheme

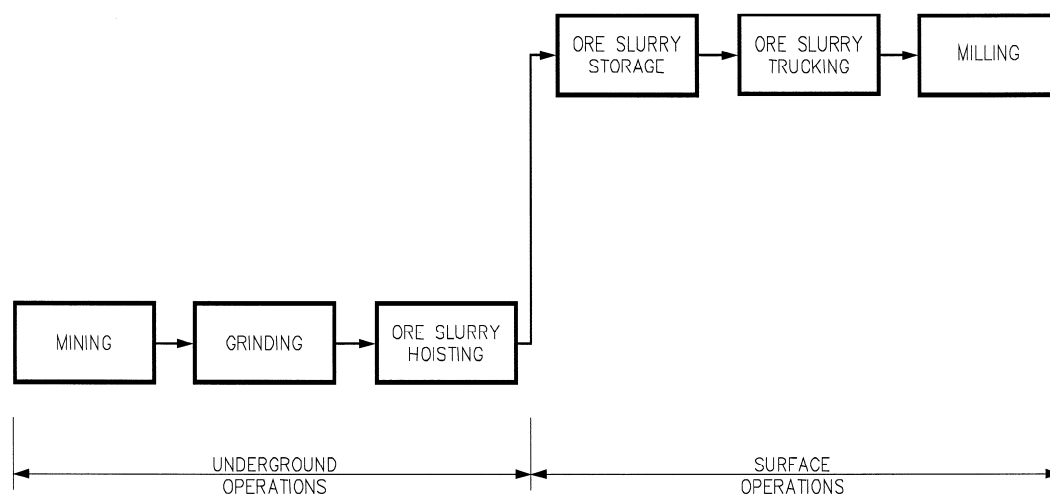


FIG. 2. Current high-grade mining and milling scheme.

Figure 2 diagrams the current high-grade mining and milling scheme followed, for example, at McArthur River and Key Lake. Process operations are:

- Mining — Raise boring;
- Grinding — SAG;
- Ore Slurry Hoisting — Positive displacement diaphragm pumps;
- Ore Slurry Storage — Air-agitated pachuca with recirculation pump;
- Ore Slurry Trucking — Purpose-designed containers on B-trains;
- Milling — Acid leach with oxygen oxidant, CCD, SX with ammonia stripping, ammonia precipitation with calcining.

Further details are available on the operations at McArthur River [5] and Key Lake [6].

4. UNDERGROUND MILLING

4.1 Concept overview

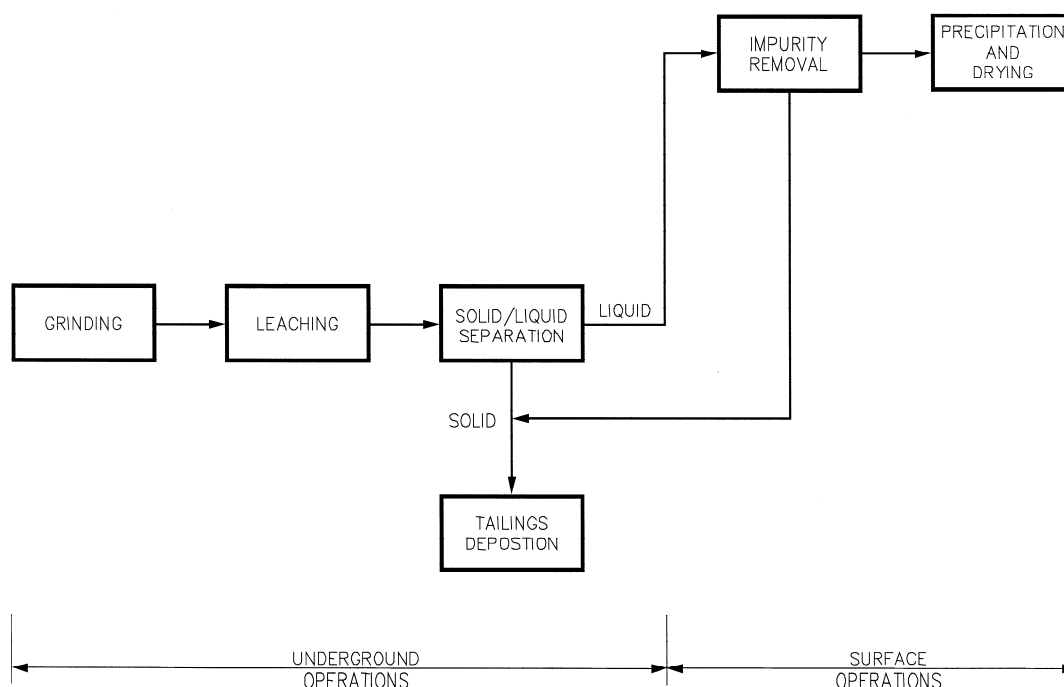


FIG. 3. Underground milling scheme.

The flowsheet in Fig. 3 shows the basics of the proposed underground milling scheme. The existence of a 20 million pounds U_3O_8 per year, high-grade underground uranium mine, similar to the McArthur River operation, is assumed. Grinding, leaching, solid/liquid separation and tailings deposition are all carried out underground. Leach liquor is pumped to surface for impurity removal, precipitation and drying. The impurities, removed as chemical precipitates, are moved back underground for disposal.

4.2. Process description

4.2.1. Grinding

Ore grade is set at the nominal 20% U_3O_8 mined at McArthur River and expected at Cigar Lake. Run-of-mine ore is ground by SAG milling or crushing/ball milling. To the extent possible, process water is mine inflow water. Classification is by cyclone, a practice proven on high-grade ore at McArthur River [7]. Ground ore slurry is thickened in a conventional thickener and pumped to surge storage provided by air-agitated leach feed pachucas fitted with recirculation/transfer pumps. From the leach feed pachucas the ore slurry is pumped to leaching at a controlled rate to maintain a constant uranium feed rate. This grinding/thickening/surge storage circuit is essentially a duplicate of the equivalent circuit at McArthur River.

4.2.2. Leaching

The leach circuit consists of a series of gas-agitated pachucas fitted with recirculation/transfer pumps. The agitation gas is oxygen, which also provides the uranium oxidation required for uranium dissolution. Sulphuric acid is metered into the leach pachucas to dissolve uranium minerals. Sulphuric acid is supplied from a plant on surface. The oxygen plant is underground. Pachuca leaching of 20% U_3O_8 ore with oxygen and sulphuric acid has been proven in bench and pilot scale tests [8]. A similar process is in operation full-scale in the current leaching circuit at Key Lake with McArthur River ore diluted to 4% U_3O_8 .

4.2.3. Solid/liquid separation

After leaching, solid/liquid separation and residue solids washing is done with a pressure filter. This pressure filtration and washing operation was proven on a mini-pilot scale. Cigar Lake ore, with its typical high clay content, was used to provide a more difficult filtration and washing performance test. Even with the high clay content, pressure filtration was found to afford lower uranium soluble losses than a CCD circuit. The filtrate is transferred to surface with lift pumps.

4.2.4. Tailings deposition

The washed leach residue filter cake is discharged from the filter directly into the tailings disposal raises. These purpose-excavated raises are developed in competent rock on an as-needed schedule.

4.2.5. Impurity removal

Impurity removal is the stage where processing moves to the surface because the necessary equipment is too bulky to install underground. As described above, the northern Saskatchewan mills all use SX for impurity removal. However, to pair with underground leaching, the best alternative for impurity removal processes is “Chemical Precipitation Purification” or CPP. This is most efficiently and effectively applied to processing a higher concentration leach solution, which will certainly be obtained from leaching ore grading 20% U_3O_8 followed by highly efficient residue washing in a pressure filter. The CPP process is technically and operationally proven. CPP is essentially the impurity removal technique used by Cogema in the early years at Cluff Lake when their ore grade was relatively high [9]. CPP bench scale tests proved successful for potential CPP application at Rabbit Lake for processing Cigar Lake ore leach solution under a scheme evaluated by the Cigar Lake Joint Venture [10]. The suite of CPP reagents is fairly innocuous — sulphuric acid, lime and hydrogen peroxide. Impurities are chemically precipitated (thus the name Chemical Precipitation Purification) as a mixture of gypsum and metal hydroxides. These solids are pressure filtered. Filter cake is transferred back underground for disposal with the leach residue filter cake.

4.2.6. Precipitation and drying

Hydrogen peroxide, and magnesium oxide for pH control, are used to precipitate a uranium peroxide product. This is dewatered and dried. The precipitation and drying circuit is a duplicate of the existing equivalent circuit in the Rabbit Lake mill, which has successfully operated this hydrogen peroxide precipitation for more than twenty years [11] [12].

4.2.7. Underground equipment arrangements

Fig. 4 is a conceptual layout for leaching.

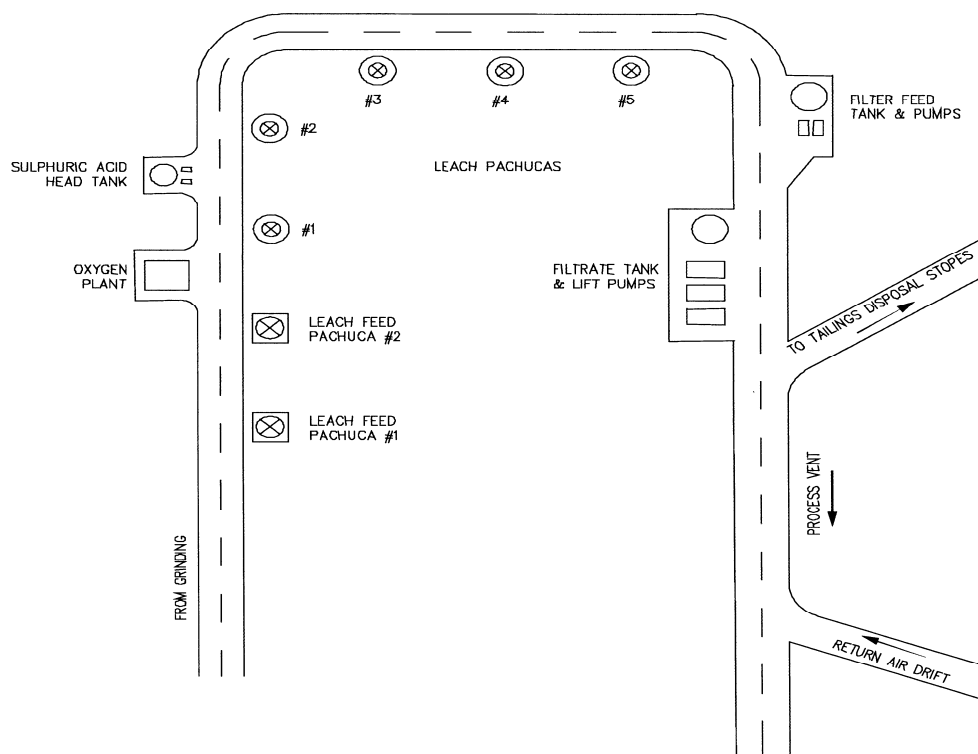


FIG. 4. Underground leaching layout.

Fig. 5 shows the spatial relation between the leaching area and the tailings disposal raises. As can be seen, the underground processing area is compact, with the tailings disposal raises nearby.

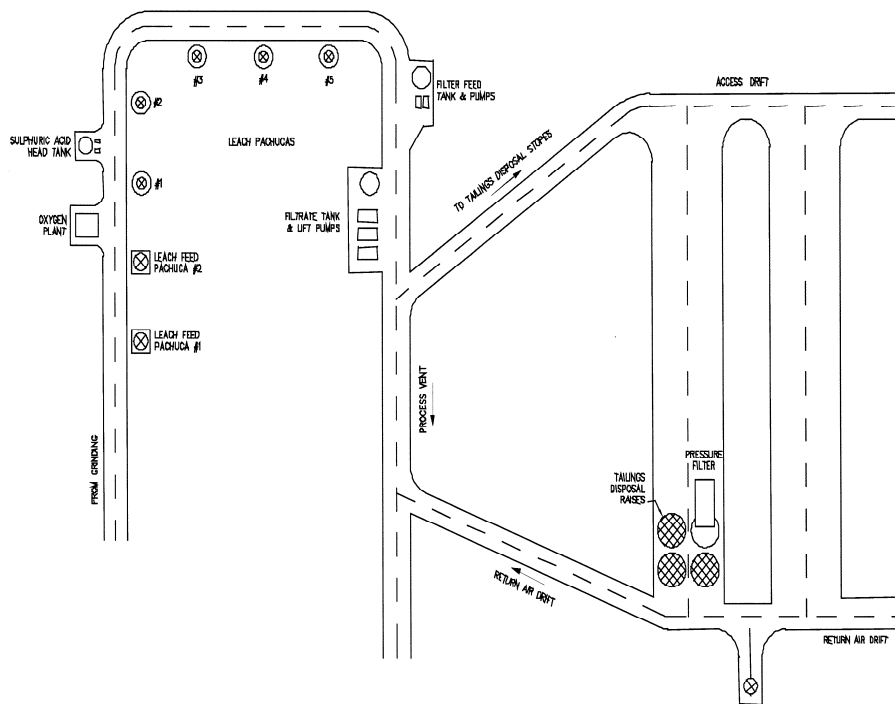


FIG. 5. Underground leaching and tailings disposal layout.

5. POTENTIAL BENEFITS

5.1. Environmental

- Visual impact of the operation is reduced by keeping grinding, leaching, solid/liquid separation and tailings disposal underground;
- The leach residue tailings, which retain most of the radioactivity from the mined ore, stay underground. There is no tailings management facility on surface. Stored deep underground as filter cake in stopes developed in competent basement rock, the residue is arguably more isolated from the environment (for example, ground water) than was the ore before mining;
- Discharging tailings directly from the filter into the tailings stopes avoids the conventional practices of reslurrying for pumping and water-saturated storage under a water cover. This storage of tailings as relatively dry filter cake prevents the troublesome resolubilization of certain species such as molybdenum, arsenic and selenium which is often observed in conventional surface tailings management facilities;
- Preliminary hydrogeological modeling of this tailings disposal scheme showed that contaminant transport from the tailings to surface waters (for example, a nearby lake) would be extremely slow; i.e. there would be zero impact on the groundwater entering the lake after the usually required modeling period of 10 000 years. Relatively high radium concentrations in McArthur River-type ore/tailings would have a negligible impact on adjacent surface and groundwater due to extremely long travel times in combination with radioactive decay. Modeling results showed radium remaining below Saskatchewan Surface Water Quality Objectives (SSWQO) at all times out to the limit of the model time — 300 000 years;

- The Key Lake mill has operated a reverse osmosis (RO) water treatment plant for 12 years. Around the world, uranium metallurgists have bench scale and pilot plant tests underway to extend the application of membrane technology to other and more highly contaminated mill streams (i.e. streams carrying higher concentrations of dissolved solids, including but not limited to sulphates). Application of membrane technology to water treatment for the underground milling scheme, combined with the relatively short and innocuous suite of reagents used (i.e. oxygen, sulphuric acid, lime, magnesia, hydrogen peroxide) is expected to provide an aqueous effluent with minimal loading to the environment. Re-using the membrane treatment plant permeate as process water and injecting any surplus permeate back underground could even further reduce this already minimal loading.

5.2. Capital costs

At the conceptual study level, relative to a conventional mining and milling scheme (refer to Fig. 2), capital cost savings on the order of 35% are expected.

5.3. Operating costs

At the conceptual study level, relative to a conventional mining and milling scheme (refer to Fig. 2), operating cost saving are expected on the order of 30%.

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CONVERTING THE CAETITÉ MILL PROCESS TO ENHANCE URANIUM RECOVERY AND EXPAND PRODUCTION

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Abstract

The Caetité uranium mill was commissioned in 2000 to produce about 340 t U per year from an uranium ore averaging 0.29% U_3O_8 . This production is sufficient to supply the two operating nuclear power plants in the country. As the Brazilian government has recently confirmed its plan to start building another ones from 2009, the uranium production will have to expand its capacity in the next two years. This paper describes the changes in the milling process that are being evaluated in order to not only increase the production but also the uranium recovery, to fulfil the increasing local demand. The heap leaching process will be changed to conventional tank agitated leaching of ground ore slurry in sulphuric acid medium. Batch and pilot plant essays have shown that the uranium recovery can increase from the 77% historical average to about 93%. As the use of sodium chloride as the stripping agent has presented detrimental effects in the extraction and stripping process, two alternatives are being evaluated for the uranium recovery from the PLS: (a) uranium peroxide precipitation at controlled pH from a PLS that was firstly neutralized and filtered. Batch essays have shown good results with a final calcined precipitate averaging 99% U_3O_8 . Conversely the results obtained at the first pilot plant essay has shown that the precipitation conditions of the continuous process calls for further evaluation. The pilot plant is being improved and another essay will be carried out. (b) uranium extraction with a tertiary amine followed by stripping with concentrated sulphuric acid solution. Efforts are being made to recover the excess sulphuric acid from the pregnant stripping solution to enhance the economic viability of the process and to avoid the formation of a large quantity of gypsum in the pre-neutralization step before the uranium peroxide precipitation.

1. INTRODUCTION

Currently there is only one uranium mining and milling facility in operation in Brazil. The Caetité uranium mill, located in the Municipality of Caetité, Bahia State, is run by Indústrias Nucleares do Brasil S/A — INB and was commissioned in 2000 to produce about 340 t U per year from the milling of about 200 000 t of an uranium ore averaging 0.29% U_3O_8 . This production is sufficient to supply the two nuclear power plants that are currently in operation in the country. As the Brazilian government has recently confirmed its plans to start building another ones from 2009, the Caetité uranium mill will have to expand its production capacity in the near future. To fulfil this increasing demand, changes in the Caetité milling process are being evaluated in order to increase not only its production but also the uranium recovery. This paper shows the current milling process and discusses the changes that are being evaluated.

2. THE CURRENT CAETITÉ URANIUM MILL

The Caetité mining and milling facility is in a site called Uraniferous Province of Lagoa Real — UPLR, located in the mid-southern region of the State of Bahia, in areas pertaining to the municipalities of Caetité and Lagoa Real (Figure 1). From the economic standpoint, uranium is the only local mineral wealth, occurring mainly in the form of oxide, and constituting the mineral ore known as uraninite, hosted in gneiss rock.

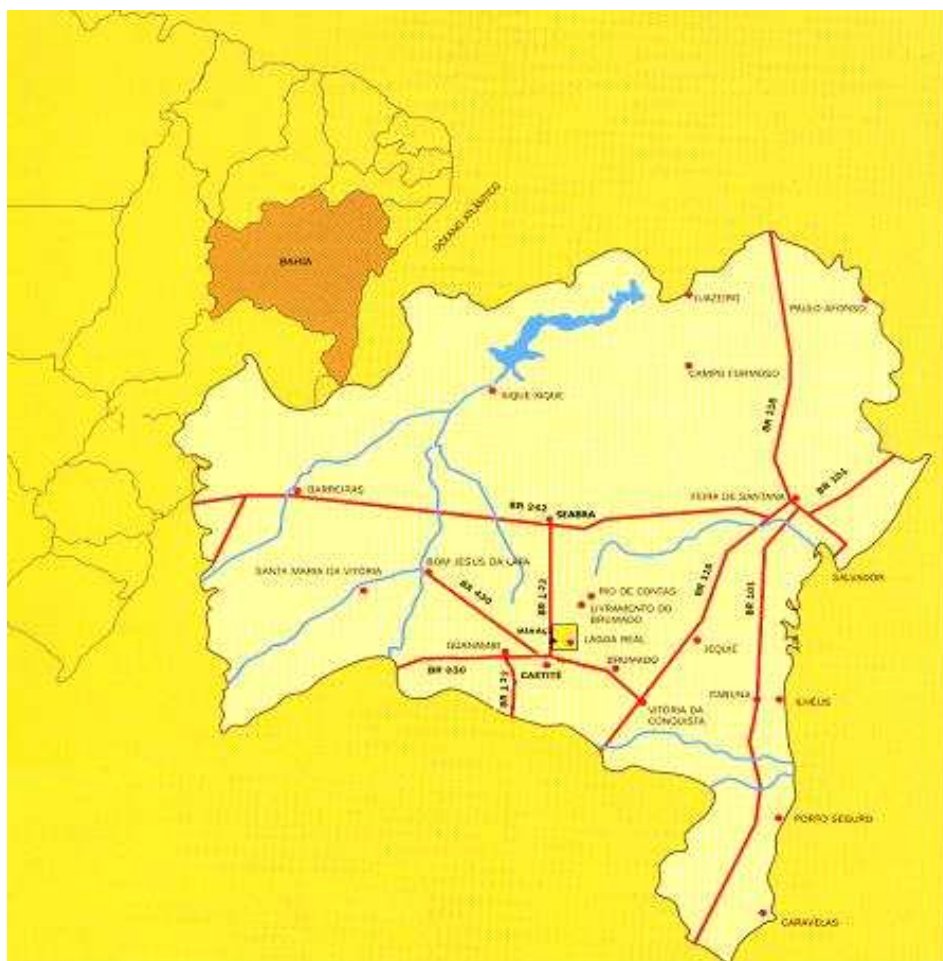


FIG. 1. Location of the uraniumiferous province of Lagoa Real in the state of Bahia.

2.1. Resources

Following two decades of prospecting and survey works permeated by some intermissions, 35 uranium anomalies were identified, which are distributed over a surface area of 1 200 km², roughly along three semi-arched lines covering an extension of approximately 30 km in length. Twelve of such anomalies displaying significant uranium content have already been surveyed at different detail levels. Seven of which, whose surveys were partially completed, have developed to the category of deposit and account for geological reserves of some 70 000 t U with 0.20% U average content [1], including Cachoeira Mine, earlier called 13th Anomaly, which became the first occurrence of uranium being commercially exploited by INB in the region.

Cachoeira Mine is currently being exploited through open pit mining that will be changed to underground mining in the next two years. Table 1 shows the estimated amount of uranium remaining in the Cachoeira Mine as well as an estimated potential resource present in other deposits in the UPLR region.

TABLE 1. ESTIMATED UPLR REGION RESOURCES

Source	U (t)
Cachoeira Mine — open pit	890
Cachoeira Mine — underground	2 710
Other deposits	65 500
TOTAL	69 100

2.2. Existing ore treatment process plant

The general flow sheet of the current process being used at the Caetité milling facility is shown in Fig. 2.

2.2.1. Crushing

Ore transported from the mine in 25 t dump-trucks feeds a primary jaw crusher and then is transferred to a stockpile of up to 3 000 t in an ore size no larger than 125 mm. The ore is recaptured by a vibrating system located under the stockpile and conveyed to a secondary jaw crusher to reduce the ore size to minus 50 mm, and transferred to a two decks (19 and 13 mm) vibrating screen that works in a closed circuit with two hydrocone-type crushers to reduce ore size to minus 13 mm. The minus 13 mm crushed ore is transferred to an intermediate bin that continuously feeds a drum mixer (6 m long and 1.2 m in diameter rotary drum) where water and concentrated sulphuric acid are added to agglomerate the fine particles and start the leaching process. The drum mixer discharges the mixture onto a set of semi-permanent transfer conveyors that feed a 6-m high radial stacker which, in turn, unload the agglomerated ore into a pile in a leaching pad having a 1% slope and lined by a 1.5 mm thick HDPE (high-density polyethylene) membrane. The leaching pad admits two piles which once leached, are removed by hydraulic loaders and trucks to make room for new piles. Each pile contains up to 35 000 tonnes of ore, not exceeding 5.5 m in height and occupying an approximate surface area of 45 × 80 meters.

The primary jaw crusher has a capacity of 250 tph while the closed crushing circuit has a capacity of up to 100 tph.

2.2.2. Leaching

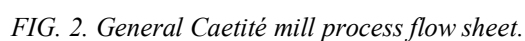
The pile created as above is submitted to three successive washes by dropping systems at a mesh of 45 × 45 cm, which irrigate both the upper and lateral surfaces at a rate of 30 L·h⁻¹·m⁻²:

- (a) 1st wash or leaching: 25 g/L H₂SO₄ solution at the rate of 0.6 m³/t ore;
- (b) 2nd wash: 5 g/L H₂SO₄ solution at the rate of 0.3 m³/t ore;
- (c) 3rd wash: raw water at the rate of 0.3 m³/t ore.

The PLS from the first pile wash is collected in a 10 000 m³ pond where it is homogenized and clarified with the addition of a flocculant before being transferred to a 5 000 m³ pond from where it is pumped to the next step. The second and third washing solutions are

collected in a 30 000 m³ pond and is used in the first wash of the next pile. All ponds are lined with two superposed 1.5 mm thick HDPE membrane, equipped with a liquid detection system located between the membranes as well as between the lower membrane and the 50cm thick compacted clay layer located at the bottom of the pond.

After leaching, piles of crushed and leached ore are removed and incorporated into to the mine waste in specific areas in the solid waste deposit.



2.2.3. Uranium Recovery from PLS

Uranium is separated from the impurities through the solvent extraction technique, in a continuous system of four mixer/settler cells, using a solvent containing 7 wt% of a tertiary long-chain amine (Alamine[®]336, Cognis do Brasil Ltda.) in aliphatic kerosene and 3 vol% of isotridecyl alcohol to improve the phase separation. The uranium is then stripped in another set of four mixer/settler cells by 1.75 mol/L sodium chloride solution with its pH adjusted to 1.2 by sulphuric acid, from where it is precipitated at a temperature of 70°C as ADU through the addition of a solution of ammonium hydroxide in specific reactors. After thickening, the underflow is filtered and washed with an ammonium sulphate solution and water in a vacuum belt filter before drying. Alternatively it may be repulped by a diluted ammonium sulphate solution in an agitated tank, centrifuged and finally dried.

The unloaded solvent is scrubbed by a 0.75 mol/L sodium carbonate solution to remove its chloride content before being fed back into the extraction step. The resulting aqueous chloride solution is then stored and partially reused in the preparation of a new stripping solution.

The plant design gave priority to the recycling of all the water used in the ore processing so as to prevent its releasing to the environment and reduce the consumption of raw water in a region where this resource is scarce. Liquid effluent is treated with lime suspension to raise its pH to about 9. The resulting pulp is transferred to specific ponds lined with 1.0 mm thick HDPE membrane, where the solid phase is retained and the clear liquid phase is reused in the process. Bottom drainage systems known as sub-aerial drains have been installed in such ponds, to provide better efficiency of the solid phase densification, and consequently the better use of the pond storage capacity. Furthermore this system replaces the conventional tailings retention designs resulting in significant environmental advantages.

By May 2009 some 2 000 tonnes of U were produced at the milling facility from the processing of 51 leaching piles. The average uranium recovery was about 77%, with an average sulphuric acid consumption of about 40 kg/t of ore.

3. EXPANDING ORE AND PLS TREATMENT PLANTS

In order to cope with the increasing uranium demand, due to the building of other local nuclear power plants, INB has decided to expand the production of uranium ore concentrate at its Caetité mining and milling facilities to 1 100 t/y U with no interruption of its current production. It also aims at keeping costs to a minimum by incorporating the equipments from the old discontinued uranium milling facility located at the municipality of Caldas, MG, as much as possible.

As the leaching process at Caldas milling facility was done by mechanically agitated tanks using sulphuric acid, INB decided to change the Caetité leaching process in order to use those equipments and to achieve an increase in its overall uranium recovery as a result. INB intends to start operating the new grinding and leaching circuit by mid-2011. It will be also necessary to increase the capacity of the PLS treatment plant and INB intends to change the process when accomplishing it. The building and operation of the new leaching and PLS plants will be done in three stages:

1st stage: building of a tank agitated leaching plant with a capacity of 335 000 t ore/y by end 2011. At the start-up it will be operated with a capacity of 220 000 t ore/y, to feed the current PLS treatment plant and producing 500 t/y U.

2nd stage: From the building of the new 1 100 t/y U PLS treatment plant by 2012, the leaching plant will process 335 000 t ore/y in order to produce some 680 t/y U.

3rd stage: The leaching plant will be expanded to process 500 000 t ore/y by 2014 in order to adjust its capacity to the new PLS treatment plant.

The operation and process of each unit will be further discussed and an explanation of the changes and additions that will be implemented will be presented below.

3.1. Crushing

The crushing circuit will not be changed. Its capacity of about 600 000 t ore/y is sufficient to meet the demands of the milling expansion programme.

3.2. Grinding

One rod mill from Caldas milling facility will be removed to the Caetité mill site. Its original capacity is 52 t/h of $<100\ \mu$ ground ore. Computerized simulations showed that it is possible to convert this rod mill into a ball mill and keep its capacity to grind the Caetité ore in sizes $\leq 590\ \mu$. It will satisfy the 1st and the 2nd stages of the production expansion programme. To meet the 3rd stage it will be necessary to add a new ball mill with a capacity of about 200 000 t ore/y.

3.3. Leaching

In the new milling flow sheet, the heap leaching process will be changed to conventional tank agitated leaching of the $\leq 590\ \mu$ ground ore slurry in sulphuric acid medium [2]. Batch and pilot plant essays showed that the uranium recovery increases to about 93% under the following conditions:

Grind size:	$\leq 590\ \mu$
Slurry density:	65 solids wt%
Leaching time:	4 hours
Temperature:	60 °C
Oxidation potential:	~500 mV
Acid concentration in the PLS:	~10 g/L

To meet the 1st and the 2nd stages of the production expansion programme, fourteen 25 m³ leaching tanks will be transferred from the Caldas mill to the Caetité mill as well as two 60 m² vacuum belt filter to be used in the solid/liquid separation step. In the plant design such equipments will be placed in two series of seven tanks, each one followed by a filter. Other existing equipments like tanks for preparation of reagents, pumps, belt conveyors, PLS filter and storage tanks will also be transferred.

At the plant start-up, by 2011, only one set of leaching tanks and only one vacuum belt filter will be operated at a rate of 32 t ore/h. This means a production of about 500 tonnes of U per year that can be processed by the current PLS treatment plant and will satisfy the 1st stage of the production expansion programme. With the building of the new PLS treatment plant by

2012, the two lines of ore leaching and liquid/solid separation will be operated to satisfy the 2nd stage of the production expansion programme. To satisfy the 3rd stage another similar ore leaching and solid/liquid separation line will be set up by 2014, using the equipment from the INB-Caldas mill.

3.4. Uranium recovery from PLS

In the current Caetité mill process, the uranium stripping is carried out by sodium chloride solution, and all aqueous effluent is recycled after lime treatment up to pH 9 [3] [4]. As the chloride ion is not removed in this treatment, its content in the PLS has increased, causing a drop in the uranium extraction and stripping efficiency. To overcome such detrimental effect over the uranium output, a solvent scrubbing step with sodium carbonate solution was introduced in the process. For the expansion of the PLS treatment plant, INB intends to replace the current process. Two alternatives are being evaluated, as presented below.

3.4.1. Direct Precipitation

In this process, the uranium is precipitated as uranium peroxide at controlled pH. Before the uranium precipitation, the PLS is firstly neutralized through the addition of ground limestone until the pH reaches 3.2, and then it is filtered. Batch essays have shown good results with a final calcined precipitate averaging 99 wt% U_3O_8 . Conversely the results obtained in the first pilot plant essay — 93–98 wt% U_3O_8 — has shown that the conditions of the precipitation in the continuous process must be better evaluated [5] [6]. The pilot plant has been improved and another essay is being carried out.

3.4.2. Solvent Extraction

The uranium is extracted from the PLS through a tertiary amine diluted in aliphatic kerosene and followed by stripping with a concentrated sulphuric acid solution (4.5 mol/L). This extraction and stripping process is well known [7]. Efforts are being made to recover the excess sulphuric acid from the pregnant stripping solution in order to enhance the economic viability of the process and to avoid the formation of large masses of gypsum in the PLS pre-neutralization step before the uranium peroxide precipitation.

4. CONCLUSIONS

The Caetité mill was designed and built about ten years ago in order to produce about 340 t/y U. This amount is sufficient to supply the local annual demand of the two existing nuclear power plants. With the recent Brazilian Government announcement that another ones will be built in the near future, other uranium deposits in the Caetité region will have to be exploited to expand the uranium ore production. On the other hand, the Caetité mill will have to expand its production to about 1 100 t of U per year in order to cope with the increasing demand for uranium ore concentrate. The heap leaching process will be changed to the tank agitated leaching technique and two alternative processes are being assessed to replace the current PLS treatment process.

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DEVELOPMENT AND EXPANSION OF THE LANGER HEINRICH OPERATION IN NAMIBIA

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Abstract

The Langer Heinrich Uranium Mine (LHU) is located in the west of central Namibia, Southern Africa. It lies 80 km east of the major deepwater port at Walvis Bay and the coastal town of Swakopmund. Designed to produce 2.6Mlb/a U_3O_8 , LHU was the first conventional mining and processing operation to be brought into production in over a decade. The construction and staged commissioning of the project was successfully achieved on 28 December 2006 and the mine was officially opened by the President of Namibia on the 14th March 2007. The ramp up to nameplate production was hampered early on by some mechanical and process issues all of which required technical solutions to be developed. With these in place, production now exceeds nameplate and lessons learnt have been incorporated into an expansion to 3.7 Mlb/a currently nearing completion. Further expansion options are also being evaluated and a number of innovative flowsheet developments are under consideration, driven by a recent, large increase in the proven reserves. This paper tracks the development of the LHU operation focusing largely on the metallurgical processes employed, some lessons learnt and some considerations for the future.

1. INTRODUCTION

The Langer Heinrich Uranium Mine (LHU) is located in the west of central Namibia, Southern Africa. It lies 80 km east of the major deepwater port at Walvis Bay and the coastal town of Swakopmund (see Figure 1).

LHU was the first conventional mining and processing operation to be brought into production in over a decade. Paladin Energy Ltd (Paladin) was able to deliver the project on schedule and within the original budget of US \$92M despite the significant cost pressures experienced by the mining industry during the twenty month construction term.

The mine is currently in full production and in the process of increasing capacity from the original 2.6 Mlb U_3O_8 /annum to 3.7 Mlb/annum.

2. NAMIBIA

Namibia is a politically stable country with excellent infrastructure and an established diverse mining industry involving uranium, diamonds, gold and base metals.

The Namibian Government actively encourages growth of its mining industry, which is a solid contributor to the country's economy. Operating mines include the Rossing Uranium mine, located 40 km north of the project, which has been in production since 1976.



FIG. 1. Location of the Langer Heinrich uranium mine.

3. PROJECT HISTORY

Following the discovery of the calcrete hosted uranium mineralisation in the early 1970s; Gencor conducted an extensive project evaluation over an 8-year period up until 1980.

In 1998, the Project was sold to the Australian listed public company, Acclaim Uranium NL (Acclaim) who also completed a highly favourable Pre-Feasibility Study. However,

adverse uranium market conditions and low prices in the late 1990s again curtailed development and Acclaim sold its holding in LHU to Paladin in 2002.

Following the acquisition, Paladin initiated a Bankable Feasibility Study (BFS) which was completed in April 2005. This BFS confirmed that the LHU project could generate highly attractive returns using defined reserves only.

Site works began in September 2005 and the construction and staged commissioning of the Langer Heinrich Uranium Project was successfully achieved on 28 December 2006.

The mine was officially opened by the President of Namibia on the 14th March 2007 and the first commercial product shipment occurred in the same month. The operation achieved nameplate production in December 2007.

4. GEOLOGY

Uranium mineralisation at Langer Heinrich is associated with the calcretisation of valley-fill fluvial sediments in an extensive tertiary palaeodrainage system. Calcrete is a secondary, chemically precipitated limestone that forms under arid to semi-arid climatic conditions.

The uranium mineralisation occurs as carnotite, an oxidised uranium and vanadium secondary mineral. The deposit occurs over a 15 km length in seven higher grade pods (see Details 1–7 in Fig. 2.) within a lower grade mineralised envelope.

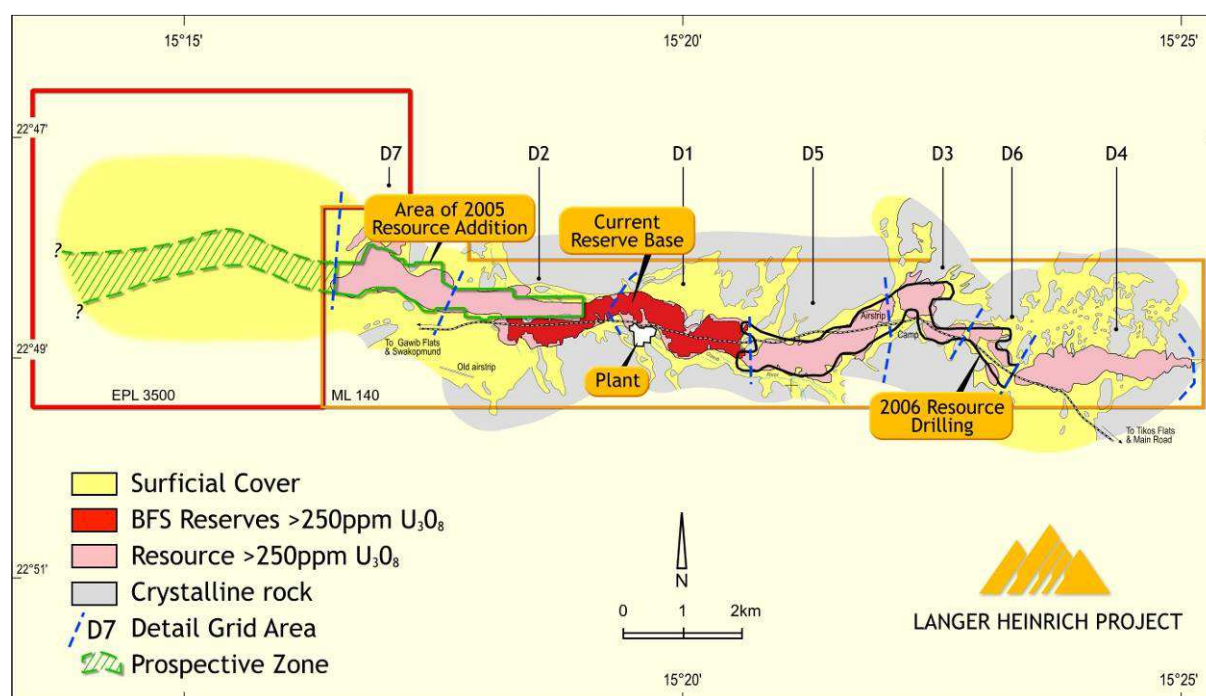


FIG. 2. Site "Detail" location plan.

The carnotite occurs as thin films lining cavities and fracture planes and as grain coatings and disseminations in the calcretized sediments.

Mineralisation is near surface, 1–30 m thick and is 50–1 100m wide depending on the width of the palaeovalley.

After calcretisation and uranium deposition, parts of the host sediments were eroded as a result of uplift and rejuvenated river flows. The present day Gawib River has dissected and modified both the calcrete and associated mineralisation. In places this prevailing ephemeral drainage system has blanketed the deposit with up to 8 m of river sands and scree.

5. ORE RESOURCES

At a 250 ppm U_3O_8 cut off grade the current resource contains 32.8 Mt at 0.06% for 19 582 t U_3O_8 in the Measured category, 23.6 Mt at 0.06% for 13 276 t U_3O_8 in the Indicated category and 70.7 Mt at 0.06% for 43 557 t U_3O_8 in the Inferred category. These resources conform to both the JORC (2004) and NI 43-101 guidelines and are quoted inclusive of any ore reserves.

Ore reserve has been announced and reported conforming to both JORC and NI 43-101 guidelines. Based on the current reserve of 50.6 Mt at 0.06% for 29 874 t U_3O_8 the Project has a life of a minimum of 17 years.

6. BASIS FOR DESIGN

Based upon the findings of the BFS, the processing plant was designed to satisfy the following production criteria (Table 1):

TABLE 1. PRODUCTION CRITERIA FOR LHU PROCESSING PLANT

Operating Criteria	Units	Value
Ore Treatment Rate	t/a	1 500 000
	t/hr	190.2
Water Consumption	m ³ /a	1 300 000
Annual Production	t/a U_3O_8	1 180
Availability	%	95
Utilization	%	95
ROM Grade	ppm U_3O_8	875
“Barren” cut size	mm	0.5
Mass Split to Barren	%	55
Leach Temperature	°C	>75

7. PROCESS DESCRIPTION

With the uranium being present as a coating on the grains it is not necessary to grind the material finer, but only to break up agglomerates and remove the surface layer.

As a consequence, after a primary Jaw Crusher the process employs 2 rotary Scrubbers (in parallel) to break down the agglomerates and to remove the uranium minerals from the grain surfaces. Scrubber discharge is screened, with the oversize material being recycled to the Scrubbers via a Secondary Cone Crusher (see Figs 3–4).

Screen undersize is pumped to a cluster of cyclones cutting at 0.5 mm. Cyclone o/flow (fines) passes through a Safety Screen and into the Pre-leach Thickener Feed Sump, whilst Cyclone u/flow feeds onto a double deck Primary Screen.

The oversize from this screen is now virtually void of uranium and is discarded as “Barren Solids”. Screen undersize is dewatered by cyclones and then further screened at 0.5 mm. The undersize from these Secondary Screens is again routed to the Pre-leach Thickener Feed Sump whilst screen oversize is discarded as “Barren Solids”.

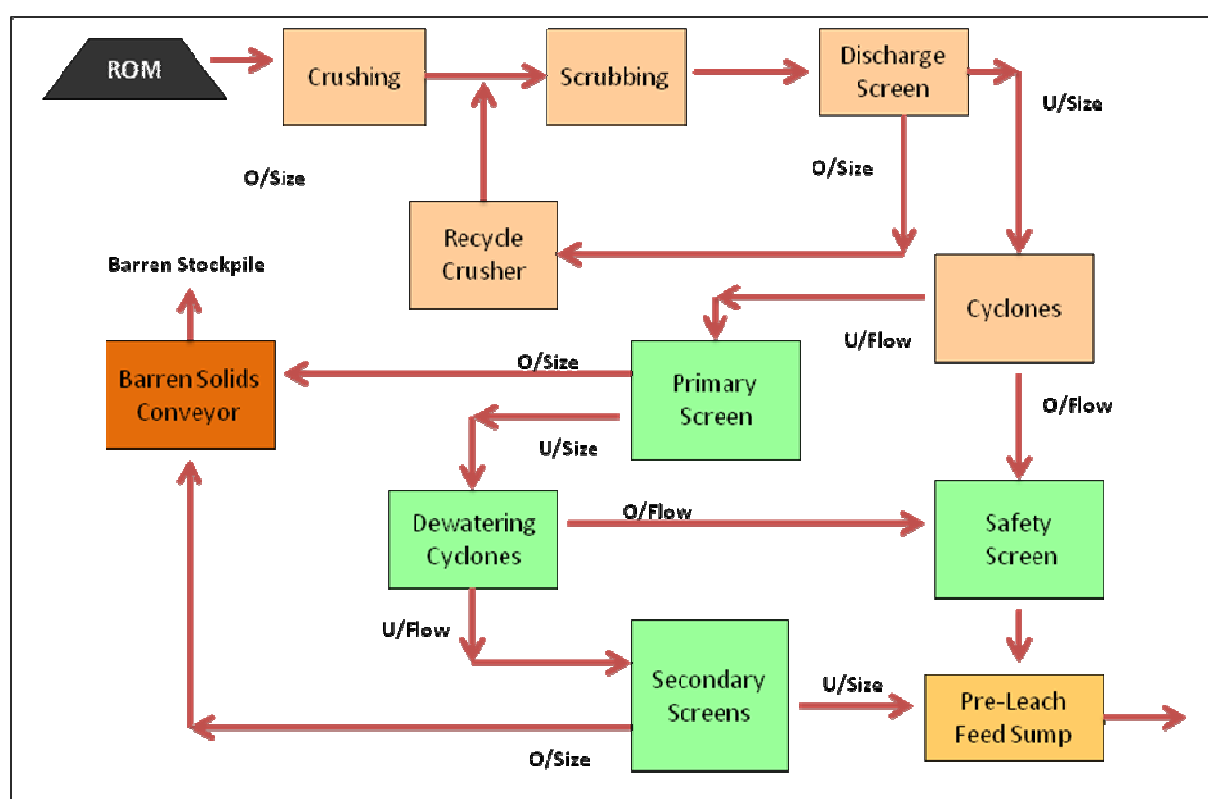


FIG. 3. Crushing, scrubbing and screening.



FIG. 4. LHU scrubbing circuit.

Typically the Barren Solids will contain 40–50% of the solids mass but only 5–10% of the uranium in the ROM feed.

Pre-leach thickener underflow is transferred to a conditioning tank where the slurry is diluted using some of the solution from the CCD No 2 Thickener o/flow (see Figs 5–8). In addition, this leach feed slurry is conditioned with sodium carbonate and sodium bi-carbonate.

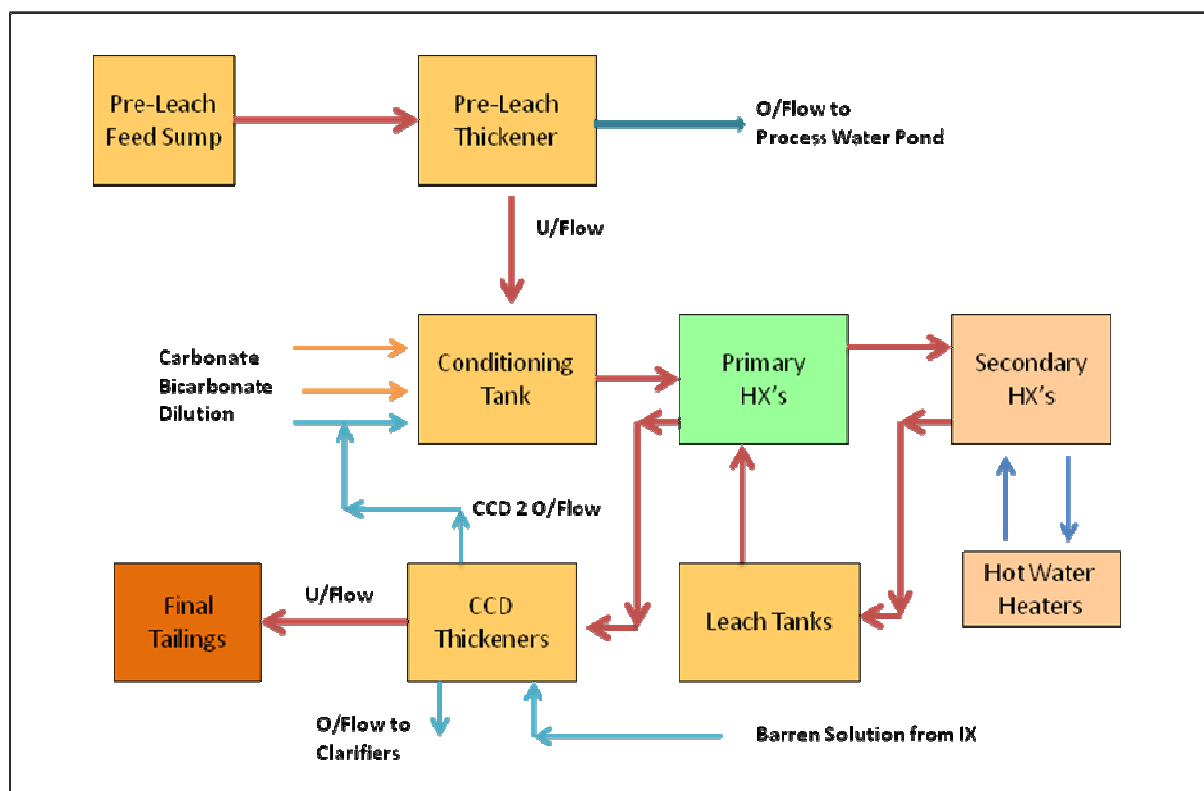


FIG. 5. Leach and CCD circuits.

From the conditioning tank the slurry is pumped firstly through primary heat exchangers where it is pre-heated by leached slurry, and then to secondary heat exchangers (see Fig.6) where hot water is used to raise the temperature to $>75^{\circ}\text{C}$. This slurry then proceeds to the leach tanks.



FIG. 6. Secondary heat exchanger.

After leaching and cooling (via the primary heat exchangers) the slurry proceeds to the counter current decantation (CCD) thickeners where the Pregnant Leach Solution (PLS) is removed from the solids (see Fig.8).



FIG. 7. Leach tanks during construction.



FIG. 8. CCD thickeners.

This PLS undergoes clarification before being pumped through a number of fixed bed ion exchange columns (originally 12) where the uranium is recovered onto resin (Figs 9–10). These columns operate on a Lead-Lag-Elute cycle.

Once the Lead Column is saturated it is switched to the elution mode and what was the Lag Column becomes Lead, and a previously eluted column is switched to a lag duty.

Uranium is stripped from the loaded resin using a sodium bicarbonate solution and this eluate is transferred to the Sodium Diuranate (SDU) Tanks where Caustic Soda is added to precipitate the uranium as SDU.



FIG. 9. Ion exchange columns.

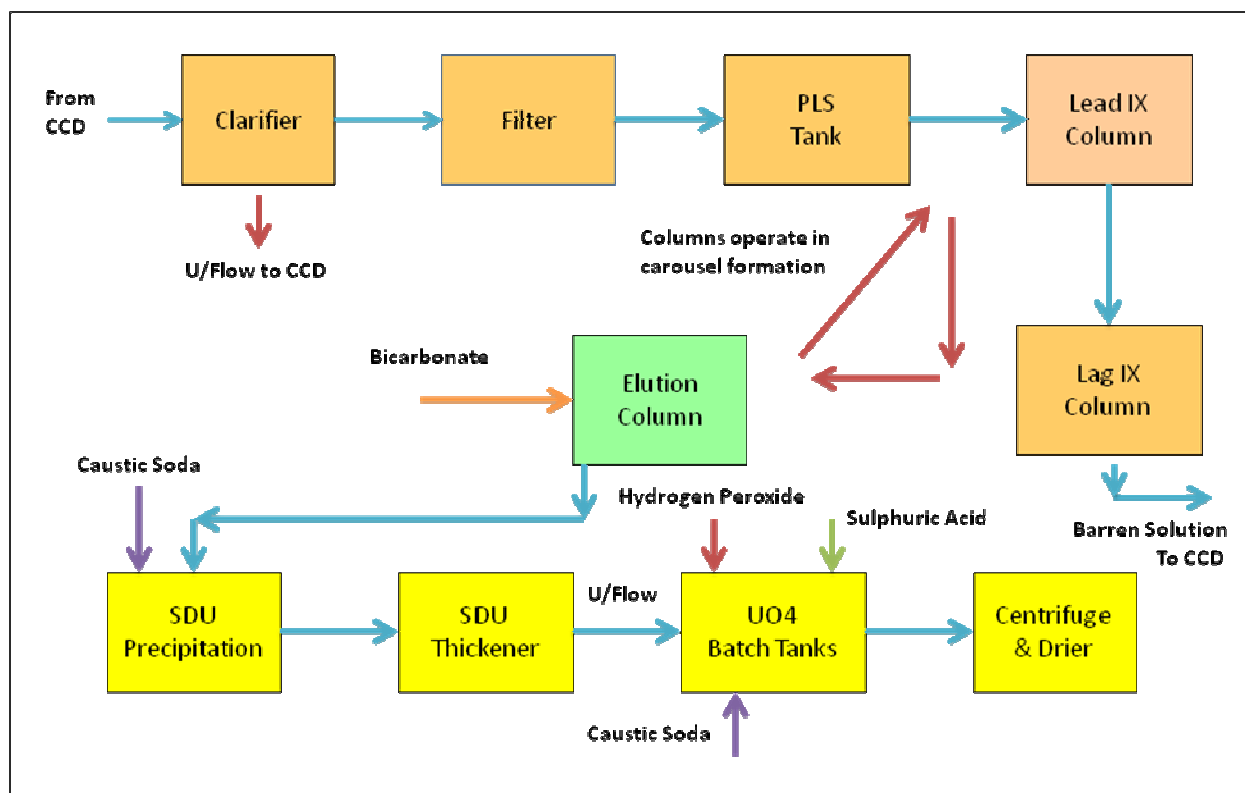


FIG. 10. Ion exchange and precipitation.

SDU is recovered by a thickener and then pumped to one of three Batch Precipitation Tanks where firstly the pH is adjusted using Sulphuric Acid and then UO_4 is precipitated by the addition of Hydrogen Peroxide. Caustic Soda is also added to control the pH during this precipitation process.

This product is then dewatered by a centrifuge, dried and drummed as UO_4 .

8. PLANT RAMP UP

The ramp up to nameplate production was hampered early on by some mechanical and process issues all of which required technical solutions to be developed.

The variability in material characteristics within the ore body can be quite extreme particularly with depth. The friability of the ore changes as does the grain size distribution. The main impact of this is in the scrubbing and screening plant where the mass split to “Barren Solids” can change dramatically. This can result either in a reduction of the up-grade ratio (low mass rejects to Barren Solids) as a result of excessive fines in the feed, or an increase in Barren Loses as less friable material exhibits poorer breakage characteristics and high grade material reports as screen oversize.

Excessive fines can also cause poor thickener settling characteristics in the pre-leach (have to reduce throughput) or the CCD (impacts on wash efficiencies).

The alkaline leach circuit is now operating at 92–95% efficiency but to achieve this consistently it was necessary to install additional heating capacity as fluctuations in daily and seasonal temperatures could impact on leach efficiency.

The failure of the original leach tank linings was a major event as the lining blocked the heat exchangers resulting in severe damage to the units. A number of engineering and operational changes have been implemented which prevent a similar event, and new lining materials have been successfully installed on the tanks.

The importance of a clear PLS on IX capacity and performance was demonstrated many times early on as poor settling in the CCD and Clarifier resulted in overloading of the final polishing filtration stage causing excessive back-washing. IX performance also suffered as a consequence of excessive fines clogging the fixed bed columns.

Finally, the precipitation chemistry was shown to be extremely sensitive to a number of physical and chemical conditions which could potentially impact not only on product impurity levels but also on the product particle size and its subsequent dewatering.

9. STAGE II EXPANSION

A Stage II expansion is currently being constructed with all facilities scheduled for completion by the end of June 2009. The target is to reach a production level of 3.7Mlbs/annum.

This expansion considered the introduction of a Resin in Pulp plant either as a scavenger circuit or as a primary recovery system. The final decision however was to settle for an expansion to the CCD, IX and product drying facilities as indicated below (see Fig.11).

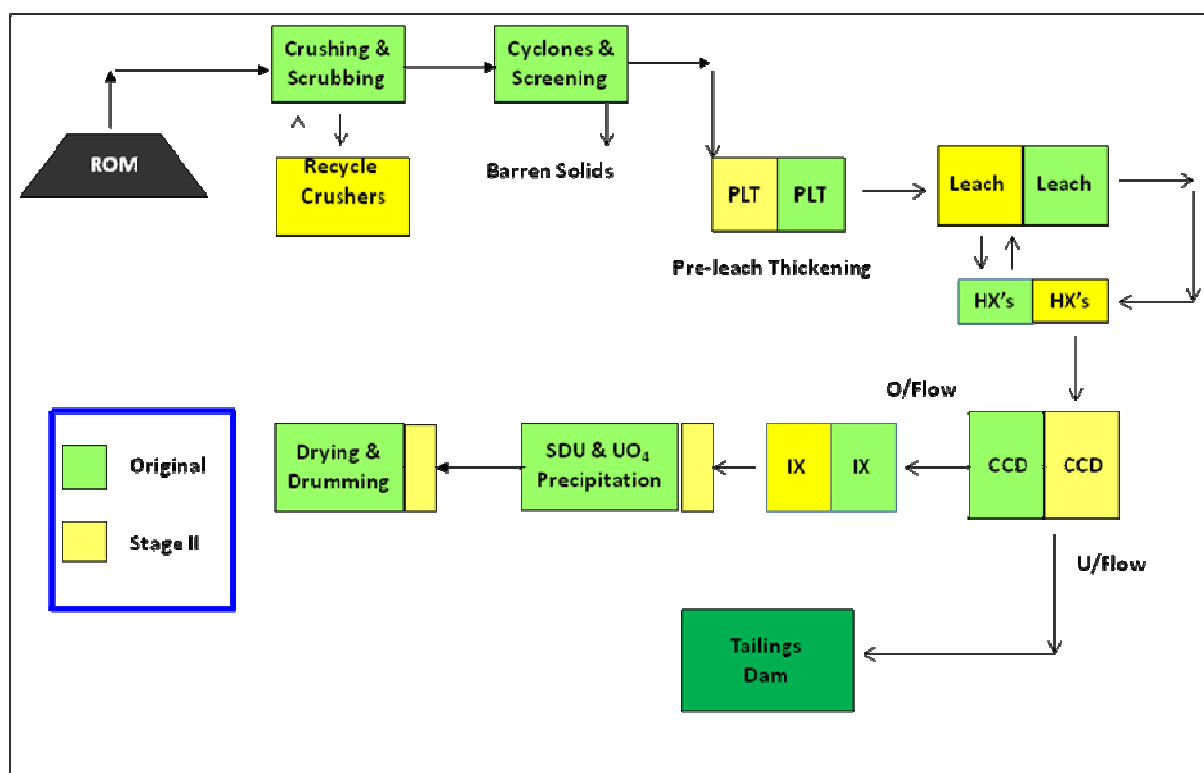


FIG. 11. Stage II expansion flowsheet.

In designing this expansion and sizing the new equipment cognisance was also taken for the potential of a further expansion in 2010. The timing and extent of this expansion is due to be announced in June.

During the past 12 months, the RIP option has been further evaluated with the establishment and operation of a pilot plant on site (the adsorption circuit supplied by Kemix of South Africa and the Elution circuit by CleanTeq of Australia).

As well as RIP, an alternative heat recovery system is to be piloted and alternative IX column systems are being evaluated.

EXPERIENCE GAINED FROM THE FORMER URANIUM ORE PROCESSING AND THE REMEDIATION OF THE LEGACY SITE IN HUNGARY

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Abstract

Uranium explorations in Hungary started 1953. By 1957 the uranium ore reserves were confirmed and the feasibility of mining in the Mecsek Mountains demonstrated by opening the first shaft. In 1962 the mill was built. The mining and processing of the uranium ore were terminated in 1997 mainly on economical reasons. The remediation of the site has started immediately and had been practically finished in 2008. The paper summarises the remediation work, and some lessons learned from the former mill practice, and from the remediation activity.

1. INTRODUCTION

The uranium exploration-related works were initiated by Professor S. Szalai and his colleagues in 1947, when they started the investigation of the radioactivity in some coal mines. Nevertheless the uranium prospection started only after an agreement was signed between the Hungarian and Soviet Government on uranium exploration work in 1952. Soon after this event some Russian expert groups arrived in Hungary, one of them worked on the southern slope of the MECSEK Mountains, where they (geophysics Ms. Csuprikova and Mr. Puharszkij) detected a rather huge radioactive anomaly. By the further exploration works with digging trenches, shafts up to 5–15 m the presence of uranium in elevated concentration and even industrial grade uranium ore on the site has been proven.

The complex work of the geologists, mineralogist, geochemists and geophysics led to the conclusion that the uranium was found in the upper Permian geological set in **greyish-green sandstone**, which was called productive set later on. The ore was found in form of lenses.

Uranium exploration works were undertaken in many part of the country. Though some elevated concentration of the radioelements have been detected in many places, small occurrence beside the MECSEK were found only in Miocene set at village Dinnyeberki, 30 km from MECSEK occurrence. There one in situ leaching test was undertaken, but because of the low permeability of the host rocks the test was unsuccessful. Only underground mining was developed. During the life time of the mine approximately 1 200 km of underground tunnels were excavated with five shafts, two shafts (No. IV and V) exceeded 1 000 meters. The overall production, including the ore export reached approximately 21 000 t of U and generated approximately 50 million tonnes of waste rock. There was no backfilling of workings.

The run-off-mine ore (28 million t) was radiometrically sorted. Using this method app. 8.5 million t of waste rocks (rejects, 30%) with low uranium content (average 118 gU/t) was separated and removed from the ore and placed on waste rock piles ore partly used (with higher uranium content) for heap leaching. This method of upgrading played an important role in the ore processing.

In the mill 18.8 million t of ore (U~ 0.10%) has been processed with acid leaching.

Alkaline leaching (7.2 million t) accompanied the conventional ore processing. This method was used for low-grade ore (U~150 g/t) and for some rejects from the radiometric sorting station. Experimental ISL field has been operated for a limited time for Miocene formations.

2. THE MOST IMPORTANT LEGACIES

The total area of the legacy site is app. 216 ha. App. 44 ha area was contaminated with radioelements.

2.1 Mines

During the mining 5 mines were constructed with total cavity volume of app. 18 million m³. In one of them the water level must be kept below 106 m under the surface for protection of the nearby drinking water aquifer. The others are under natural flooding. It is believed that the former mines will be filled up by 2018 and the water from the relevant adit has to be treated for removing of the uranium.

2.2. Mine waste rocks

Altogether app. 12 million t of mine waste rocks on three large waste rock piles (WP N1, 2, 3) and six smaller ones have been left behind with app. 550 t of uranium.

The WP N3 has been used for placing the different debris from the demolition of the former industrial buildings and contaminated equipment, contaminated soil from clean-up activity obtained during the remediation works. It is believed that this area is well protected from hydro geological point of view because it situated above one former mine from which the water is continuously pumped to the surface aiming at the protection of drinking water aquifer. Residues from heap leaching have been relocated also on WP N3 area, together with sludge from water treatment stations. The total area of the waste rock piles is app. 82 ha.

2.3. Rejects from radiometric upgrading

Altogether app. 8.5 million t of wastes have been separated by radiometric sorting machines. Some part of the rejects was treated by heap leaching but most of it was just placed on the WP N3. The estimated uranium content of these wastes amounted to 1 000 t.

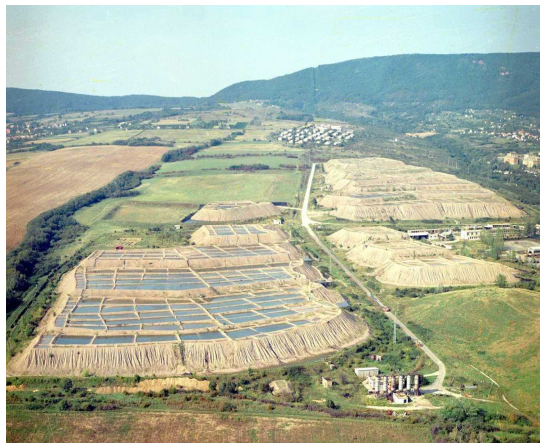


FIG. 1. The heap leaching site (Site N2).

2.4. Heap leaching residues

There were two separate heap leaching sites (47 ha). Altogether 7.2 million t rock (low-grade ore+ rejects from radiometric upgrading) has been processed. The residues were relocated to the WPN3 area. The uranium content of these residues is app. 400 t. The heap leaching site is shown in the Figure 1.



FIG. 2. The mill and heap leaching area (Site N1) in front of the mill.

2.5. The mill

There was only one mill using acid leach technology. The uranium rich elutes from heap leaching were processed further in the mill too. The mill together with the radiometric station occupied 37 ha. In the mill 18.8 million t of ore was processed during the life time of the mill. At the head of the mill the radiometric sorting station was operated. The mill site is

shown in the Fig. 2. In the front of the mill the heap leaching of the low-grade ore and rejects from the radiometric station can be seen.

2.6. Mill tailings

The mill tailings have been placed on two tailings ponds sites (Fig. 3). The total mass of the accumulated tailings is app. 20.4 million t containing app. 1 380 t of uranium. The volume of discharged tailings water was app. 32 million m³, with app. 22 g/l TDS (mainly magnesium sulphate + sodium chloride), which has partly seeped into the groundwater from the tailings ponds. the area occupied by tailings is app. 160 ha.



FIG. 3. The two tailings ponds with free water.

2.7. Roads

The most part of the roads were contaminated, so app. 44 ha area was subject to the cleanup.

3. SUMMARY OF THE REMEDIATION WORKS

The main important goals of the remediation were:

- Decreasing the radiological impact from the legacies to acceptable level;
- Developing a drinking water protection system mainly by removing of the contaminated subsurface water in the vicinity of the tailings ponds.

To meet the above mentioned goals following actions have been done.

3.1 Closing the mines

All fuel-contaminated soil and rock were removed (4 347 m³) and partly treated microbiologically on the surface (3 255 m³ rock). The shafts were backfilled mainly with waste rocks found on the site. Shafts towers (N4, N5) have been blasted, together with some

facility buildings. Most part of the waste rocks earlier deposited around the towers was hauled on WP N3. The the mine cars were sold as scrap materials for blast furnaces.

3.2 Remediation of the mill site

The mill was demolished, some equipment were decontaminated and sold, but most of it was just placed on the storage area for contaminated materials formed on the WPN3. App. 443 thousand m³ of contaminated soil was replaced by non-contaminated earth. The site is released for unrestricted reusing. The volume of debris from the demolishing of the mill amounted to 74 thousand m³.

3.3 Waste rock piles

Some smaller WPs were relocated on WP N3. This waste rock pile was used as a general storage area because of its favourable hydro-geological position (WP N3 is situated above the mine cavities of mine N1, from which the mine water is continuously removed). Waste rock piles are covered with non-contaminated earth (1–1.5 m).

The remediated WP N3 is shown in the Fig. 4.



FIG. 4. The remediated waste rock pile N3. On the top the still operating storage area (for water treatment sludge) can be seen.

Contaminated seepage collected by the belt ditches are directed to the mine water treatment station for removing of the uranium a minor part of the seepage is treated in place on anion exchange columns.

3.4 Remediation of the heap leaching sites

The heap leached residues were relocated onto WP N3. The residues were mixed with lime (app. 2 kgCaO/t) for mitigation of the migration of uranium. The here and there found contaminated groundwater is seeped out and treated in place or directed to the mine water treatment station for treatment.

3.5 Remediation of the tailings ponds.

The most costly work was the remediation of tailings ponds (app. 40% of total cost spent for remediation). The first step was the elimination of the free water after its treatment

for removing of radium. Special task was the stabilization of the very weak slime zone. This task was solved utilizing the experience of Wismut GmbH and experience gained in the frame of Phare project.

Multilayer cover design was selected for covering. The total thickness of the cover is 1.5-1.6 m, comprising of clay layer. The calculated infiltration rate is app. 30–50 mm/a.

The two remediated TPs are shown in the Figs 5 and 6. The effective dose for population living not far from the tailings ponds area has decreased bellow 1 mSv/a after covering of the tailings piles.



FIG. 5. Remediated tailings pile N1 (remediated in 2008, ~100 ha).



FIG. 6. Remediated tailings pile N2 (remediated in 2005, ~60 ha).

4. WATER QUALITY PROTECTION SYSTEMS

In this respect two tasks had to be solved:

- Removing of uranium-contaminated mine water from one mine having direct hydrological connection with drinking water aquifer and its treatment together with other uranium contaminated waters (seepage from waste rock piles);
- Extracting of groundwater contaminated with tailings water seeped into the subsoil from the tailings piles.

For treatment of mine water (from mine N1, other former mines are under natural flooding) and other uranium-contaminated waters the existing former water treatment station

was reconstructed. Additionally a small end-product facility was built allowing obtaining uranium in form of uranium peroxide which is sold. In the mine water treatment station app. 0.5 million m³ of mine water (U~4 mg/l) is being treated annually.

Groundwater protection system consists of extracting wells (27) and drainage built around the tailings ponds (3.2 km long). The extracted water is discharged directly into the receiver (deeper groundwater) or is treated with lime milk for decreasing of the TDS (shallow groundwater). For treatment of groundwater a water treatment station was built on the tailings ponds site.

From 2001, app. 3.4 million m³ of groundwater has been extracted with app. 44 000 t of TDS (mainly MgSO₄ and NaCl). The water extraction activity still has to be continued because the most part of the solute seeped into the groundwater is still can be found on the site.

5. EXPERIENCE GAINED FROM THE ORE TREATMENT

In this paragraph some important technological aspects will be mentioned which could be taken into account if comparing different flow sheets compared.

5.1. Radiometric sorting

This process step has proved to be very effective for separation of the very low grade rock pieces. Using this method app. 60% of original mass was removed from the feed. The uranium losses with the rejects were less than 5%. Even some part of this uranium subsequently was removed by heap leaching process.

5.2 Leaching

The leaching process was continuously developed. The stepwise processes when the most refractory ore can be leached at high free acid concentration provide high uranium recovery but needs elevated acid consumption, but such process is suitable for treatment of brannerite- containing ore, too.

5.3. Recirculation of chloride bound on anion exchange resin

It was demonstrated that the chloride bound on anion exchange resin during the elution process when sodium chloride + hydrochloric acid is used can be easily removed in form of hydrochloric acid suitable for elution if washed with sulphuric acid solution. Using this type of chloride recycle (two columns are needed for this step) the consumption of commercial hydrochloric acid was decreased to 25–30% of the original one. Evaluation of the using such chloride recycle is strongly recommended if the elution is being carried out with chloride containing solutions.

6. EXPERIENCE GAINED FROM THE REMEDIATION

6.1. Heap leaching

It seems that the reusable pads are more reasonable than the used continuously expanding ones, first of all for decreasing of used land for heap construction. The land contamination also can be reduced using the same pad for leaching and hauling the residues to the final disposal area.

After relocation of the residues groundwater contamination was found mainly along the pipe lines and pumping stations. This mean that the solution transporting system must be more carefully design than was earlier.

6.2. Tailings ponds and their vicinity

The most important lesson is that the barren pulp leaving the mill must be neutralized very carefully. In our case the dissolved from the ore magnesium remained in the disposed tailings water in form of magnesium sulphate. This regrettable fact was accompanied by relatively high water conductivity of the underlying soil beneath the tailings ponds. These two facts resulted in grate infiltration rate of the tailings water which led to the huge pollution of the groundwater in the vicinity of the tailings ponds.

The volume of the contaminated groundwater most likely exceeds 20–30 million m³, which is can cause remarkable pollution in drinking water aquifer. Therefore the localization and removing of this water is essential for the protection of drinking water quality nearby the tailings piles site.

In respect of covering, it is an important lesson that the length of slope without braking and the diverting channels should be planned also very carefully to avoid water erosion taking place at first period of covering.

6.3 Mapping of the site

In many cases originally not known smaller contaminated areas were found. This caused sometimes great problems both in respect of the planned work and placing the “found” contaminated soil. To avoid such problem the sites have to be very carefully mapped at the beginning of the planning of the remediation work.

7. SUMMARY

The remediation of the site has been finished, but the groundwater protection activity must be continued according to the original plan. Reason of this is the fact that huge volume of groundwater around the tailings ponds is still contaminated. It is expected also that the mine water has to be treated because of its high uranium content (4–10 mg/l).

It is worth mentioning that the company developed so called integrated water management system allowing collecting all waters to be discharged in one common discharge basin. As a result of this the water discharge is easily and well controlled in respect of both the volume and composition.

Beside the water treatment issues the long-term monitoring has to be continued too.

ENVIRONMENTAL AND REGULATORY ISSUES
(Session 5)

URANIUM IN AQUATIC SEDIMENTS; WHERE ARE THE GUIDELINES?

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Abstract

Sediment data has been collected on and around the Ranger uranium mine for over 20 years. This included studies such as annual routine monitoring of metal concentrations, adsorption-desorption conditions, phase associations, transport mechanism, release potential, bioaccumulation and bioconcentration etc. Building on this, performance-based monitoring of the sediments from on-site water bodies was undertaken to ascertain the spatial and temporal distribution of contaminants as a basis to determine ecological risks associated with the sediments which in turn underpins closure planning. Highlights of these studies are interpreted using an ecological risk assessment approach. Ideally interpretation of aquatic sediment contamination in Australia is guided by the national guidelines for water quality and a weighted multiple lines of evidence approach whereby the chemistry of sediments is compared with reference and guideline values and predictions of bio-availability, and biological effects data allows cause and effect relationships to be derived. However, where uranium in aquatic sediments is concerned there is a lack of national (Australian) and international guidelines that are applicable to tropical sediments and the biological effects data available are limited or confounded by other variables. In the absence of clear uranium guidelines for sediments an internationally reported “Predicted No Effect Concentration” (PNEC) for uranium in temperate sediments was used as a “pseudo-guideline” value to identify sites with concentrations that might present an environmental risk and that should be further investigated. The applicability of the PNEC to the tropical Ranger site was understandably questioned by stakeholders and peers. The issues raised highlighted the need for international guidelines for uranium in aquatic sediments for tropical and temperate climates and an internationally accepted approach for deriving same.

1. INTRODUCTION

Water management at Ranger uranium mine in tropical northern Australia (Fig. 1), involves segregation of waters according to quality. Good quality waters from relatively undisturbed areas are passively released via retention ponds, natural creek lines and billabongs. Poorer quality waters that have contacted stockpiles are treated in a plant or passed through constructed biological wetland filters to passively reduce the concentrations of metals, including uranium and radium before their release off-site. The concentration reduction is achieved principally through partitioning of the metals from the water column into the sediments, resulting in contaminant build-up in the sediments.

Environmental Requirements (ERs) for Ranger, enshrined in both Commonwealth and Northern Territory regulations, specify environmental objectives to be achieved during the life of the mine and following closure. While the ERs describe the broad objectives for rehabilitation, specific criteria are required to determine whether these objectives are met; including criteria to guide the rehabilitation of aquatic sediments contaminated by uptake of uranium and heavy metals.

Radiological criteria for the site are being established separately based on predictive modelling for radiation doses to humans [1]. However, the risk of uranium to non-human biota is related to its chemical rather than its radiological toxicity, therefore the ecotoxicity of the sediments needs to be assessed.

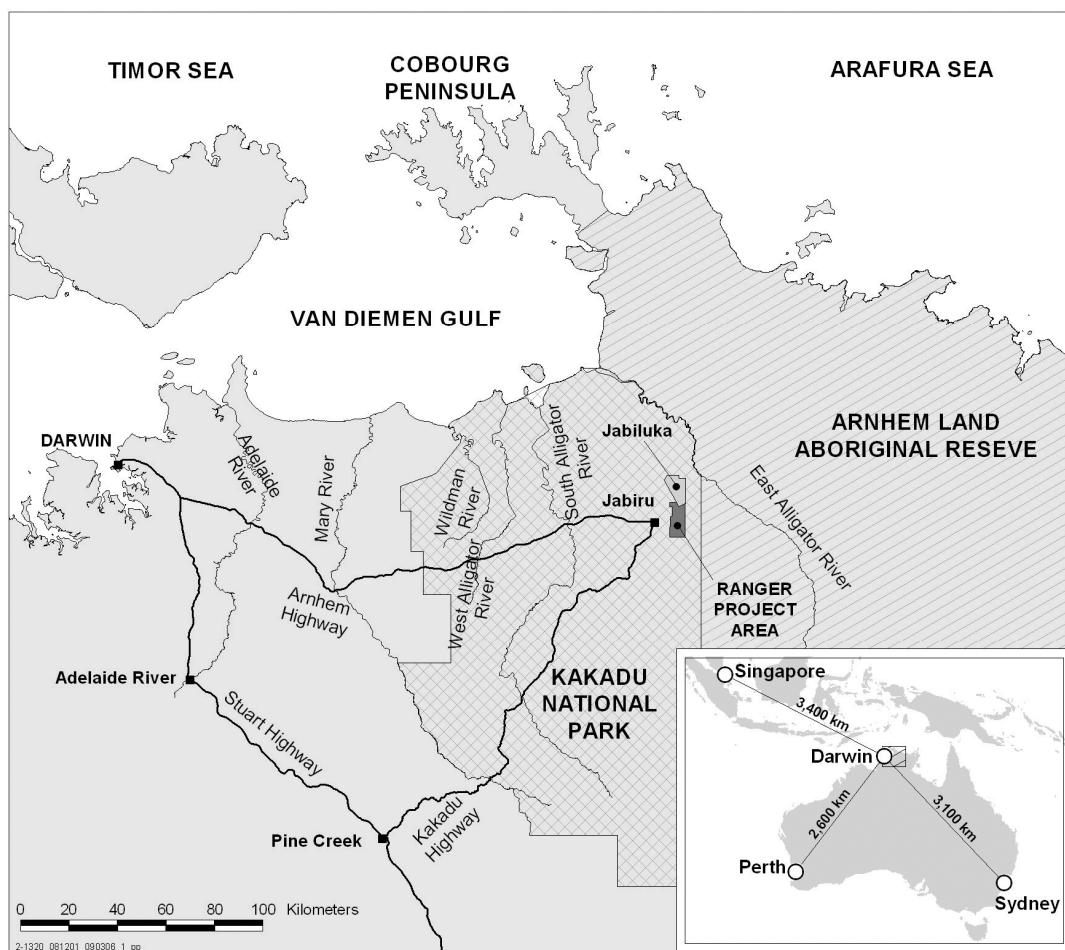


FIG. 1. Location of Ranger uranium mine.

1.1. Sediment monitoring at Ranger

Energy Resources of Australia Ltd (ERA) and the Commonwealth's Supervising Scientist Division (SSD) have conducted monitoring and research of Ranger mine and its surrounds for more than two decades. While the majority of the research and monitoring has focussed on the water column, there is a substantial body of work covering the characterisation and behaviour of sediment contaminants including concentration data gathered during more than 20 years of statutory prescriptive monitoring.

In keeping with changing trends of sediment assessment [2] [3] and moves to performance-based rather than prescriptive regulation, the prescriptive statutory monitoring program was changed to a less regular but targeted assessment of the impact of mining activities on sediments in billabongs, water retention ponds and constructed wetlands.

The zones of known sediment contamination, based on operational understanding and previous research and monitoring, are those associated with the Retention Pond 1 constructed wetland filter (RP1WLF) and the Corridor Creek constructed wetland filter (CCWLF) (Fig. 2). Sites with potentially affected sediment from contact with mine runoff include Georgetown Billabong, Coonjimba Billabong, and Retention Pond 1 (RP1). Therefore, these water bodies have been the focus of studies since changing from statutory to project based

monitoring. Highlights of these studies are interpreted using tier 1 of the national sediment assessment approach.



FIG. 2. Waterbodies at Ranger uranium mine.

2. SEDIMENT ASSESSMENT METHODS

Interpretation of aquatic sediment contamination in Australia is guided by the national guidelines for water quality [3] tiered assessment approach coupled with a weighted multiple lines of evidence approach [4]. The framework approach is similar to that used in other countries (eg; Canada and USA) whereby an initial assessment is by comparison with a sediment or environmental quality guidelines (SQG or EQG) followed by higher level studies

at each tier if the guideline is not met. Higher level studies include predicting bio-availability through to collection of biological effects data to allow cause and effect relationships to be derived (Fig. 3).

In 2000, there were too few reliable Australian or New Zealand sediment toxicity studies to underpin (bi)national SQG derivation. Therefore, like many countries Australia and New Zealand refined the USA National Oceanic and Atmospheric Administration “effects range-low” and “effects range-high” values [5] as low and high interim sediment quality guidelines (ISQG-low, ISQG-high) [2].

However, where uranium in aquatic sediments is concerned, there is a lack of international and therefore national (Australian) guidelines to use in the first tier of assessment. Further, biological effects data that are available for tropical sediments are limited or confounded by other variables. In the absence of clear uranium SQG an internationally reported “Predicted No Effect Concentration” (PNEC) for uranium in temperate aquatic sediments [6] was used in this study as a “pseudo-SQG” value to identify sites with concentrations that might present an environmental risk and that should be further investigated.

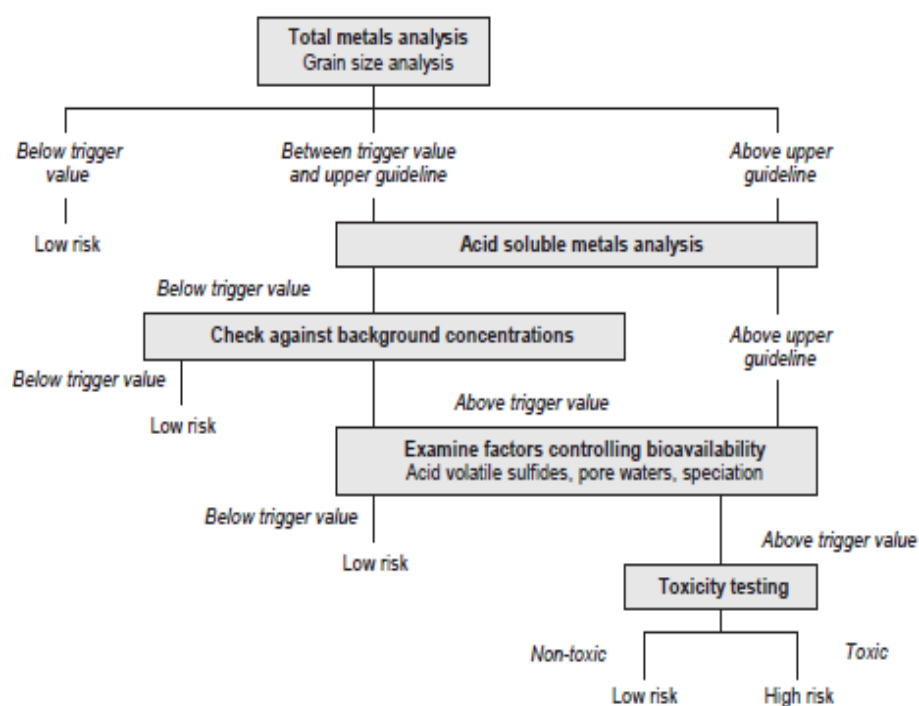


FIG. 3. Tiered risk assessment of sediments approach [4].

3. RESULTS AND INTERPRETATION

The results of sediments from onsite waterbodies, sampled between 2003–2006, are presented here against the Australian SQG for several metals and the temperate PNEC guideline for uranium in freshwater sediments. Additional methods of interpretation (e.g.; acid extractable metals, comparisons with historic data, and phase associations from historic work) are not included in this paper.

3.1. Wetland filters

As expected the sediments from the constructed wetland filters had the highest metal concentrations. The surface sediments were enriched over deeper sediments with values increasing over time with continued use of the filters to polish U, and to a lesser extent other metals from passing waters (Fig. 4). While some of the difference between the 1997 and 2003 metal loads can be attributed to differences in methods, the increase is not unexpected given the efficiency (> 90%) of uranium removal from the passing water during the period [7]. Of the metals determined, only U appears in concentrations that exceed the first tier guideline trigger, as was the case for all sites (Fig. 4).

A similar temporal and spatial pattern was seen in sediment cores from the younger CCWLF, though the concentrations were lower consistent with fewer years in service as a treatment system.

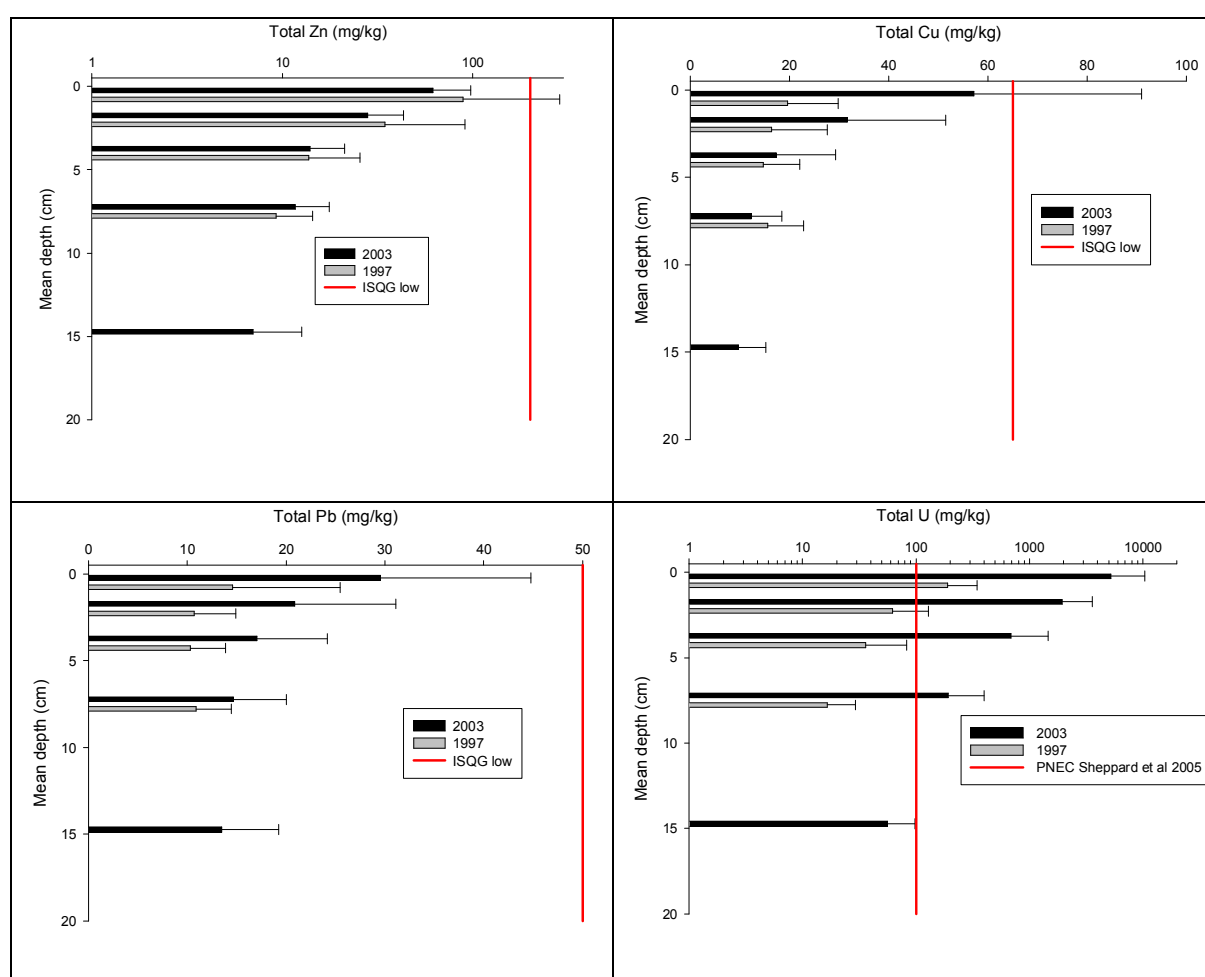


FIG. 4. Total (1997 < 5 mm aqua regia; 2003 < 2 mm reverse aqua regia) metals with sediment depth in the RPI wetland filter (error bars = 1 SD) showing ISQG low (Zn, Cu, Pb) and U PNEC guidelines.

Retention pond

Sediments from RP1 showed variable concentrations of U with some cores showing very little change down the profile (eg. Site 6, Fig. 5) — indicating that concentrations were natural — and some showing elevated surface concentrations equal to temperate PNEC (e.g. Site 16, Fig. 5). The sodium acetate extractable fraction¹ (“HAc” in Fig. 5), representing the easily leachable/reactive and therefore potential bioavailability, fraction accounted for ~ 50% of the uranium present in the surface layers. Although the concentrations in RP1 are much lower than in the constructed wetland filters, in some cores they are an order of magnitude higher than reference site billabongs which are reported [8] to have total U concentrations of about 10 mg/kg dry weight of which only about 20% is extractable by an acetate extraction.

RP1 is earmarked for removal upon closure, to be replaced by a natural drainage system similar to the pre-mining ephemeral creek. However, if any sediments are to remain in-situ in the creek line an understanding of their potential biological effects is required. This could however be more costly than removing and replacing the sediment.

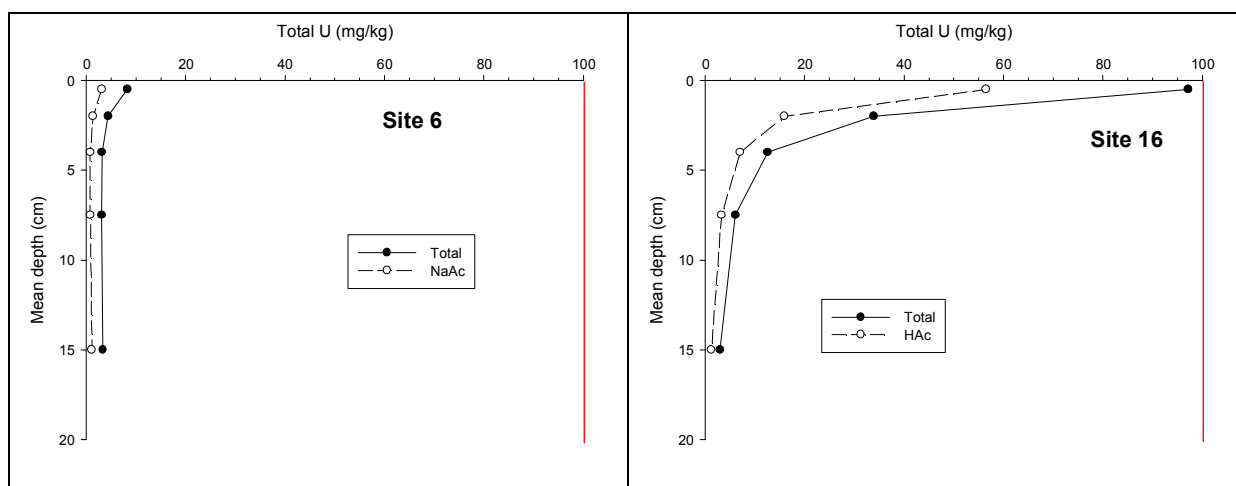


FIG. 5. Total (< 2 mm reverse aqua regia) and extractable (sodium acetate) uranium concentration with sediment depth in RP1.

¹ 1M sodium acetate adjusted to pH 5.5 (1:5 soil solution M/V).

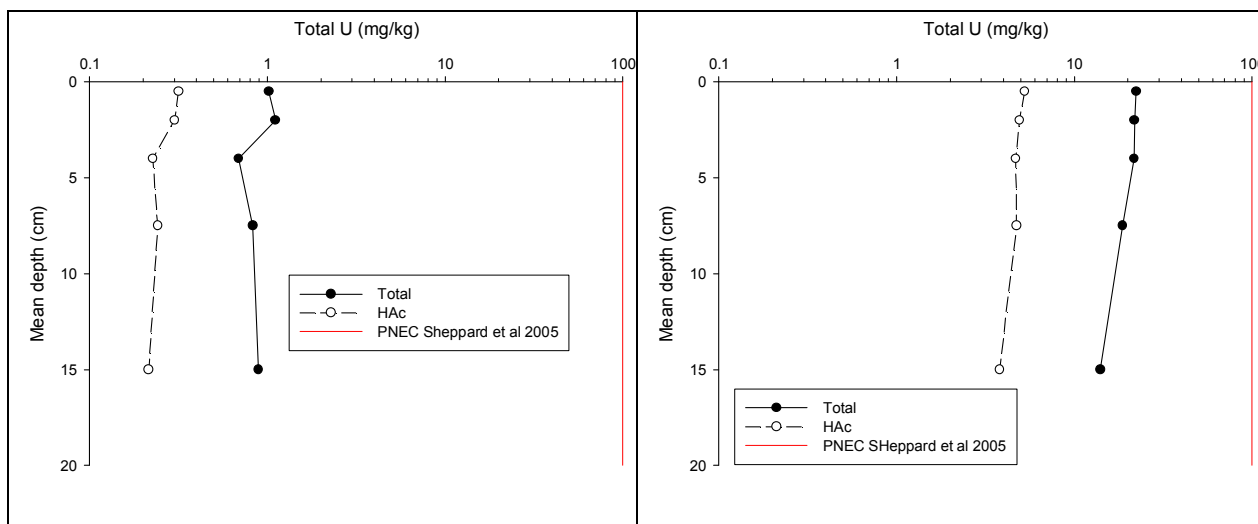


FIG. 6. Total (< 2 mm reverse aqua regia) and extractable (sodium acetate) uranium concentration with sediment depth in Georgetown Billabong.

3.3 Natural billabong

The metal concentrations in all Georgetown Billabong cores is very low (Fig. 6). The total U is ~ 1–20 mg/kg throughout cores. The sodium acetate exchangeable and total phases of each metal follow almost identical trends. The sodium acetate exchangeable fraction is relatively low compared to those in the other water bodies. Uranium extractability is between ~ 20–35%, similar to reference site billabongs.

Georgetown Billabong does not have high loads of metals passing through it as the wetland filters do and metal concentrations in the sediments remain very low. The metal concentrations are similar but slightly increased compared to those in the off-site reference water bodies. The low extractability is related to the U being close to natural background concentrations, whereas the U wetland filters (and in some areas of RP1) is anthropogenically enriched and therefore more readily extractable and potentially more bio-available.

The use of the PNEC for temperate species [6] in the absence of an Australian uranium SQG drew criticism from scientific peers; leaders in the field of sediment toxicity and guideline derivation who also highlighted problems with the few other studies of uranium sediment toxicity, suggesting that there were no suitable guidelines or studies from which to derive suitable guidelines for U toxicity in the north Australian tropical freshwater sediments.

The major issues cited [9] for the various studies related to:

- The ecology-based guideline of 100 mg U/kg (species abundance and richness) was derived from sediments that had co-occurring contaminants that may have contributed to observed impacts, but effects to single species have been observed at 9 mg U/kg;
- Use of species that are relatively insensitive to metals (e.g. Use of species with a Lowest Effect Observed Concentration (LOEC) of 4 mg Cu/L, whereas many freshwater species have loecs <0.1 mg Cu/L);

- Exposure conditions not environmentally relevant due to inadequate sediment spiking procedures resulting in potentially unrealistically high dissolved uranium concentrations (unmeasured);
- Use of nominal (unmeasured) concentrations, no measurements of exposure (e.g. Uranium partitioning between sediment and water, and range finding (not definitive) tests; and
- Differences in sensitivities between tropical and temperate species.

Published reports on U sediment toxicity or biological effects use various methods (e.g. [10] [11] each with limitations [12]. Given the lack of agreement on suitable approaches amongst the scientists, can we expect regulators, environmental managers and policy makers to identify which study provides the most appropriate sediment quality guideline for an initial risk assessment of their site?

While the high conservation status of the area surrounding Ranger means that it is necessary to derive site specific guidelines for that site, this is an imposition that many companies and governments could not afford and may not need. There needs to be internationally accepted U sediment quality guidelines (temperate and tropical at least) to use as a first level risk assessment trigger value. Agreement on how to derive such guidelines and the correct procedures to use for U toxicity testing is needed to ensure data being collected in the interim will be acceptable to all parties for the end purpose of deriving such a guideline. Such an approach will require an international commitment and collaboration, be it of industry collaborators or associations, academia and/or multinational governing entities, and should be facilitated by a recognised organisation of international status (e.g. UNEP, WHO or the World Bank).

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THE CANADIAN NUCLEAR SAFETY COMMISSION COMPLIANCE PROGRAM FOR URANIUM MINES AND MILLS

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Abstract

The Canadian Nuclear Safety Commission (CNSC) is the principal nuclear regulator in Canada. The CNSC is empowered through the Nuclear Safety and Control Act (NSCA) and its associated regulations, to regulate the entire nuclear cycle which includes: uranium mining and milling, uranium refining and processing, fuel fabrication, power generation and nuclear waste management. A CNSC uranium mine licence is required by a proponent to site, prepare, construct, operate, decommission and abandon this nuclear facility. The CNSC licence is the legal instrument that authorizes the regulated activities and incorporates conditions and regulatory controls. Following a favourable Commission Tribunal decision to issue a licence to authorize the licensed activities, CNSC develops and executes a compliance plan of the licensee's programs and procedures. The CNSC compliance plan is risk-informed and applies its resources to the identified higher risk areas. The compliance program is designed to encourage compliance by integrating three components: promotion, verification and enforcement and articulates the CNSC expectations to attain and maintain compliance with its regulatory requirements. The licensee performance is assessed through compliance activities and reported to the Commission to inform the licensing process during licence renewal. The application of the ongoing compliance assessment and risk management model ensures that deviations from impact predictions are addressed in a timely manner. The Uranium Mines and Mills Division of the CNSC are preparing to meet the challenges of the planned expansion of their Canadian uranium mining industry. The presentation will discuss these challenges and the measures required to address them. The Uranium Mines and Mills Division (UMMD) have adopted a structured compliance framework which includes formal procedures to conduct site inspections. New UMMD staff are trained to apply the regulations to licensed sites and to manage non-compliance. The development of project management skills helps ensure an integrated program approach to manage risks at these nuclear facilities. The training initiatives currently in place or under development to meet the technical skills development of new staff and the use of experienced staff for mentoring and knowledge transfer will also be discussed.

1. INTRODUCTION

The Canadian Nuclear Safety Commission (CNSC) is the principal nuclear regulator in Canada. The CNSC is empowered through the Nuclear Safety and Control Act (NSCA) and its associated regulations, to regulate the entire nuclear cycle which includes: uranium mining and milling, uranium refining and processing, fuel fabrication, power generation and nuclear waste management. The CNSC's mandate is to ensure that the use of nuclear energy in Canada is for peaceful purposes and does not pose an undue risk to health, safety, security and the environment. CNSC expects nuclear facilities to achieve high reliability performance because of the high level of public interest and the sophistication of this technology. The principal regulatory control is the licence. After uranium mine or mill licence has been issued, a risk-informed compliance program is applied to the approved licence application documents to verify compliance with regulatory requirements. This paper discusses the compliance program objectives, components, delivery and review.

2. WHO IS THE CNSC?

The CNSC is composed of Commission members appointed by the Governor in Council, Government of Canada and Commission staff. There are currently eight Commission members and 800 staff located in 11 different (headquarters, site and regional) offices across Canada. The staff is a multidisciplinary team of experienced professionals who specialize in technical and safety-related assessment, licensing and compliance. CNSC staff implements the policies of the Commission and makes recommendations to the Commission concerning licensing and other regulatory matters.

The Directorate of Nuclear Cycle and Fuel Regulation is the service line responsible for the regulation of uranium mining and milling, refining and fuel fabrication. The Uranium Mines and Mills Division (UMMD) is responsible for regulating uranium and mills and operates from a regional office located in Saskatoon, Saskatchewan.

2.1. Uranium mine and mill licences

The active Canadian uranium facilities are operated by two licensees:

- (a) Cameco Corporation, a private corporation based in Saskatoon Saskatchewan; and,
- (b) AREVA Resources Canada Inc., a subsidiary of AREVA France, also based in Saskatoon, Saskatchewan.

These two licensees operate three mills and four mining areas, involving five CNSC licences. These are summarized in Table 1.

TABLE 1. LIST AND STATUS OF URANIUM MINE/MILL FACILITIES IN CANADA

Site	Licensee	First Operating Approval	Current Status
McArthur River	Cameco	1999	Operating
Key Lake	Cameco	1983	Operating
Rabbit Lake	Cameco	1975	Operating
Cigar Lake	Cameco	---	Under construction — delayed due to underground flooding
McClellan Lake	AREVA	1999	Operating

Prior to any licence being granted, pursuant to the NSCA and its associated regulations, the CNSC must meet its obligations under the Canadian Environmental Assessment Act (CEAA). Paragraph 5(1)(d) of that Act stipulates that an environmental assessment (EA) must be carried out to identify whether a project is likely to cause significant adverse environmental effects, taking into account the appropriate mitigation measures. Only when such a determination has been made can any federal authority, including the CNSC, issue a permit or licence, grant an approval, or take any other action for the purpose of enabling the project to be carried out in whole or in part.

For the purposes of a uranium mine and mill licence renewal, the EA is reviewed by CNSC staff. Should the review conclude that the project remains within the scope of the previously assessed project, a further environmental assessment would not be required.

The Uranium Mines and Mills Division (UMMD) follows the CNSC's staged licensing process which proceeds progressively through site preparation and construction, operating, decommissioning and abandonment phases laid out in the Uranium Mines and Mills Regulations. At each licensing stage, the applicant is required to submit comprehensive details of the proposed design, impact assessments, and the manner in which the project is expected to safely operate. Under the leadership of the UMMD Project Officer, these submissions are reviewed by a multidisciplinary team of specialists which make up a Facility Assessment and Compliance Team (FAC Team). Subject matter experts include experts in geotechnical, engineering, hydrogeology, geochemistry, biological sciences, transfer pathway modelling, milling, mining, waste management, environmental impact assessment, radiation health physics, quality control and organizational management. In order to maximize the uniformity and consistency of compliance determinations, CNSC makes use of the dynamics of FAC Teams. CNSC staff's review determines whether the licence applicant is qualified and has made adequate provisions for the protection of the environment, the health and safety of persons, and the maintenance of national security and the measures required to implement international obligations to which Canada has agreed. If satisfied, the Commission may issue a licence that contains the appropriate conditions.

2.1.1. Uranium mine and mill licence

The UMMD licence is the legal instrument that authorizes the licensee to carry out the approved activities and to operate the nuclear facility. This document is approved by the Commission following a one-day or two-day public hearing process.

The licence specifies the approved term, the activities that are authorized and conditions related to general requirements, operations, modifications, nuclear substances and radiation devices, environmental protection, workers health and safety records and reporting, and safeguards.

The licence incorporates by reference in the licence application information stipulated in the regulations which set the boundary conditions and the operating limits of the nuclear facility. In addition, the licensee's commitments regarding environmental effects mitigation measures and any recommendations for a Follow-up Program are integrated into the licence and supporting documentation.

2.1.2. Approved activities and facilities

Although the form of the licensee's application for a uranium mine and mill licence is not stipulated in the CNSC's regulations, the UMMD has adopted an approach which organizes the applicant's supporting information using a hierarchy of documents. This hierarchy follows the structure of policy-program-procedure, where the level of detail becomes more specific with the documents at the lowest tier. Several advantages have been realized with this approach which includes:

- A more efficient and systematic review of the licence application to verify that all the regulatory requirements for an application have been met;
- A sound basis for the mining facility compliance program;

- Better understanding of the mining facility's licensing basis for the CNSC's project officer and specialist staff; and
- Logical definition of the delegation of authority to approve or accept changes to the licensing basis by CNSC staff.

The Mining Facility Licensing Manual (MFLM) has been the principle document in the licensing of uranium mines and mills since 1992. The MFLM is the top level document that is referenced in the licence as Appendix B and provides a road map to all licensing documentation and through which a direct regulatory link to the implementing programs, measures, procedures and work instructions is provided.

The MFLM defines the physical works and summarizes the activities to be carried out at the facility; limits the scope of the activities by specifying the operating and nuclear substance possession limits and commits the facility to operate according to specified quality management, environmental and health and safety policies. A typical UMMD licence documentation structure is provided in Figure 1.

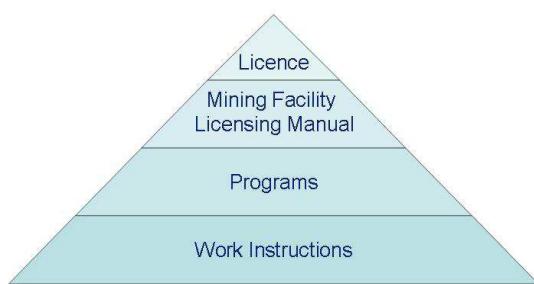


FIG. 1. A typical uranium mines and mills licence documentation structure.

The MFLM is the regulatory basis for the Compliance Program applied to uranium mines and mills. The MFLM incorporates into a single document the Safety and Control Areas identified in the regulations. The risk management systems that are used to manage undue risk to the CNSC mandated areas including the mitigation measures, limitations and regulatory controls are described in detail. The MFLM and integrated programs and procedures are the basis for the verification component of the Compliance Program.

3. SAFETY AND CONTROL AREAS: RISK MANAGEMENT

The CNSC requires that, in order to appropriately protect the public, the worker and the environment, licensees establish, implement, assess, and continually improve a management system in which safety is the highest priority. Once a licence has been issued, the CNSC verifies the implementation of the management system, and especially the performance of the licensee in delivering its key processes and programs.

In order to evaluate the overall licensee compliance and the safety performance, the CNSC has broken down licensee operations into a systematic list of safety and control areas. The evaluation is systematic and risk arguments are used to justify the amount of resources spent in each area, program or process.

The licensee's performance is evaluated by ratings on Safety and Control Areas and reported to the Commission in the production of Commission Member Documents for licence renewals or amendments. Evaluation results are used to communicate to Commission Members and other stakeholders the status of compliance by a licensee to its current licence, its significance in terms of safety and any risk of continued operation.

The evaluation integrates all of the data gathered and reviewed by CNSC staff from field inspection activities and desktop reviews. The integration of findings also serves to refine the next planned inspection cycle, and to review any further areas that show potential risk.

3.1. Safety and control areas

The Safety and Control Areas are pre-defined structures used by CNSC staff in the licensing review and approval of a uranium mine and mill. These are aligned with the program structure contained in the Mining Facility Licensing Manual. Initially, a generic set of programs are applied to each mining facility at the beginning of the licensing stage (site preparation and construction) and are augmented with regulatory controls, limits and mitigation measures as the risk of the facility operation increases. At the operating stage, risk management systems become more site specific to the operational activities that are approved (mining, milling and waste management) by the licence. The licensee is expected to identify the hazards and impacts (public, worker and environment) from the operation of its facility through a risk assessment process, and make adequate provisions to protect and minimize the consequences of their approved activities. These mitigation measures usually take the form of management, administrative or engineering controls. CNSC staff review the safety and control area and verify that these mitigation measures are developed, implemented and are effective.

Inspection criteria and expectations are derived from the Safety and Control Areas and are focused on management, operations and support functions. An integration of all three functions can provide the inspector with a real time impression of a licensed activity, like mining, to evaluate compliance with the regulatory expectation. The following table gives an example of Safety and Control Areas for uranium mines and mills with the CNSC staff's expectation to meet the regulatory requirements. Table 2 is organized by three main components: management, operations and support functions.

TABLE 2. CNSC STAFF'S EXPECTATIONS FOR SAFETY AND CONTROL AREAS

Safety and Control Areas	CNSC Staff Expectations
1. Management	
Quality Management	The licensee is expected to have managed processes that monitor and control the conduct of facility operations. The licensee is expected to establish, implement and maintain written operating procedures and carry out the licensed activities in accordance with the policies, programs and methods, and for the purposes described in the licence application.
Training	Training programs must provide licensee staff members with the necessary knowledge and skills to safely carry out their duties. Training programs must also ensure that a sufficient number of qualified workers are available to carry out the licensed activities. The assessment grades for training are based on the review of training programs and use criteria based on methodology known as the Systematic Approach to Training.
Emergency Preparedness	The licensee is required to have a documented emergency plan and emergency preparedness program. Emergency plans should take into account accident scenarios that have, or could have, adverse impact on the environment and the health and safety of on-site staff or the public (e.g., fire, major accident/injury, environmental spill, major fall of ground). Adequate training, testing, resources and equipment are necessary to ensure that individuals and organizational units are prepared and have the resources to effectively respond to and deal with emergency situations
Public Information Program	Paragraph 3(c)(i) of the <i>Uranium Mines and Mills Regulations</i> requires that licence applications contain information on “the proposed program to inform persons living in the vicinity of the site of the mine or mill of the general nature and characteristics of the anticipated effects of the activity to be licensed on the environment and the health and safety of persons.” Licensees’ Public Information programs are assessed against criteria set out in Regulatory Guide G-217, <i>Licensee Public Information Programs</i> .
Fire Protection	Implementation of a comprehensive Fire Protection program will reduce the risk to the health and safety of persons and to the environment from fire. The licensed facility is currently required to comply with the <i>National Building Code of Canada</i> (1995 Edition), the <i>National Fire Code of Canada</i> (1995 Edition), to arrange to have biennially a third party review of the facility’s compliance with the inspection requirements of the <i>National Fire Code</i> and to take all reasonable precautions to protect the environment and the health and safety of persons.
Nuclear Security	The licensee is expected to control access and to prevent the loss or illegal use, possession or removal of nuclear substances from the facility.
Safeguards	<p>The CNSC’s regulatory mandate includes ensuring conformity with measures required to implement Canada’s international obligations under the Treaty on the Non-Proliferation of Nuclear Weapons. Pursuant to the Treaty, Canada has entered into Safeguards agreements with the International Atomic Energy Agency (IAEA). The objective of these agreements is for the IAEA to provide credible assurance on an annual basis to Canada and to the international community that all declared nuclear material is in peaceful, non-explosive uses and that there are no undeclared nuclear material or activities in this country.</p> <p>Under the Safeguards requirements for mines and mills, the licensee is expected to: provide reports to the CNSC on the movement of all nuclear materials on a timely basis; submit annual information to the CNSC on its operations, which forms part of Canada’s annual declaration to the IAEA regarding the Canadian nuclear fuel cycle; and, provide prompt access to the IAEA, upon request, to enable Agency inspectors to undertake verification activities.</p>
2. Operations	
Mining	The CNSC expects the licensee to provide the materials, equipment, resources, policies,

Safety and Control Areas	CNSC Staff Expectations
	<p>programs, procedures and training necessary to safely carry out the licensed activities, to protect the environment, and to control the release of nuclear and hazardous substances into the environment. It is also expected that all potential risks from the operations are identified and that mining processes and engineering and administrative controls are established to limit these potential risks. Contingency and emergency plans are also to be developed and practised to provide for the health and safety of mine personnel.</p>
Milling	<p>While operating its mill, the licensee is expected to take all reasonable precautions to protect the workers, the environment, and to control any releases of nuclear and hazardous substances into the environment. These precautions include making provision for engineering and administrative controls, and redundant systems such as secondary containment. The licensee is expected to maintain the integrity of its facilities and to use documented procedures to operate and monitor them.</p> <p>The licensee is expected to have managed processes that monitor and control the conduct of facility operations, including inspections and recordkeeping, change control in regard to modifications, procedural adherence, internal communications, and event investigation and reporting. In addition, the licensee must obtain written CNSC approval to make changes to certain documents, components or systems. CNSC staff requires that all approval requests for modification contain sufficient information to permit staff to make informed decisions.</p>
Waste Management	<p>The licensee is expected to use managed processes to operate and maintain the integrity of its waste management facilities. Measures to adequately segregate radiological and other contaminated wastes for controlled storage and handling are required. Process monitoring and control is required to ensure that the treated effluent meets the effluent quality requirements and contaminants are maintained as low as reasonably achievable (ALARA). The licensee is expected to take all reasonable precautions to protect the workers and to control the release of nuclear and hazardous substances into the environment. The necessary precautions include engineering and administrative controls, redundant systems such as secondary containment, and liquid effluent controls.</p>
Packaging and Transport	<p>In compliance with the <i>Transportation of Dangerous Goods Regulations</i>, and more specifically, the CNSC's <i>Transport and Packaging of Nuclear Substances Regulations</i>, the licensee is expected to have the necessary programs, procedures, materials and equipment to properly package and transport nuclear substances, and to label the transport containers as required to accurately document their contents.</p>
3. Support	
Radiation Protection	<p>The licensee is required to ensure doses remain below dose limits, and to implement a Radiation Protection program that keeps radiation exposures and doses as low as reasonably achievable (ALARA) through implementation of: management control of work practices; personnel qualification and training; control of occupational and public exposure to radiation; and by ascertaining the quantity and concentration of any nuclear substance released as a result of the licensed activity.</p>
Environmental Protection	<p>The licensee is required to develop and implement policies, programs, and procedures to control the release of radioactive nuclear and hazardous substances into the environment, and to protect the environment. The licensee is also expected to have suitably trained and qualified staff to effectively develop, implement and maintain their Environmental Protection program. If environmental monitoring verifies the potential for environmental effects, then additional preventative or control measures may be required.</p> <p>The final treated mine effluent released at the final point of control must meet the effluent discharge limits stipulated in Appendix C of the licensee's operating licence. This effluent discharge is also subject to regular <i>Metal Mining Effluent Regulations</i> mandated toxicity testing and to more stringent Action Levels specified in the licensee's Environmental Code of Practice.</p>

Safety and Control Areas	CNSC Staff Expectations
Health and Safety	<p>The regulation of non-radiological health and safety in uranium mines and mills involves three regulatory agencies: Saskatchewan Ministry of Advanced Education, Employment and Labour (Saskatchewan Labour), Human Resources and Social Development Canada (HRSDC), and the CNSC. An agreement signed by the Province of Saskatchewan with HRSDC, in May 2003, provides for the regulation of conventional safety by Saskatchewan Labour on behalf of HRSDC.</p> <p>The CNSC expects uranium mines and mills to develop, implement and maintain effective safety programs to promote a safe and healthy workplace for employees and to prevent and reduce to a minimum the incidence of occupational injuries and illnesses. Licensees are expected to identify potential safety hazards, assess the associated risks, and put in place the necessary materials, equipment, programs and procedures to effectively manage, control and minimize these risks. In addition, licensees must have processes and procedures to investigate accidents and incidents to identify root causes, to implement corrective actions and to verify that the corrective actions are completed and will effectively prevent recurrence.</p>

These expectations, derived from the Nuclear Safety and Control Act and Regulations, are written as a performance standard to articulate the general expectations to meet the minimum regulatory requirement. This approach is different than other jurisdictions where regulatory requirements to fulfill obligations are codified or described in detail. The Canadian Nuclear industry is afforded the flexibility to propose what will work for their unique circumstance and allow for the incorporation of innovation and advances in technology. CNSC staff recognizes that the performance-based regulations can cause confusion with an applicant that is unfamiliar with the Canadian regulatory system. Our staged licensing approach establishes a long-term relationship between CNSC staff and the licensee. Over the course of obtaining the necessary authorizations to develop and operate a uranium mining facility, our licensees become familiar with our requirements and are able to propose and implement infrastructure, policies and programs that are more site-specific to their needs, and comply with regulatory requirements.

4. THE UMMD COMPLIANCE PROGRAM

The compliance program is designed to encourage compliance by integrating three components: promotion, verification and enforcement and articulates the CNSC's expectations to attain and maintain compliance with its regulatory requirements. The Regulatory Policy that applies is P-211 Compliance. These elements are translated into specific activities, planned to the extent possible, and delivered to maximize compliance by the licensees with CNSC regulatory requirements.

The objectives of the compliance program are two fold to:

- Gain a reasonable assurance, through communication, inspection and desktop review activities, that a licensee is aware of, and is operating in compliance with, the NSCA, its regulations, standards, codes and approved program elements; and
- Review and inspect the facility to determine or verify if the risk to the health and security of Canadians and the environment remain acceptably low.

Regular reviews are built into the program to adjust the activities for changing facility or CNSC conditions (quarterly, yearly) and to take into account evolving risk or stakeholder

feedback. Products of the compliance cycle are synchronized to ensure that the re licensing process utilizes current compliance information.

Some CNSC compliance activities are unplanned and reactive, as they follow up on unplanned licensee events and are resourced depending on the risk. Program evaluations or enhanced inspections, including safety culture assessment(s), would be undertaken in cases where a licensee's performance has degraded, where a licensee has undergone an important reorganization or significant changes to the facility or its operation.

CNSC staff maintains transparent performance objectives and criteria for the evaluation of the programs they monitor. This minimizes the level of subjectivity in the evaluation of the program implementation. The compliance process consists of field inspections and desktop reviews as a baseline and may incorporate activities that promote, verify and enforce compliance.

The main features of the Compliance Process include:

- Compliance with requirements of the Nuclear Safety and Control Act, its regulations, standards and codes and program elements;
- Focusing on licensee program implementation (programs performance outputs and overall outcomes);
- Planning activities as far as practicable;
- Defined and transparent activities for promotion, verification and enforcement;
- Established cost efficient baseline work, considering risk;
- Focused supplemental verification activities (beyond baseline) in safety areas that have increased evaluation of risk;
- Predictable enforcement measures based on risk, and featuring discretionary powers; and
- Follow-up of previous inspection findings until closure of required action.

4.1. Promotion

The purpose of compliance promotion is to maximize voluntary compliance with regulatory requirements (the Act, CNSC regulations, licences, certificates, decisions and Orders made under the Act and regulatory documents) by persons regulated by the CNSC. Good and timely promotion provides the most effective outcome for the level of effort provided.

Compliance promotion is proactive, and it involves essential CNSC staff communication with licensees (or groups of licensees) to explain or interpret existing, new or modified regulatory requirements and their rationale, as well as the compliance criteria used to monitor compliance. As a result, uranium mine or mill licensees are normally given reasonable opportunity to understand requirements and become compliant. Communications with stakeholders are important to improve clarity of regulatory requirements, and minimize the need to turn to enforcement measures.

The Outreach Program provides an opportunity for CNSC staff to communicate directly with local community members and articulate our functions and processes to regulate the industry. Although our regulatory framework allows for public participation in the decision making process, with venues such as community town hall meetings or on-site meetings, it provides an opportunity for less formal discussions and relationship building. This activity

should not be interpreted as our Duty to Consult under Canadian law. Rather, these opportunities are a prelude to formalizing recommendations for the Commission and are often referred to in our written submission (Commission Member Document) as additional support or concern on important issues related to new licences or licence renewals.

An Environment Quality Committee (EQC) was established early in the development of the new Saskatchewan mining operations which allowed involvement and participation by the northern communities with the licensee and regulators on the environmental performance and ongoing issues resolution at these new facilities. These communication opportunities also provide a forum to disseminate highly technical information. On occasion, traditional knowledge of the local areas and valued ecosystem components are contributed by this group which can result in improved planning and operational control at these nuclear facilities.

Recently, our outreach strategy has expanded to include potential new mine operators within Canada. The potential new applicants are invited to meetings with CNSC staff to discuss the Canadian nuclear regulatory framework. In addition, CNSC staff has prepared an information document for the licensing of new uranium mines which explains in further detail the environmental assessment process, the licensing process and the Commission Hearing protocols. The time frame of the processes is explained and the CNSC staff's expectations are discussed. We have found that this promotional activity has greatly enhanced the understanding of new applicants and their expected performance within the Canadian nuclear regulatory framework.

4.2. Verification

The objective of verification tasks is to determine and to document the status of compliance of a licensee with applicable regulatory requirements, including those of the Act, CNSC regulations, licence conditions, the facility's licensing documents, and Commission decisions.

Acceptance criteria that can be used to assess compliance are derived from one or more of the following:

- Facility licensing application and Environmental Impact Statement;
- CNSC regulatory documents that clarify how the Commission intends to apply the legal requirements;
- Information supplied by licensees to the Commission in their application that defines how licensees intend to meet legal requirements in performing the licensed activity; or
- CNSC staff's expert judgment, including knowledge of best-industry practices.

Verification tasks may lead to enforcement measures, as required. Since it is impossible to witness all operations of a uranium mine or mill, CNSC staff audits licensee operations and samples licensee activities through inspection activities and desktop reviews. The audit function is supported by a framework of self reporting. The CNSC inspection process focuses on the capability of licensees to effectively manage the licensed activities and self report to the CNSC. The requirements of self reporting are described in the General Regulations.

4.3. Inspection

Regulatory inspections are an ongoing and essential regulatory task at licensee sites. This task is structured and includes opening and closing site meetings, review of records,

attendance at production and planning meetings, discussions or interviews with site workers, and field observations around the site. These are the main means of detection and collection of real time information about the performance of licensees, and possible emergent issues. Early detection of new issues as they unfold allows CNSC staff to verify the capacity of the licensee's management systems and to demonstrate their site staff's identification and corrective action program tools to solve problems, or identify emerging issues.

Inspection results are an important source of information for verification purposes. Several types of inspection activities have been established and are carried out by the CNSC, and are further described as follows:

- Type I inspections consist of detailed evaluations or audits of the content and adequacy of a licensee program, group of programs or large processes. Type I inspections are also used when: site monitoring, self reporting, unplanned events, performance indicators, or when significant changes have been implemented by the licensee, such as a major reorganization, changes to the facility or operations;
- Type II inspections are selective evaluations of the implementation or performance of the licensee programs, processes and practices. Type II inspections typically focus on the delivery or performance of licensee programs, processes and practices, under various operating conditions. Findings from Type II inspections play a key role in detecting the existence of systemic problems with licensee programs, processes or practices, and to determine whether there is a necessity to expend further resources in the verification of compliance (such as an evaluation of the process itself) and the safety impact.

As they evaluate program outputs, CNSC inspectors present positive findings as well as negative findings, and therefore balanced reports recognize and promote favourable licensee behaviour and industry best practices while ensuring compliance with regulatory requirements. CNSC compliance inspections require that compliance objectives and criteria are established beforehand and communicated in a transparent way to the licensees. Inspections generally follow a plan and a schedule. The powers of the inspector allow for unannounced, unplanned and reactive inspections. These protocols allow the CNSC inspector to maintain positive relations with the licensee, and a predictable format from site to site.

4.4. CNSC Staff Performance Report

Table 3 is an example of the “report card” format that is used in our Commission Member Documents (CMDs) to inform the Commission on the licensee's performance during a mid-term or licence renewal.

The performance rating scheme is as follows:

A — Exceeds requirements. A rating of “A” is merited when assessment topics or programs meet and consistently exceed applicable CNSC requirements and performance expectations. Performance is stable or improving. Any problems or issues that arise are promptly addressed such that they do not pose an unreasonable risk to the maintenance of health, safety, security, environmental protection, or conformance with international obligations to which Canada has agreed.

B — Meets requirements. A rating of “B” is merited when assessment topics or programs meet the intent or objectives of CNSC requirements and performance expectations. There is

only minor deviation from requirements or expectations for the design and/or execution of the programs, but these deviations do not represent an unreasonable risk to the maintenance of health, safety, security, environmental protection, or conformance with international obligations to which Canada has agreed. That is, there is some slippage with respect to the requirements and expectations for program design and execution. However, those issues are considered to pose a low risk to the achievement of regulatory performance requirements and expectations of the CNSC.

C — Below requirements. A rating of “C” is merited when either assessment topics or programs deviate from the intent or objectives of CNSC requirements or performance deteriorates and falls below expectations to the extent that there is a moderate risk that the programs will ultimately fail to achieve expectations for the maintenance of health, safety, security, environmental protection, or conformance with international obligations to which Canada has agreed. Although the risk of programs and performance falling significantly below requirements in the short term remains low, improvements in performance or programs are required to address identified weaknesses. The licensee or applicant has taken or is taking appropriate action.

D — Significantly below requirements. A rating of “D” is merited when assessment topics or programs are significantly below requirements or there is evidence of continued poor performance to the extent that whole programs are undermined or compromised. Without corrective action, there is a high probability that the deficiencies will lead to an unreasonable risk to the maintenance of health, safety, security, environmental protection, or conformance with international obligations to which Canada has agreed. The licensee or the applicant is not addressing issues effectively. The licensee or applicant has neither taken appropriate compensating measures nor provided an acceptable alternative plan of action.

E — Unacceptable. A rating of “E” is merited when there is evidence of an absence, total inadequacy, breakdown, or loss of control of an assessment topic or a program. There is a very high probability of an unreasonable risk to the maintenance of health, safety, security, environmental protection, or conformance with international obligations to which Canada has agreed. An appropriate regulatory response, such as an order or restrictive licensing action, has been or is being implemented to rectify the situation.

TABLE 3. CNSC STAFF RATING OF PROGRAM AREAS — AN EXAMPLE

Program Area	Program	Implementation
Operations		
• Mine Operations	B	B
• Mill Operations	B	B
• Waste Management	B	B
• Transport and Packaging	B	B
• Fire Protection	C	C
Quality Management	B	C
Radiation Protection	B	B
Environmental Protection	B	B
Non-radiological Health and Safety	B	B
Emergency Preparedness	B	B
Training	B	C
Nuclear Security	PROTECTED	PROTECTED
Safeguards	B	B
Public Information	B	B

4.5. Enforcement

Enforcement includes all activities to bring a licensee back into compliance and to dissuade non-compliance with legal requirements. Enforcement is applied using a graduated approach, where severity of the enforcement measure depends on the safety significance of the non-compliance and other related factors. Graduated enforcement tools include the following:

- Written notices (recommendations, action notices, or directives);
- Meetings with senior licensee executives;
- Increased regulatory scrutiny;
- Requests from the Commission or an authorized person [see subsection 12(2) of the General Nuclear Safety and Control Regulations] to explain how the licensee plans to address a concern raised by the Commission or the authorized person;
- Orders;
- Licensing actions (i.e., amendment or suspension of part of a licence, revocation of personnel certification, and revocation or suspension of a licence); and
- Prosecution.

Examples of licensing actions are as follows:

- Short-term licence or extension: If the CNSC is not satisfied that a licensee has the required commitment to safety, as indicated by the current compliance history, CNSC staff may recommend that the Commission grant a licence for a shorter term. Alternatively, the Commission may grant a short-term extension to allow the licensee sufficient time to make required improvements before the licence is considered for renewal;
- Licence amendment: CNSC staff may recommend a licence amendment to the Commission. The licensee is notified in writing of the proposed action and is given an

opportunity to be heard by the Commission. Licence amendments cover a wide range of possibilities and are decided on a case-by-case basis. Examples of licence amendments include the following:

- Limitations to mining or milling outputs;
 - A requirement to obtain commission approval before new activities commence; and
 - A requirement to appear before the commission on a regular basis to provide status reports on progress in improvements to operation and maintenance programs;
- Licence suspension or revocation: CNSC staff may recommend to the Commission that it suspend or revoke a licence. This course of action can be taken in any of the following circumstances:
- The licensee is in serious non-compliance;
 - The licensee has been successfully prosecuted;
 - The licensee has a history of non-compliance; and
 - The CNSC has lost confidence in the licensee's ability to comply with the regulatory requirements.

5. COMPLIANCE STRATEGY, PROGRAM REVIEW AND SUPPORTING ACTIVITIES

Uranium mine or mill compliance activities are implemented through annual work plans ensuring they cover the baseline requirements and the facility-specific strategy for focused compliance activities. Planning takes place in conjunction with Technical Divisions (through the use of FAC Teams). The assessment of licensee's performance allows technical lines to allocate resources to risk areas within the different service lines.

6. COMPLIANCE STRATEGY

The compliance strategy is a key input into the planning process since some of the actions imposed on the licensee are multi year endeavours. The compliance strategy describes the long term (2 5 year) strategy for focused compliance effort (i.e., beyond baseline activities) to address areas where enhanced compliance verification is desired. CNSC staff also reviews and identifies Commission concerns or requests documented in Reasons for Decisions and public hearing transcripts and incorporate these in our compliance activities. Monthly and quarterly reviews of licensee data on compliance, safety, and incident reports, allows the CNSC staff to modify its yearly compliance plan. These reviews are compiled by inspection staff to validate the course of regulatory action for the next quarters to ensure planning is based on the latest information available.

This section discusses the baseline plan and the factors that can influence the priorities and resources required for the compliance program.

6.1. Baseline and focused compliance activities

In order to fulfil its mandate and provide the Canadian public with confidence that the licensees are compliant and operating safely, CNSC plans key verification activities.

It is impractical to attempt to verify every requirement from the regulations and the licence on a regular basis. FAC Teams establish their priorities to be covered explicitly in baseline verification activities. They identify priorities by reviewing all regulatory and licence conditions applicable to each licensee (or group of similar licensees) and identify which must be included from the baseline program based on risk, at an adequate frequency.

A baseline plan includes a reasonable set of integrated verification activities performed on a regular basis to provide ongoing assurance that acceptable compliance levels are being achieved and maintained. Verification activities include Type I inspections, Type II inspections and desktop reviews performed on licensee reports, including planned reports and unplanned event reviews. The extent of baseline verification activities is based on risk considerations.

The baseline activities may be supplemented by focused activities in the yearly plan, where the licensee is demonstrating less than acceptable behaviour or sustained difficulties in achieving acceptable standards, where underlying issues related to the lack of compliance or safety significance need to be determined, or when the CNSC has lost confidence with the capability of a licensee. These supplementary activities might be triggered by unplanned licensee events or indications received through inspections or regulatory performance indicators. Technical Divisions (through the FAC Teams) may suggest the level of resources appropriate to verifying compliance or to determine the impact of non compliances on the overall safety and control area or licensee ratings.

6.2. Licensee self reported information review

CNSC staff reviews safety-related events that have occurred at uranium mine or mills. The reviews do not aim to duplicate reviews done by licensees, but rather to ensure that licensees have adequate processes in place to fully identify root causes, take necessary corrective actions, and to ensure that lessons learned from past events are incorporated into their day-to-day operations. CNSC staff normally carries out detailed reviews of those events considered particularly significant to safety, or if repetitive in nature.

Self reporting shows how licensees understand requirements, their analysis and operating experience, and their capability to detect, assess and take corrective action without regulatory prompts. This aspect of voluntary compliance is cost effective since it involves reviewing standardized licensee data which has been analysed by the licensee, and it minimizes unnecessary expenditures such as team travel. The willingness to report, analyse and take corrective actions by licensees is interpreted as a sign of proper safety culture.

Preliminary reports for the serious situations or events must be provided to the CNSC immediately. The least significant reportable events are required to be reported annually and records maintained on site for inspector review, primarily for trending and analysis of long-term safety and regulatory issues.

Given the importance of self reporting, and the potential impact on safety culture of a licensee that self-reports correctly, CNSC staff continues to encourage the licensee to report all events. However, the CNSC is concerned with licensees who fail to report in accordance with established requirements as it may be indicative of potential weakness in safety culture.

The submission of data from licensees includes safety issues, unplanned events, non compliances, various statistics on safety performance, environmental monitoring and radiation protection monitoring data, and regulatory performance indicators. CNSC staff reviews the data to detect potential issues. Staff also verifies the quality and completeness of licensee analysis and licensee corrective actions, and may request additional information.

6.3. Licensee unplanned events inspections

Licensees are also required to submit event reports when significant safety (or security) events occur at their facilities. While immediate reporting of some events allow for the CNSC to activate their emergency plan, other event reports are reviewed by CNSC staff for safety significance and the existence of non compliances. In addition, CNSC staff assess if appropriate assessment/corrective actions are being taken by licensees. CNSC staff looks for general event trends. CNSC staff also expects that licensees review and analyse low importance events and audit their processes.

At public Commission meetings, CNSC staff may present “Significant Development Reports” on safety-significant issues. These may arise during or as a result of the conduct of any regulated activity and on any other matter of interest to the CNSC or to the public.

6.4. Licensee submissions reviews and assessments

Licensee submissions are evaluated using a risk informed approach to determine priority. Staff makes a distinction between a review aimed at determining compliance versus a submission requiring review for obtaining an approval under the licence. This last type of review relates to the licensing process.

As a compliance activity, after a licence is issued, CNSC staff may conduct reviews of changes to licensee programs. These reviews may be framed, conducted and delivered under a desktop review in an office environment. Internal requests may be made to the licensee, to verify status, completeness, testing or sampling in the field.

6.5. Cost recovery

The selected compliance activities are integrated into work plans and budgeted as part of the annual CNSC planning process. Because the CNSC is a fee-for-service agency, Regulatory Activity Plans are developed for major licensees and communicated to licensees along with an estimate of cost recovery fees, in compliance with Cost Recovery Regulations. Activities related to the licensing and compliance effort are estimated for the annual planning cycle. The licensee is billed on a quarterly basis for the actual effort expended.

Quarterly Compliance Activity Reports may be derived from the financial data and timesheets. Variances between planned and actual compliance activities are reported, evaluated, and used to update the planning assumptions.

7. CNSC STAFF TRAINING

Planning is only the first step in an effective compliance program. Experienced, qualified and certified staff is essential to ensure consistency, fairness and accuracy.

The Uranium Mines and Mills Division of the CNSC are preparing to meet the challenges of the planned expansion of the Canadian uranium mining industry. New staff are trained to apply the regulations to licensed sites and to manage non-compliance. The development of project management skills helps ensure an integrated program approach to manage risks at these nuclear facilities.

Each Technical Division involved in compliance activities makes available and updates the appropriate training in the Uranium Mines and Mills Division compliance process for

CNSC staff. Specialists remain current in their field, and in addition, inspectors get additional training based on a needs analysis of the CNSC compliance process. This includes training in such topics as:

- Regulatory oversight;
- Conduct of inspections and administrative (statutory) investigations;
- Awareness of legal investigations;
- Radiation protection;
- Radiation instrumentation;
- Event review/root cause analysis;
- Interviewing techniques;
- Report writing; and
- Leadership skills.

7.1. UMMD project officer profile

In the Uranium Mines and Mills Division, the Project Officer is responsible for managing regulatory functions for the assigned facility. The key regulatory functions of licensing, compliance, enforcement and reporting requirements are managed by the Project Officer. The Project Officer is expected to be the lead in the FAC Team and that input from technical specialists and inspection divisions are incorporated into the facility evaluation. The Project Officer also acts as an advisor to licensees, CNSC inspection and licensing staff, the public and other agencies.

Each Project Officer is assigned a mining facility file and is responsible for all aspects of its management. These project management responsibilities include:

- Managing and evaluating licensing processes and programs;
- Co-ordinating and conducting compliance and enforcement activities;
- Managing assigned projects;
- Developing and maintaining regulatory documents; and
- Reporting on the facility's regulatory performance on a regular and consistent basis.

While some of the training is classroom, some of the needed competencies are acquired through mentoring. The training requirements are given in a divisional training program. The Strategies, Programs and Learning Division is responsible for updating the training package, and to frame a mentoring process, based on the inputs of the technical divisions and the Uranium Mines and Mills Division.

Training initiatives are currently in place or under development to meet the technical skills development of new staff. The use of experienced staff for mentoring and knowledge transfer is being used as an interim measure.

Licensees provide training to CNSC staff in specific areas, where licensees expect CNSC staff to follow internal licensee rules and practices, such as in the area of radiation protection, and specific facility risks. CNSC maintains agreements with licensees that provide the training and make the training material available. CNSC maintains responsibility to review the content of the training in order to assure that it is complete and does not pose any undue risk to the health or safety of CNSC staff.

7.2. Inspector certificate

The Uranium Mines and Mills Division provide its Project Officers with an Inspection Training Program. The training program is intended to provide the necessary skill development to obtain an inspector certificate under section 29 of the Nuclear Safety and Control Act. This inspection training includes:

- (a) Nuclear safety and control act training;
- (b) Nuclear safety and control act regulations training;
- (c) Mining and milling 101:
 - Type of mines;
 - Milling operation; and
 - Effluent control and monitoring;
- (d) Licensing session;
- (e) Compliance session:
 - Safety and control areas; and
 - Progressive approach to enforcement;
- (f) Basic radiation practices and principles training:
 - Mine; and
 - Mill;
- (g) Field training:
 - Inspection orientation;
 - Accompany a certified inspector during an inspection;
 - Inspection planning;
 - “Shadow” an inspection from start to the completion of the inspection report;
 - Plan/conduct/report an inspection with Project Officer oversight;
 - Plan and conduct a Type II CNSC inspection;
 - Solo inspection; and
- (h) Qualification and certification criteria completed and documented for sign-off by Director for inspector card.

A checklist of generic inspection areas for uranium mine and mill facilities is used to guide CNSC staff on the conduct of field observations.

8. CONCLUSION

The CNSC Compliance Program for Uranium Mines and Mills is structured to ensure the regulatory requirements are complied with and to assure the Canadian public that the operation of these nuclear facilities are not causing, or will not cause undue risk to the public, the workers and the environment.

Team work and multidisciplinary assessments are used for licensing and compliance. A risk-informed regulatory activity plan is applied and reviewed to ensure that it is current and focused. Our compliance activities are designed for ongoing assessment and a risk management approach is used to attain the mandated objects of the Nuclear Safety and Control Act.

CNSC staff conducts stakeholder meetings and make presentations as part of our Outreach Program to provide clarity and confidence to the Canadian public on the nuclear regulator’s capacity.

Our licensees' performance is regularly reviewed and we expect continual improvement and high reliability from them.

CNSC inspectors are certified under the Nuclear Safety and Control Act to assure consistent application of our expectations and regulatory requirements.

SCREENING ASSESSMENT OF RADIONUCLIDE MIGRATION IN GROUNDWATER FROM THE “DNEPROVSKOE” TAILINGS IMPOUNDMENT (DNEPRODZERZHYNISK CITY) AND EVALUATION OF REMEDIAL OPTIONS

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Abstract

The paper presents results of mathematical modeling of the hydrogeological conditions at the “Dneprovskoe” (“D”) tailings impoundment –object of the former industrial association of “Pridneprovsky Chemical Plant”, which contains uranium ore processing wastes. This radioactively polluted site is located in a densely populated region (at the outskirts of Dneprodzerzhinsk City) near the major watercourse of the Ukraine — Dnieper River. The mathematical modeling utilized Visual Modflow (for groundwater flow) and Ecolego (Facilia AB, Sweden) radioecology modeling software (for radionuclide transport). Modeling results indicate the possibility of essential radioactive contamination in future of the phreatic aquifer in alluvial deposits between the “D” tailings and the Dnieper River (mainly due to migration of uranium). Therefore long-term management strategies should preclude water usage from the aquifer in the zone of the in-fluence of the “D” tailings. Filtration discharge of uranium to the Dnepr River does not represent a significant risk due to large dilution by surface waters. The important modeling conclusion is that besides the uranium ore processing wastes inside the tailings, the major source of radionuclide migration to groundwater is represented by contaminated geological deposits below the tailings. This last source was formed due to leakage of wastewaters during the operational period of the “D” tailings (1954–1968). Therefore an exemption and re-disposal of wastes from the “D” tailings to a more safe storage location (proposed by some remedial plans) will not provide significant benefit from the viewpoint of minimizing of radionuclide transport to the groundwater and Dnieper River (especially in short- and medium-term perspective). The rational remedial strategy for the “D” tailings is conservation of tailing wastes in-situ by means of specially designed “zero flux” soil screen, which would minimize infiltration of meteoric waters to the body of the “D” tailings (and would respectively minimize groundwater contamination).

1. LOCATION OF PRYDNEPROVSK CHEMICAL PLANT (PCHP) AND GENERAL CHARACTERISTIC OF ITS TAILINGS

1.1. Location

The Pridneprovsk Chemical Plant (PCHP) was one of the first uranium plants in the former Soviet Union. Nowadays the PChP represents a highly radioactive and chemically contaminated site. This site contains a number of contaminated buildings and large amounts of wastes of uranium production, which are placed in nine tailings. The radionuclides of the uranium decay series migrate from the tailings into the groundwater and towards discharge areas — Konoplyanka River and Dnepr River.

The PCh.P is located close to Dneprodzerzhynsk town, near the Dnepropetrovsk City. The PCh.P site is located at the right bank of the Dnepr River (see Figure1). Territory of the PCh.P is partially located on the terrace of the Dnepr River (middle and lower parts) and partially on the slope of the Quaternary Plato (upper part). There are three tailings within the territory of the PCh.P: “Western”, “Central Yar” and “Souse-Eastern” tailings. They occupy the lower parts of the former ravines, which developed within the Dnepr River terrace. One

more tailing “Dneprovskoe” is located not far from the PCh.P, in the flood plain of the Dnepr River. Some other tailings are located on the Quaternary Plato (see Fig. 1).

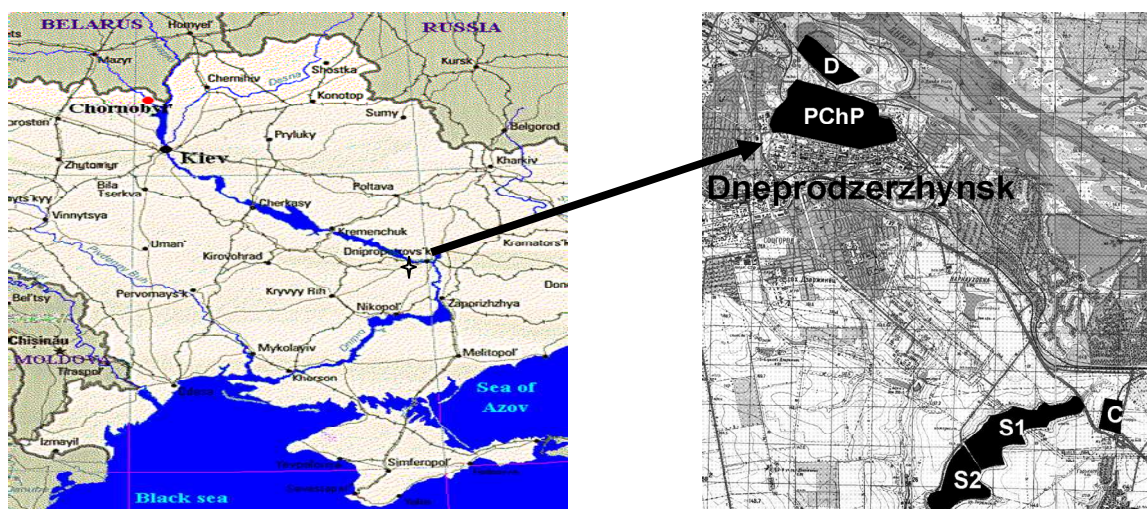


FIG. 1. Location of the Prydneprovsk Chemical Plant and its tailings: D — tailing “Dneprovskoe”; C — “Base C”; S1 — 1st section of tailing “Sukhachevskoe”; S2 — 2nd section of tailing “Sukhachevskoe”.

1.2. General characteristics of tailings

General characteristics of tailings are shown in Table 1.

TABLE 1. GENERAL CHARACTERISTICS OF THE PCH.P TAILINGS

Tailing names	Period of operation	Area, hectares	Amount of the waste, $\times 10^6$ t	Volume, $\times 10^6$ m ³	Gross activity, TBq
„Western“	1949–54	6.0	0.77	0.35	180
„Central Iar“	1951–54	2.4	0.22	0.10	104
„South-Eastern“	1956–80	3.6	0.33	0.15	67
“Sukhachevskoe” 1 st section	1968–83	90	19.0	8.6	710
“Sukhachevskoe” 2 nd section	1983–92	70	9.6	4.4	270
„Base C“	1960–91	25	0.3	0.15	440
„Dneprovskoe“	1954–68	73	12.0	5.9	1400
„Lantan fraction“	1965–88	0.06	0.0066	0.0033	130

Tailing of „Lantan fraction“ is situated close to the 2nd section of tailing “Sukhachevskoe”. The waste unit „Blast furnace N6“ is situated in the northern part of waste site “Base C”, which was used for storage of uranium ores from Ukrainian and foreign suppliers.

2. HYDROGEOLOGICAL CONDITIONS AND MONITORING SYSTEM

2.1. Hygrogeological conditions

The base rocks at the PCh.P site consist of Archeozoic and Proterozoic granites. The upper part of geological section consists of weathering crust, and of Neogene and Quaternary deposits. The upper part of granites is fractured and together with the weathering crust, these rocks host the lower confine-unconfined aquifer [1].

The Neogene layer is widespread on a Quaternary plateau, and is represented by sandy deposits. These deposits host the unconfined aquifer, which together with the lower aquifer in fractured granites makes a hydraulically joined complex. The Neogene deposits are covered from the top by red clays of Quaternary age. Above the layers of red clays the loess layers are bedded.

The unconfined aquifer sporadically exists in the loess layer. On the slope of plateau (towards the Dnepr River) the aquifers in Neogene and loess deposits pass to the unconfined aquifer in alluvial deposits, which is usual for terrace and flood plain of Dnepr River. Alluvial aquifer together with the aquifer in crystalline rocks is combined into an aquifer complex.

In addition to aquifers of natural origin, tailings “Dneprovskoe” and “Western” contain saturated layers in the wastes of uranium production. Saturation of uranium production wastes causes migration of radionuclides toward the lower aquifer and to the groundwater discharge regions. General characteristics of saturated deposits at PChP site are shown in the Table 2.

TABLE 2. GENERAL CHARACTERISTICS OF SATURATED DEPOSITS AT PCHP SITE

Rock	Permeability, m/day	Water yield, parts per unit	Porosity, cm ³ /cm ³	Average thickness, m
Wastes	0.04–2.7	0.15	0.36–0.42	8.0
Loess	0.02–0.1	0.15	0.58–0.88	10
Alluvial sands	3–10	0.15	0.3–0.35	8
Neogen sands	4–10	0.15	0.3–0.35	10
Weathered crust and fractured zone	3–7	0.02	0.1	

Dnepr River is the main discharge region for the Neogene and Alluvial aquifers. In addition the groundwater from internal PChP tailings partly discharges into small river Koplianka, which flows between the PChP and tailings “Dneprovskoe”. The aquifer in loess deposits discharges into streams, which run along local system of gullies.

The layout of groundwater head isolines for the PChP site and tailings “Dneprovskoe” is shown at Fig. 2. The hydraulic head distribution is obtained by means of groundwater modeling [4]. The Visual ModFlow 3 Pro groundwater modeling software, Map-Info and Surfer computer programs were used for these modeling analyses. The groundwater model includes aquifers in crystalline rocks and in the alluvial deposits. The geological layers were introduced into groundwater flow model taking into account the relief of their bedding. Geological-Hydrogeological GIS system, which included cartographic information, geologi-

cal layers layout, wells layout, and data on contamination of groundwater, was used for regional groundwater model development. Spatial steps of numerical grid of the groundwater model range from 15–62 m.

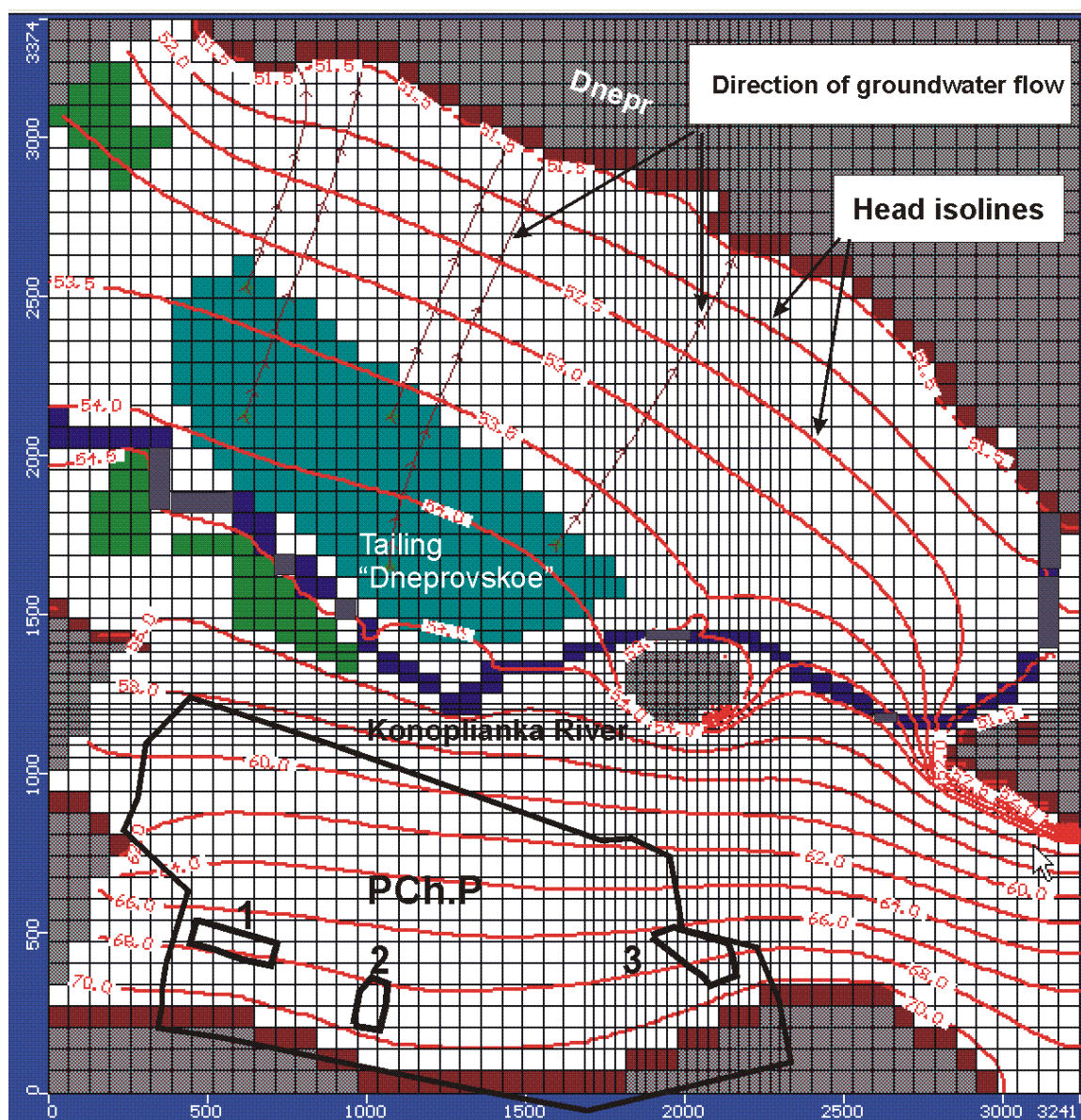


FIG. 2. The layout of groundwater head isolines for the PChP site and tailings “Dneprovskoe” (1 — tailings “Western”, 2 — tailings “Central Yar”, 3 — tailings “Souse-Eastern”).

Based on modeling results, groundwater flows from the tailings “Dneprovskoe” to the Dnepr River with the gradients of head of ≈ 0.003 – 0.004 . The unabsorbed particle associated with groundwater flow needs approximately 40–50 years to get to the Dnepr River. Hydraulic head gradients at the PChP site are much higher. The unabsorbed particle associated with groundwater flow needs approximately 3–5 years to get from internal tailings of the PChP (“Western”, “Central Yar” and “Souse-Eastern”) to the Konoplianka River.

2.2. Monitoring system

In the year 2000, the Ministry of Fuel and Energy of Ukraine established the enterprise «Barrier» to conduct environmental monitoring and manage radioactively contaminated materials (including groundwater) at the PChP site.

The system of the hydrogeological monitoring, controlled by the enterprise «Barrier», consists of 57 wells. The 49 of these wells are situated at the tailings “Dneprovskoe”. The tailings “Western” is equipped by 4 wells, the tailings “Central Yar” is equipped by 3 wells. There are no monitoring wells at the tailings “South-East”. Also, there is no network of monitoring wells at the waste site “Base C”. The current technical state of monitoring wells, situated at tailings «Sukhochevskoe», have not been assessed yet. The layout of monitoring wells at PChP site is shown on Fig.3.

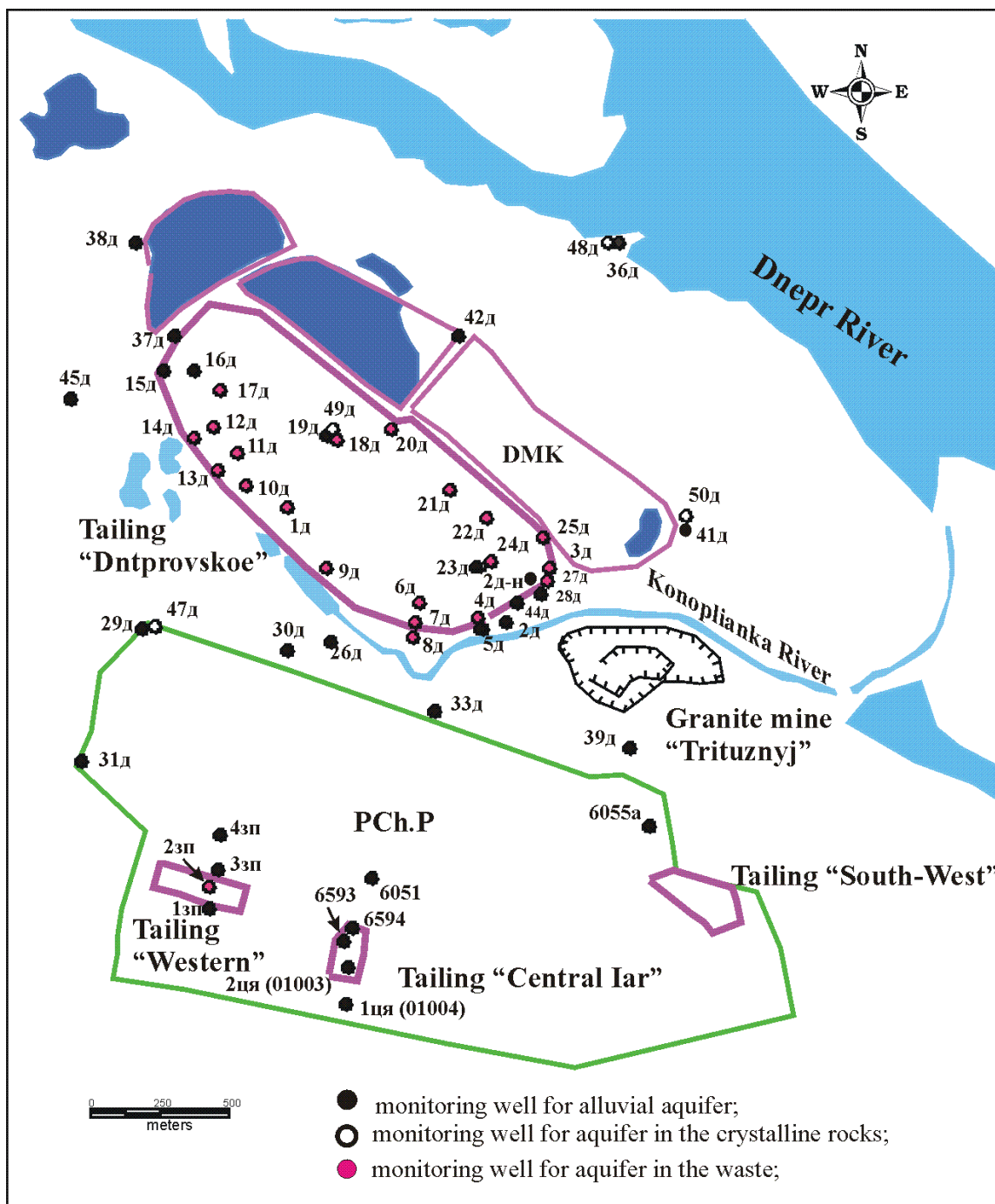


FIG. 3. The monitoring well network at PChP site.

In spite of the large number of monitoring wells, many of them are in bad technical condition. The well filters are often clogged, and wells have not been purged out systematically. In addition, some wells are not under control of the enterprise «Barrier».

The more systematic environmental monitoring of the PChP site started in 2004. This process was initiated by the staff of the «Center of monitoring studies and remedial technologies», «Institute of hygiene and medical ecology», National Academy of Sciences of Ukraine and the Permanent site inspection of the Committee of the nuclear regulation and radiation

safety. The “Conception and suggestions to the program of environment radiation control and monitoring in the former Prydneprovsk Chemical Plant” was developed in 2007. In 2005–2007 some basic works on development of environmental radiation monitoring system of the PChP site were carried out. Some results of groundwater monitoring are shown in Table 3.

TABLE 3. RADIATION CHARACTERISTICS OF GROUNDWATER OF PCHP SITE IN SELECTED WELLS FOR YEARS 2005/2006 [2]

Well #	Salinity, g/L	U-234, Bq/L	U-238, Bq/L	$\Sigma\alpha$, Bq/L	$\Sigma\beta$, Bq/L	$^{234}\text{U}/^{238}\text{U}$
6593a	2.0	1.19±0.25	1.58±0.26	3.0±0.9	1.0±0.3	0.75
	1.8	1.8±0.4	2.3±0.4	6.7±1.2		
6594	3.6	28.4±4.3	31.6±4.3	56±11	25±5	0.9
	4.4	64.2±12.8	45.9±9.3	115±22		1.4
1-3Π	2.3	0.56±0.11	0.35±0.07	0.81±0.24	0.93±0.28	1.6
	1.8	0.32±0.08	0.23±0.05	0.55±0.11		1.4
2-3Π	91	506±76	562±77	1180±177	151±30	0.90
	86	481±82	419±82	900±180		1.15
3-3Π	11.4	376±56	384±56	1160±174	276±55	0.98
	10.3	314±62	286±56	600±120		1.1
2-Д	7.3	0.73±0.16	0.90±0.18	2.62±0.78	4.6±1.4	0.81
	7.2	<0.03	0.20±0.02	0.23±0.04		0.42
4-Д	6.4	0.26±0.05	0.22±0.05	0.84±0.24	10±3	1.18
	11.1	2.5±0.5	2.4±0.5	5.0±1.0		1.04
19-Д	19.3	7.3±1.3	6.8±1.3	15.1±3.0	7.9±2.3	1.07
	18.4	9.38±2.40	5.69±0.31	16.0±3.2		1.6
16-Д	2.3	2.36±0.35	2.41±0.35	5.8±1.4	-	0.98
			5.4±1.2	5.8±1.2		
48-Д	5.8	0.09±0.03	0.09±0.03	< 0.2	2.0±0.6	
		0.40±0.06	0.43±0.06	0.8±0.04		1.00
MPC		0.5	0.5	0.1		

The most serious radioactive contamination in the subsurface environment was registered in the vicinity of uranium mill tailings sites. Uranium migrates from tailings to the aquifer in the sandy alluvial deposits.

The groundwater is also contaminated by chemicals, and its content of total dissolved solids (TDS) in some areas of tailings is very large (e.g., 10 times exceeding drinking water standards). Very large TDS for groundwater is observed at tailing “Western” — about 100 g/L. The chlorine and the sodium ions are often prevailing in chemical composition of groundwater. Sulfate and hydrocarbonate are prevailing in groundwater of the tailing

“Dneprovskoe”. Elevated concentrations in groundwater are also observed for ammonium, magnesium, potas-sium, sodium and calcium.

Efforts of the Ukrainian side in development of monitoring system for the PCh.P Site are supported by the IAEA within the framework of the regional project RER/9/094: “Upgrading National Capabilities in Controlling Public Exposure”. Currently, the enterprise “Barrier” disposes some basic equipment, required for groundwater monitoring and sampling [3].

3. SCREENING ASSESSMENT OF RADIONUCLIDE MIGRATION FROM “DNEPROVSKOE” TAILINGS

3.1. Radionuclide transport modeling software

In the reported groundwater modeling exercise radionuclide migration from tailings “Dneprovskoe” was simulated. The developed model describes migration of radionuclides along the flow lines (flow tubes) of groundwater in the system: “Tailings — alluvial aquifer — Dnepr River”. The model takes into account vertical infiltration of contaminated porous solu-tions from the body of tailing to the alluvial aquifer, and the consequent lateral advective-dispersive transport of radionuclides in aquifer towards the Dnepr River (taking into account retardation, caused by radionuclide sorption on geological materials).

To develop the radionuclide transport model the Ecolego software package was used. In this software package the conceptual model of the studied system is represented by the interaction matrix (Fig. 4). The diagonal elements of such a matrix correspond to the components (compartments) of the modeled system. External diagonal elements describe radionuclide transfers between compartments [4].

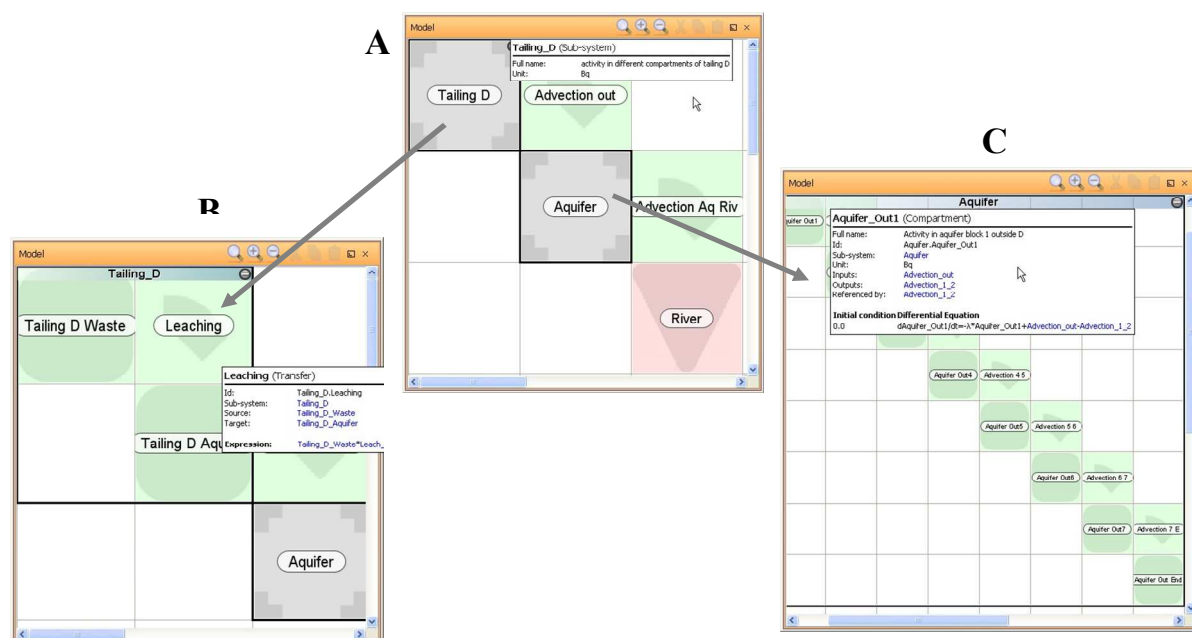


FIG. 4. Interaction matrix of the Ecolego for the model of radionuclide migration from tailings “Dneprovskoe”: (A) general matrix; (B) matrix for the sub-system “tailings”; (C) matrix for the sub-system “aquifer”.

The developed radionuclide transport model accounts for all important radionuclides of uranium decay series: uranium-238, uranium-234, thorium-230, radium-226, lead-210 and polonium-210. The model estimates radionuclide leaching from the source of migration, concentration changes in the source caused by lixiviation of radionuclides by groundwater and radioactive disintegration. Groundwater transport from tailing “Dneprovskoe” in direction of Dnepr River was simulated as a flow tube transport. The geometrical dimensions and hydraulic parameters of the flow tube were estimated using the regional groundwater model (developed using Visual ModFlow 3 Pro).

3.2. Parameters of the radionuclide transport model

The simulation of radionuclide migration from tailings “Dneprovskoe” was carried out for two scenarios: “base case” (that is most probable) and “conservative” (pessimistic). On the basis of in-situ Kd calculations and review of literature sources, the set of radionuclide sorption distribution coefficients was formed for modeling purposes (Table 4). The Table 4 contains the Kd estimates for tailings material and for the alluvial aquifer sediments.

Before the simulation of radionuclide migration from tailings “Dneprovskoe” using the Ecolego model, the simplified estimation of advective transport of radionuclides in the alluvial aquifer toward the Dnepr River was carried out (which considered the delay caused by sorption only). The results are shown in the Table 5.

The starting time of simulation using Ecolego flow tube transport model was the year 2000. The term of modeling predictions was 5000 years. Based on site characterization data, the model assumed, that initial radioactive contamination of geological environment was distributed in two compartments of the model: in the tailings of uranium processing and in alluvial aquifer directly under the bottom of tailings.

TABLE 4. THE RADIONUCLIDE KD SET FOR THE SIMULATION OF RADIONUCLIDE MIGRATION FROM TAILINGS “DNE-PROVSKOE”

4. Radionuclide	5. Kd, ml/g		
	6. Tailings material	7. Alluvial aquifer	
	8. Base case	9. Base case	10. Conservative case
11. U	12. 30	13. 5	14. 1
15. Th-230	16. 10000	17. 3000	18. 600
19. Ra-226	20. 700	21. 200	22. 40
23. Po-210	24. 2000	25. 400	26. 80
27. Pb-210	28. 1300	29. 600	30. 125

TABLE 5. ESTIMATED VELOCITY OF ADVECTIVE TRANSPORT OF RADIONUCLIDES IN THE AQUIFER (CONSIDERING THE DE-LAY CAUSED BY SORPTION) (V_{RN}) AND ESTIMATED TIME OF MIGRATION FROM TAILINGS “DNEPROVSKOE” TO DNEPR RIVER (T_{RN})

Migrant	Base scenario		Conservative scenario	
	V_{RN} , m/year	T_{RN} , years	V_{RN} , m/year	T_{RN} , years
Water	24	41	49	21
<i>Radionuclide</i>				
U	2.8	354	12.4	81
Th-230	0.005	205232	0.024	41056
Ra-226	0.07	13694	0.36	2749
Po-210	0.04	27375	0.18	5485
Pb-210	0.02	41056	0.12	8563

3.2. Modeling predictions of groundwater transport of uranium from tailings “Dneprovskoe” to Dnepr River under different remediation scenarios

The results of predictions of radionuclide transport in groundwater from tailings “Dneprovskoe” to Dnepr River under different scenarios using Ecolego migration model are shown on Fig.5 and in the Table 6. For conservative scenario a noticeable release of uranium to the Dnepr River begins at ≈ 50 years, and gains its maximum within ≈ 300 years. Maximum release of uranium to the Dnepr River for the conservative scenario is twice more than for the base case scenario. Simulated remedial measures (coverage of tailing by a soil screen, removing of tailings) demonstrate lowering of current and cumulative releases of uranium to the Dnepr River. According to the simulation, the release of uranium to the Dnepr River is lowered approximately twice in comparison with the base case scenario. Creation of soil screen and removing of tailings have similar effect during the period of first 500 years of forecast.

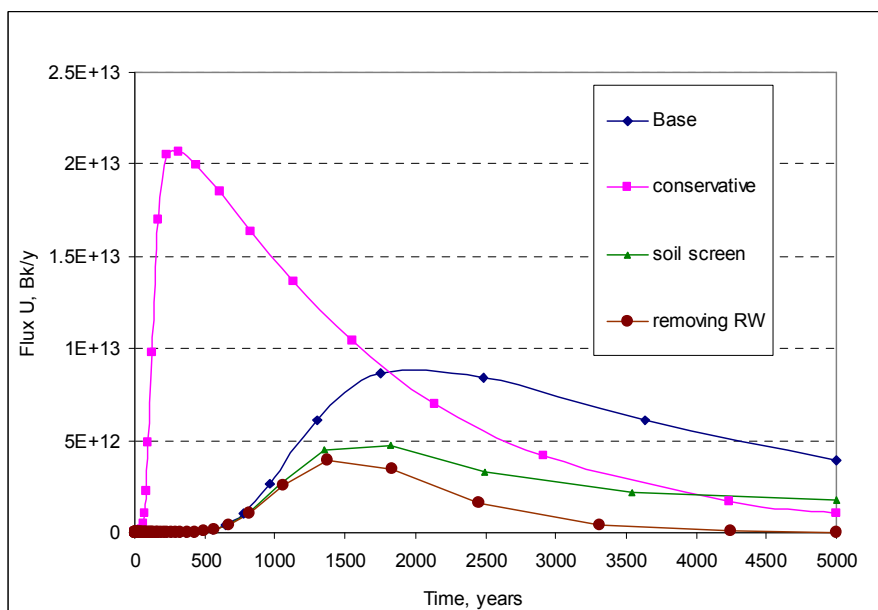


FIG. 5. Modeling predictions of release of uranium with groundwater from tailings “Dneprovskoe” to the Dnepr River.

TABLE 6. MODELING PREDICTIONS OF RELEASES OF URANIUM TO THE DNEPR RIVER FOR DIFFERENT SCENARIOS

Scenario	Maximum release of U to Dnepr River, $\times 10^{12}$ Bq/year	The time of maximum release, year	Cumulative release of U to Dnepr River, $\times 10^{16}$ Bq	
			for 1000 year	for 5000 year
Base case	8.7	2000	0.06	2.7
Conservative	21	300	1.6	3.7
Soil screen	4.7	1800	0.058	1.2
Removing of tailings	3.9	1400	0.058	0.6

The important modeling conclusion is that besides the uranium ore processing wastes inside the tailings, the major source of radionuclide migration to groundwater is represented by contaminated geological deposits below the tailings. This last source has formed due to leakage of wastewaters during the operational period of the “D” tailings (1954–1968). Therefore an exemption and re-disposal of wastes from the “D” tailings to a safer storage location (proposed by some remedial plans) will not provide significant benefit from the viewpoint of minimizing of radionuclide transport to the groundwater and Dnieper River (especially in short-and medium-term perspective).

4. CONCLUSIONS

The development of the comprehensive system of the hydrogeological monitoring for the PCh.P site is an urgent issue considering serious groundwater contamination problems at the site and proximity of Dnepr River.

It is necessary to further extend the existing network of monitoring wells and to train the personnel of the enterprise “Barrier” in groundwater monitoring and sampling.

For more reliable groundwater modeling analyses it is important to carry out a number of additional site characterization and research activities:

- Characterize physical and chemical forms of radionuclides in tailings;
- Characterize spatial distribution of radionuclides in the waste sites;
- Estimate site-specific distribution coefficients of radionuclides for the geology materials at PChP site.

The future remedial measures for the PCh.P site should be based on careful modeling and risk assessment of radionuclide transport and on “cost benefit” analysis of different remedial options.

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URANIUM ISR MINE CLOSURE — GENERAL CONCEPTS AND MODEL-BASED SIMULATION OF NATURAL ATTENUATION FOR SOUTH-AUSTRALIAN MINE SITES

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Abstract

Heathgate has demonstrated the effect of natural attenuation (NA) in post in-situ recovery (ISR) aquifer regions during the operation of the Beverley mine since 2001. Enhanced natural attenuation (ENA) has been considered as the key component of the mine closure concept for the new Beverley Four Mile (BFM) project, complemented by an extensive monitoring program. Data from batch and column tests for BFM core samples was used to calibrate a reactive transport model, whose application in conjunction with the hydrological modelling of the BFM aquifer has shown that NA will result in the restoration of the aquifer in time. ENA within a staged mine development program under the site-specific circumstances is discussed.

1. INTRODUCTION

Heathgate operates the Beverley uranium mine and is currently developing the nearby BFM project on behalf of a Quasar Resources — Alliance Resources joint venture. Both sites are located on the arid plane between the Flinders Rangers and Lake Frome, approximately 550 km North of Adelaide (South Australia), and 120 km distant from the nearest regional township of Leigh Creek. ISR technology has been thoroughly adapted to the local conditions at Beverley and is applied in a moderately acidic milieu, mobilizing uranium in the aquifers by oxidation with hydrogen peroxide [1]. In particular, the optimization of ISR technology under the local constraints resulted in a stringent minimization of process waste water volumes from U processing (discharged to abandoned wellfields in isolated ‘bathtub’ aquifers) without producing radioactive solid waste [2].

For the new BFM project where mineralization is within a slow-moving flow-through groundwater system, a mine closure concept including groundwater has been developed considering state-of-the-art technology under local hydrogeological conditions. World best-practice technologies include (i) groundwater sweep either in combination with active water treatment (e.g. reverse osmosis) or by the exchange of post-mining fluid in abandoned wellfields against the natural groundwater from wellfields to be started up; (ii) in-situ treatment by injecting reactive chemicals (e.g. reductants like sulphides to immobilize metals); (iii) NA to be monitored reliably in any case (MNA) and, if required, in combination with pro-active measures as groundwater sweep or in-situ (ENA). The concept of NA has gained increasing acceptance, in particular in the field of uranium ISR [3] [4], but there were a few attempts only to predict the effect of NA for given geochemical conditions. A recent U.S.G.S. publication [5] describes the use of the geochemical code PhreeqC [6] to simulate groundwater restoration within ISR aquifers.

Section 2 demonstrates the evidence of NA observed within the Beverley aquifer so far. Section 3 outlines the mine closure concept for the new BFM (under similar mineralogical/geochemical conditions compared to Beverley), emphasizing the potential of NA/ENA as well as the specific constraints regarding waste generation and disposal which limit the applicability of active water treatment methods. A new methodology to predict the effect of NA within and downstream of completed ISR wellfields, which is based on a reactive transport model calibrated on the basis of appropriate tests with core samples, and its application to BFM mining scenarios are described in Section 4, followed by conclusions.

2. EVIDENCE OF NA EFFECTS AT BEVERLEY MINE

The Beverley mine is located in an arid region with no access to surface water for the mining operation. The plant and aquifer water balance has to be kept in view of the lack of available water of suitable quality, and a limited liquid waste disposal capacity. Water for mine operation and U processing is drawn from two main sources: the Namba Formation (mined) aquifer, and the underlying Great Artesian Basin (GAB) aquifer, separated from the Namba aquifer by a thick clay layer. The poor quality Namba water is utilised as crude process water. Relatively high-quality GAB water use is highly regulated. It is used sparingly for specific purposes including potable water supply after desalination. Minimized liquid waste volumes are disposed of through injection into previously mined sections of the confined Namba aquifer, thoroughly balancing liquid waste injection against groundwater extraction. In order to meet this neutral water balance requirement, liquid waste volumes are reduced through evaporation prior to injection into the aquifer. Since the natural groundwater within the confined and stagnant Beverley mining aquifer had been of extremely poor quality (saline with elevated radionuclide concentrations) meeting no use category, the very specific waste disposal at Beverley has been identified and proven as the option of lowest risk to the environment under the specific circumstances and has been approved by regulatory authorities under the condition of demonstration that NA be progressing at a satisfactory rate. First indications of NA in mining areas after the field leach trial were described in [7], showing naturally increasing pH from about 2 to about 3.2 over six years (1998–2004)². The specific crude process water supply from Namba wells, balanced against the waste water discharge, resulted in an induced temporary flow within the Namba aquifer. Figure 1 shows water quality data from one of the Namba wells as an representative example, clearly indicating the occurrence of more saline post-mining/waste water (two-step increase of Cl and SO₄ levels), but with a considerably retarded decrease of pH. Uranium has been below the detection level (about 1 mg/L for the on-site XRF) all the time. This illustrates the neutralisation potential of the remaining reactive minerals in the formation, leading to the efficient immobilization of U.

² The specific location where that data was sourced was consequently used for mining so no further data could be collected to check this trend over a longer time frame. The mining schedule is now far enough advanced that data examining the progress of natural attenuation in selected mined-out areas will be collected beginning in mid 2009.

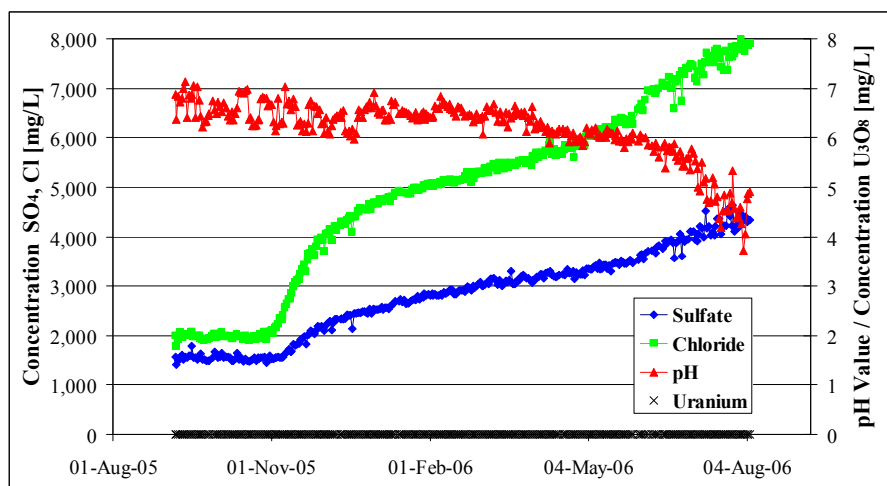


FIG. 1. Breakthrough of mining fluid in a well for process water supply.

From the very beginning of Beverley operation in 2000, Heathgate has implemented and further developed an extensive groundwater monitoring program. A numerical hydrological model of the Namba aquifer serves as a predictive tool for mapping the flow conditions. A comprehensive monitoring program for the post-mining areas has been implemented and will be followed up in conjunction with the model-based assessment of data.

3. BEVERLEY FOUR MILE PROJECT, MINE CLOSURE CONCEPT AND BASELINE CONDITIONS

The BFM deposits (East and West) are located 8–10 km northwest of the Beverley Plant. BFM East will be mined first and is located within Tertiary age sediments of the Eyre Formation (older than the Namba Formation where the Beverley deposits are located). The pregnant lixiviant from the BFM wellfields will be pumped to a new satellite sorption plant at the site to recover uranium by ion exchange (IX), then it will be chemically conditioned (H_2SO_4 , H_2O_2) and recycled as barren lixiviant to the wellfields (ISR loop). The loaded resin will be transported by road to the existing Beverley plant for elution and further down-stream processing to uranium concentrate (“yellow cake”). After commissioning the new BFM ISR operation, a (minor) water bleed from the mining cycle will be used as crude process water for the Beverley plant operation, thus, reducing and later substituting the use of Namba Formation water. The disposal of liquid waste into the abandoned Namba mining aquifer will continue. In order to keep the water balance within the Namba aquifer, the post-mining solution will be drawn from the Namba aquifer, pumped directly or via uranium recovery to the evaporation ponds for volume reduction and re-charged into the Namba aquifer together with the liquid waste. As described in Section 2, the immobilization of uranium, other radionuclides and dissolved metals will be governed by NA, but the NA effect needs to be quantified and further monitored for possible adjustment the groundwater management arrangements looking towards eventual site closure. The strategy is to achieve the lowest possible impacts taking into consideration groundwater use category, waste production, energy consumption, surface impacts and costs. Lowest impact methods need be considered in this complex manner.

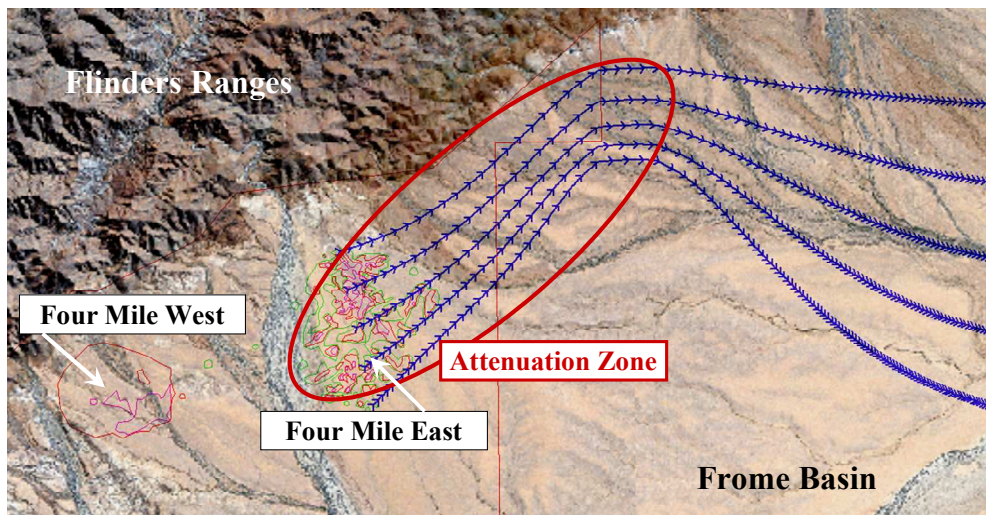


FIG. 2. Groundwater flow from BFM East (from regional hydrological model) with the pre-defined attenuation zone (7 000 m extension in flow direction).

In contrast to the stagnant mining aquifers at Beverley, the mining aquifer at BFM is part of a slow-moving flow-through groundwater system. The BFM mine closure concept therefore involves enhanced natural attenuation (ENA) with a 7 000 m long attenuation zone as shown in Fig. 2 (down-stream groundwater flow profile from a regional hydrological model [8]). The time for groundwater to traverse the attenuation zone is about 450 a. The observed baseline levels of the groundwater in the BFM aquifer include: salinity (TDS) — 1 900–4 100 mg/L; U — <0.001–0.09 mg/L; Ra — up to 239 Bq/L; F — 2–18 mg/L (variation range from many samples). According to ANZECC limits [9], the groundwater within the attenuation zone is not suitable for potable, irrigation nor stock use due to one or more of the above constituents.

The ENA options under the constraints of the BFM/Beverley site (overall water balance, limited capacity for liquid waste disposal into the abandoned mine areas at Beverley, no deep disposal for liquid waste disposal, non-acceptance of solid radioactive waste) there are the following main options of enhancing NA within the attenuation zone: (i) groundwater sweep by the exchange of post-mining fluid in abandoned wellfields against the natural groundwater from wellfields to be started up (within water balance constraints) and (ii) in-situ remediation by the injection of reagents³. Active treatment methods leading to waste production on surface should be avoided. The groundwater closure plan comprises a *staged approach*. Stage 1 includes the site investigation and assessment of the NA potential based on state-of-the-art methodology prior to mining as described in the following Section 4 (part of the approval process). During active mining (stage 2) thorough monitoring will provide real-world data to validate model-based NA predictions, to implement and optimize NA enhancement methods, and to adjust the model for more reliable predictions (*including ENA scenarios*). After mine closure, stage 3 comprises post-mining monitoring in the abandoned wellfields, in the attenuation zone and other relevant areas in the formation, further remediation measures if required and continuation of predictive modelling (iterative

²A watching brief is being kept on other technologies such as in-situ reactive barriers (introduced by bores as trenches to over 200 m depth are infeasible), and pump-and-treat technologies.

improvement based on real data). Fig. 3 illustrates a possible configuration of the mining fluid plume 10 years after mining (against mine zone outline) using a simplified 2-D model (in addition to the model described in Section 4). It is for illustrative purposes only showing the migration and early dissipation of the plume. Contours are relative to a starting concentration of 100 nominal units.

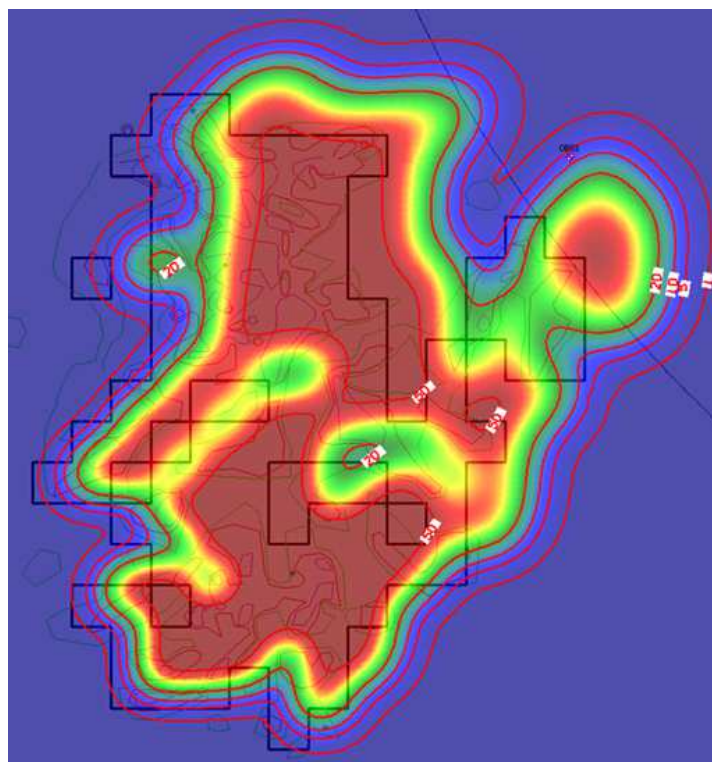


FIG. 3. Predicted mining solution contour 10 years after mine closure (conceptual diagram from hydrological model). The black outline shows the mining zone.

4. REACTIVE TRANSPORT MODEL SIMULATION OF NA AFTER BFM MINE CLOSURE

In order to demonstrate the effect of NA in both mining and post-mining scenarios for the BFM operation, a comprehensive work program (stage 1) has been established which comprises groundwater flow modelling (cf. Figs 2 and 3), geochemical laboratory test work (Section 4.2), geochemical reactive transport modelling (Sections 4.1 and 4.3) and iterative NA model validation and assessment (staged approach described above). It considers mineralogical data from core investigations as well.

4.1. Numerical model for reactive transport simulation

A novel reactive transport model (TRN) combines transport (*advection* and *dispersion*) in a *dual-porosity approach* with geochemistry (*thermodynamics* with the chemical equilibrium module PhreeqC as subroutine and *kinetics* with various, case-specific options) [10]. TRN keeps mass and charge conservation inherently. There is no numerical dispersion.

The model does clearly distinguish between primary mineral phases in the formation (to be dissolved/leached) and secondary phases (precipitated under certain chemical conditions).

4.2. Geochemical laboratory tests for model calibration

For model calibration purposes, both batch tests and dynamical column tests were performed with representative core samples and mining fluids.

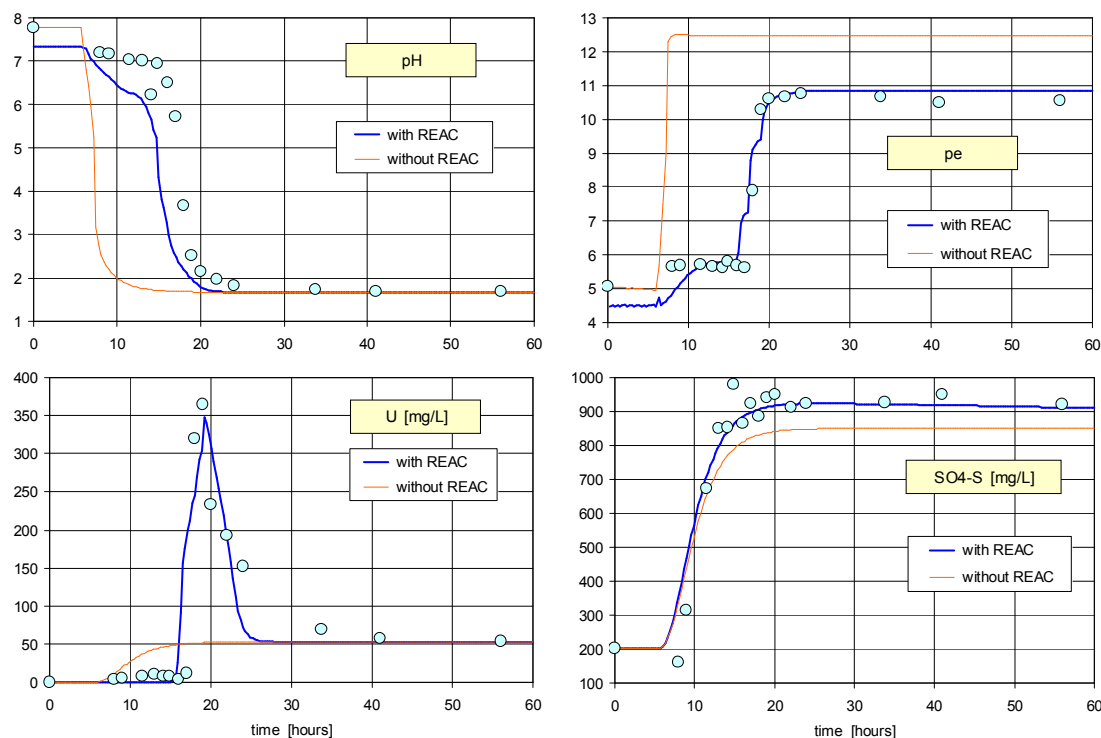


FIG. 4. Column test data in comparison with (calibrated) TRN results. For comparison, results from calculations with and without reactions (REAC) are shown.

As known from mineralogical studies and also reflected in the lab tests, uranium is mainly found as coffinite in fine to coarse grained quartzose sands, whereas both ISR chemistry *and* NA are mainly defined by the reactive minerals pyrite (reducing), calcite (fast neutralizing), kaolinite (slow neutralizing) as well as other silt/clay minerals with ion-exchange capacities. The thermodynamic and kinetic database has been extended for this application in order to reproduce the test results from both batch and (dynamic) column tests in a *consistent* manner. Figure 4 shows the time dependence of pH, pe as well as U and SO₄-S concentrations in the backflow solution. The difference between the calculations with and without reactions demonstrates the retardation effect caused by geochemical reactions and ion exchange.

4.3. NA scenarios and results

The up-scaled model was applied to realistic mining/post-mining scenarios at BFM to demonstrate the effect of NA on groundwater restoration (return to chemically neutral and reducing conditions), in particular the immobilization of dissolved uranium. Scenario 1,

assuming a wide, 1 km ISR mining area (“ISR block”), is represented in Figs 5 and 6 for two cases: first for pure NA, second for ENA by groundwater sweep.

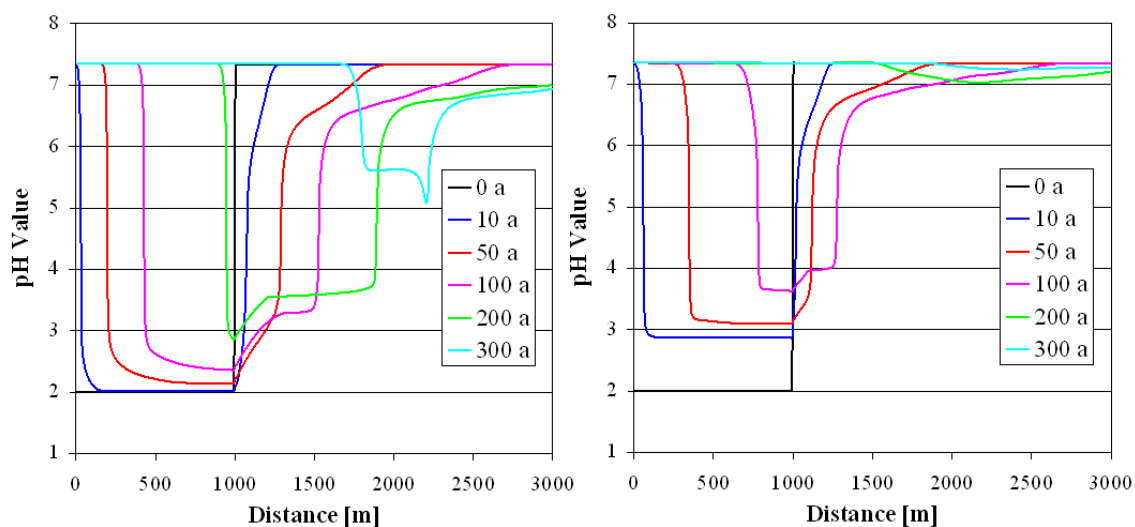


FIG. 5. TRN results for pH-scenario 1 (ISR block): Pure NA (left) vs. ENA (groundwater sweep). Results shown for various times after mine closure (parameter in legend).

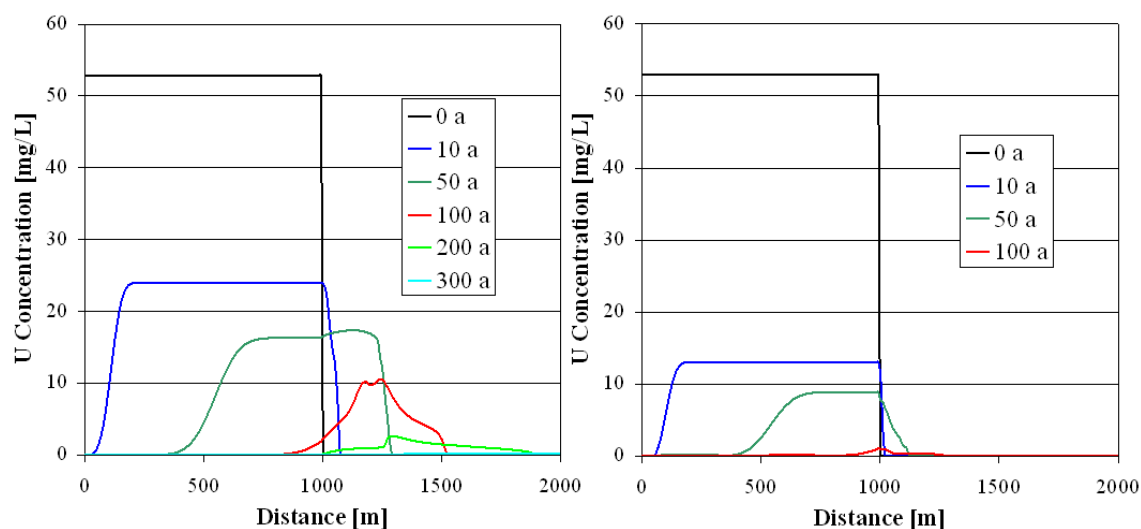


FIG. 6. TRN results for U-scenario 1 (ISR block): Pure NA (left) vs. ENA (groundwater sweep).

Fig. 5 shows that in the “ISR block” scenario NA alone would result in a maximum range of the acid (pH) front of about 1.5 km down-flow the mining area, to be neutralized within about 300 a. Groundwater sweep (one pore volume exchange) would reduce this range to about 500 m, achieved within about 150 a. Uranium will be immobilized in a much shorter range: 600 and 150 m for the pure NA and the ENA scenarios, respectively (achieved within 200 a and less than 100 a, respectively).

The “ISR block” scenario, i.e. post-mining water in the whole aquifer within a diameter of 1 000 m, is an absolutely conservative assumption. In reality, the BFM East deposit is rather patchy with ore lenses in up to 4 horizons. Accordingly, scenario 2 considers small ISR spots within the mining area as shown in Fig. 7 (share estimated from a recent assessment of economic ISR ore regions). Under such conditions, pure NA will result in the neutralization of the acid front within 50 a at a much shorter range (a few hundreds m). U would be immobilized within the mining zone within 30 a.

The (calibrated) TRN model predicts a limited impact within the attenuation zone with a range of acidity and contamination considerably less than the length of the (pre-defined) attenuation zone (7 000 m).

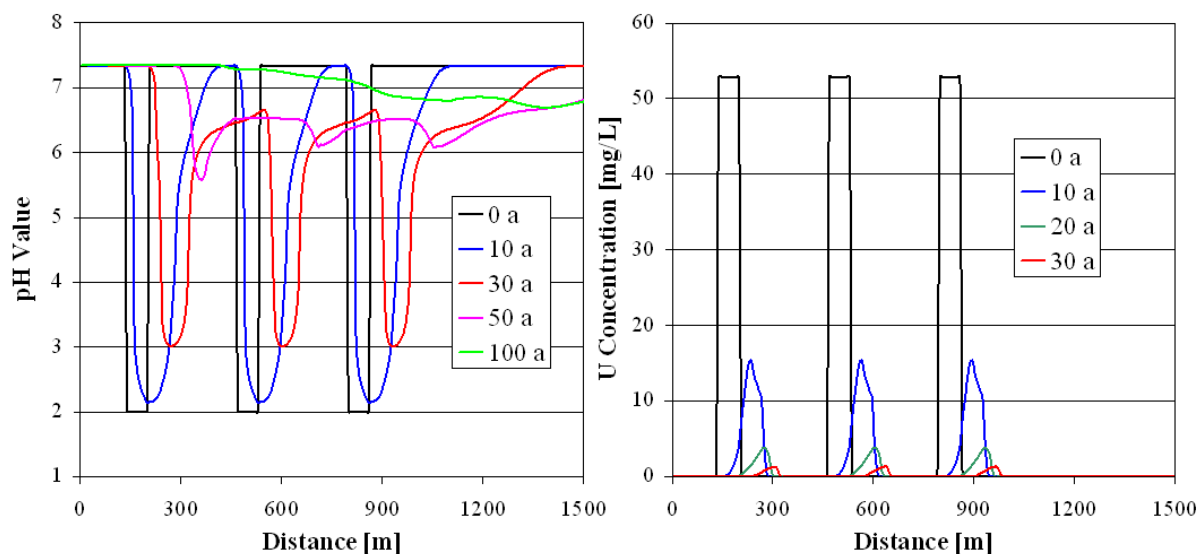


FIG. 7. TRN results for pH and U-scenario 2 (patchy ISR lenses — pure NA).

Heathgate has proposed a monitoring plan for BFM as an essential part of the staged groundwater remediation plan discussed in Section 3. Groundwater monitoring will be undertaken during and after mining to assess if NA within the attenuation zone is occurring as predicted. The process of NA will be kick started (enhanced) by transferring mining solution from old wellfields to new wellfields such that approximately one pore volume exchange with clean water is achieved at the closure of each wellfield. The results of monitoring will be compared to the groundwater quality predicted by TRN. If monitoring results are consistent with the model predictions of groundwater quality in the short term, then NA will be considered effective and monitoring will continue for the specified post-mining period. If monitoring results show that post mining groundwater quality is not consistent with predicted water quality, the geochemical model will be revised and recalibrated with the new data. The long term predictions of NA will be repeated with this recalibrated model and the likelihood of achieving aquifer remediation outcomes will be re-assessed. If the refined geochemical modelling shows that groundwater remediation outcomes will not be achieved through NA then alternative remediation strategies will be reviewed and implemented.

5. SUMMARY AND CONCLUSIONS

Heathgate has proposed a BFM mine closure plan including the most essential part of groundwater remediation, which is consistent with best-practice technologies as applied to the specific local circumstances. Enhanced natural attenuation (ENA in combination with a rigorous monitoring) will be implemented in a staged (iterative) approach. The main remediation measure, which is predicted to provide a suitable outcome, will be a one-pore volume flush of mined-out areas with natural groundwater (groundwater sweep). This approach will be in close conjunction with reactive transport model predictions and data-based assessment/adjustments/validation of the model to demonstrate that the remediation outcome will be achieved. Should effects not meeting the mine's approval conditions be predicted by the re-calibrated model runs, there will be consideration of options of further enhancing NA effects in the context of minimizing environmental impacts. The remediation of the groundwater down-flow the mining zone will not reduce the use category within the attenuation zone and beyond, as required by the mine's approval conditions.

The TRN approach refines a recent U.S.G.S. study of groundwater restoration after in-situ leach mining [5] (based on PhreeqC) by introducing a well-calibrated model in a more realistic model space and run at higher resolution.

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RECENT PILOT PLANT EXPERIENCE ON ALKALINE LEACHING OF LOW GRADE URANIUM ORE IN INDIA

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Abstract

Uranium deposits in India are low grade and are relatively smaller in extent as compared to present worldwide commercial practice. So far, the vein type deposits of Singhbhum Thrust Belt (STB) are being exploited for meeting the Indian requirements of uranium. The deposits are currently processed by acid leaching in the mills located at Jaduguda and Turamdih near Jamshedpur in Jharkhand State of India. The deposits at Jaduguda and Narwapahar are being mined by underground mining and are processed in Jaduguda mill using air-agitated Pachucas. The deposits at Banduhurang and Turamdih are being mined by open cast and underground mining respectively and are processed at Turamdih by acid leaching in mechanically agitated reactors. The occurrences of uranium in North East and Northern part of Kadapa basin are relatively moderate in size and are expected to be processed in the near future by acid leaching. Uranium is also found to occur near Tummalapalle in granitic and limestone host rocks in Southern part of Kadapa basin (Andhra Pradesh) and in Gogi in Bhima basin (Karnataka). The deposit in Tummalapalle is relatively lower in grade ($\approx 0.042\%$ U_3O_8) but is a reasonably large reserve, whereas that in Gogi is rich in uranium content ($\approx 0.18\%$ U_3O_8) but is relatively small reserve. Laboratory tests based on alkaline leaching have been carried out on both types of deposits. Studies for Tummalapalle deposits have been extended to pilot plant level and a complete flow sheet has been established with the regeneration and recirculation of lixiviants and recovery of sodium sulphate as a by-product. The process involves alkaline leaching under oxygen pressure in batch type and/or continuous leach reactor using sodium carbonate/bicarbonate as a leaching media and uranium is recovered as sodium diuranate. Based on the techno-economic evaluation of the process, an industrial scale mill (3 000 tonnes ore/day) is being set up at Tummalapalle in Andhra Pradesh by Uranium Corporation of India Limited. Based on the laboratory studies this paper would present pilot plant experience on alkaline leaching of Tummalapalle deposits.

1. INTRODUCTION

Energy, especially electricity, is a key input for accelerating the economic growth of a nation. In order to sustain the country's present level of growth of GDP with rapidly growing population and the escalating demand, the rate of growth in the primary energy should be aimed adequately high for the next five decades. Full potential of hydro and non-conventional renewable resources is expected to be exploited. In the case of nuclear power sector, the ongoing PHWR, LWR and FBR programmes would still form a small fraction of total energy generation. The development of U-Pu metal based FBRs of requisite breeding characteristics and associated fuel reprocessing technologies are expected to be completed in the next 15–20 years [1]. Fast breeder reactors have the potential to ensure that generation by nuclear power by the middle of the present century is about a quarter of the total electricity generation and this would help in maintaining the energy import to the current level of about 30% without further increase.

At present, there are 17 operating nuclear power reactors generating power slightly above 4 000 MW. Amongst these 15 of them are PHWRs and the remaining two are LWRs. Till recently, all the uranium required for the Country's PHWRs was coming from the only uranium mill at Jaduguda, Jharkhand, operated by Uranium Corporation of India Limited (UCIL). Another uranium mill has recently been added by UCIL at Turamdih, Jharkhand and started commercial production since last year. The Jaduguda mill processes ore feed mined from the mines at Jaduguda, and the nearby mines at Narwapahar and Bhatin, while the

Turamdih mill processes ore from Turamdih underground mines and Banduhurang open cast mines. The process flow sheets adopted in both these two mills are the same except for a few minor changes, which involve mild sulphuric acid leaching of the ground ore, followed by ion exchange to purify the leach liquor and two stage precipitation with the magnesium diuranate coming out of the second stage precipitation. All these mines are located in Singhbhum Shear Zone (SSZ).

In view of the operating PHWRs and additional of PHWRs being set up as well as planned by Nuclear Power Corporation of India Limited (NPCIL), the demand for the natural uranium based fuel has gone up significantly. This necessitated intensive exploration to locate, prove and estimate new uranium deposits in the country and their commercial exploitation. The exploration wing of the DAE, Atomic Minerals Directorate for Exploration and Research (AMD) has discovered and proved a number of workable uranium deposits outside the SSZ. These include the Sandstone type deposit at Meghalaya, middle proterozoic type and strata-bound type deposits at Andhra Pradesh and medium grade vein type deposit at Karnataka. A brief account of uranium occurrence in India is documented in literature [2]. The acid leaching flow sheet being practiced in Jaduguda and Turamdih mills is not universally applicable for all these other ores. The process to be adopted for exploitation of any ore depends on the nature of uranium mineralization, mineralogy and morphology of the uranium minerals and the gangue, liberation size, presence of other valuable minerals/metals in the ore, etc. Although the generic process flow sheets are well documented in literature [3], the process flow sheet has to be specifically developed for every ore, based on the laboratory and pilot plant test data for the best exploitation of the deposit.

Realizing the necessity for large scale testing of various uranium ores of the country, a pilot plant was conceived and was set up with a reasonable scale of operation. This pilot plant was designed to include all the stages from ore-to-yellow cake normally applied in the generic flow sheet for uranium extraction. First tests in the pilot plant were carried out for Tummalapalle uranium ore by alkaline pressure leaching. This paper presents and discusses the salient features of the pilot plant and the experience gained by its trouble free operation for sufficiently long periods and the scale-up and engineering data generated.

2. PILOT PLANT LOCATIONS

The need for the pilot plant has already been partly emphasized in the previous Section. When the PHWRs operating in the country were a few in numbers, the demand for natural uranium fuel was also limited and the entire need was being met from production from Jaduguda mill. However, with the growing number of PHWRs the demand of uranium has significantly increased. It has become essential to augment the indigenous uranium production by opening up new mines and setting up of new milling facilities. Since the ores from these mines have different mineralization and characteristics the existing acid leaching route being practiced at Jaduguda cannot be used. While the basic technically feasible process scheme can be developed in the mineral processing laboratory based on bench scale studies, the translation of laboratory process into a full-fledged industrial and commercial venture requires additional parameters, normally unavailable with the laboratory data, and need to be generated. For this purpose, a pilot plant with an appropriate scale of operation is necessary. The pilot plant tests are also needed to confirm the flow sheet developed based on the laboratory studies, to study effects of re-circulating process streams and of build-up of constituents on the system performance, optimization of design of equipment (including selection, sizing and lay-out) and to generate process engineering parameters for scale up and

design of full sized plant, obtain sufficient information to prepare detailed and reliable estimates of capital and operating costs for techno- economic evaluation of the Project.

With sizeable uranium resource identification in RAR category in locations like, in Meghalaya, in Lambapur-Yellapur- Peddagattu and Tummalapalle in Andhra Pradesh, Gogi in Karnataka and, Rohil-Ghateswar in Rajasthan, plans have been drawn to assess techno-economics of setting up additional uranium mines in some of these locations. The process technology needs to be developed indigenously and technology development indeed requires large scale studies in the pilot plant for generation of engineering and scale-up data.

In addition, if there are any process related issues in the currently operating uranium mills, due to change in the ore tenor, grindability characteristics of the ore, gangue mineralogy or other disturbing variables, requiring process modifications, they can be implemented after verification in the pilot plant as otherwise the modifications run a risk of adversely affecting the regular uranium production.

A pilot plant was set up at the Jaduguda in the uranium mill complex. This had many advantages to offer, the benefits of the entire infrastructure and other logistics that would be available in an existing and operating uranium plant the availability of trained manpower for maintenance of various process equipments, and more importantly, facilities for disposal of the tailings generated from the pilot plant. Based on the laboratory studies on Tummalapalle ore it was decided to test the process flowsheet on pilot plant scale for exploitation of Tummalapalle uranium ore.

TABLE 1. MINERALOGICAL COMPOSITION OF THE TUMMALAPALLE ORE SAMPLE

Mineral	Weight %
Carbonates	79.80
Quartz and feldspar clasts	12.15
Collophane	3.90
Chlorite	1.20
Chert	0.82
Pyrite	1.24
Chalcopyrite & Galena	0.06
Magnetite	0.18
Ilmenite inclusive of leucoxene	0.23
Iron hydroxides [goethite]	0.41
Pitchblende in intimate association with pyrite	0.01

3. EXPLOITATION OF THE TUMMALAPALLE URANIUM ORE DEPOSIT

The host rock for uranium mineralization in Tummalapalle deposit is siliceous dolomitic phosphatic limestone, only alkaline leaching route is viable for the recovery of uranium values. Carbonates form the bulk of the Tummalapalle ore constituting 79.80 wt%. The quartz-feldspar assemblage and collophane constitutes significant proportion of the ore

amounting to 16.05 wt%. Pyrite is the common sulphide ore mineral occurring mainly as swarms of minute pellets in dolomicrite, isolated clusters of coalesced pellets and idiomorphs. Chalcopyrite is seen as distinct grains of varying sizes. Magnetite and ilmenite are the oxide ore minerals. Goethite is the significant ore mineral and is derived from the alteration of pyrite. The complete mineralogical composition of a typical sample is given in Table 1. Chemically, the ore assayed 0.048% U_3O_8 and about 1.6% total sulphur. Almost all the sulphur was accounted by pyrites in the ore.

In view of the preponderance of the acid consuming gangue minerals, namely an intrinsic mixture of limestone and dolomite, acid leaching was precluded for economic exploitation.

Extensive laboratory studies indicated that alkaline leaching under elevated pressure and temperature conditions was essential for maximum leaching of uranium values. However, on account of the high selectivity of alkaline leaching, the leach liquor did not contain any deleterious metal cations and could be taken straight for the yellow cake precipitation stage without going through the purification steps of ion exchange. Since the barren liquor obtained after yellow cake precipitation contained significant amounts of unused leachants and precipitant and also sulphates formed by the dissolution of pyrites, efforts were made to regenerate the reagents for recycle and also recover sodium sulphate as a by-product.

4. PILOT PLANT DESIGN

The first and foremost thing to be decided was the scale of the large scale tests to be conducted in the pilot plant which will give reasonably good and reliable data for detailed engineering design. After considering various factors it was decided to set up the large scale test facilities with a throughput of 100–200 kg/h for the main stages of the process, such as leaching and other downstream operations. For uranium mills with throughputs of 1 000–5 000 tonnes of ore per day, the pilot plant tests at a feed rate of 100 kg/h will reportedly yield data on scale-up and design reliable and usually acceptable for most of the process equipment [4].

The pilot plant included crushing plant, grinding and classification circuit, dewatering equipment and re-pulping set-up, leaching reactors, solid-liquid separation devices for leach slurry, facilities for uranium concentration in leach liquor and precipitation and waste management facilities to process the leach residue and disposal. All the equipment to be used for various unit operations were suitably linked with each other by appropriate material handling devices.

4.1. Size reduction facilities (crushing plant and grinding mill- classifier circuit)

The crushing plant was set up outside the process plant shed. It houses a coarse ore bin (COB), a jaw crusher (JC) for primary crushing, a double-rolls crusher (RC) for secondary crushing, a two-deck vibratory screen (VS) for intermediate screening and a fine ore bin (FOB). All these units are inter-linked through 4 Nos. belt conveyors. Dust extraction systems contain the dust generated near the feed points and water-sprinklers were provided on the belt conveyors. The crushing plant is schematically shown in Figure 1. The COB is provided with a 150 mm × 150 mm (6" × 6") square grid mesh to prevent oversize particles getting into it. The COB can store upto 6 tonnes of r.o.m ore. The overall throughput of the crushing plant is about 2 tph. The crushing plant receives material in the size 150 mm (6") and below and the

final product is at 6 mm ($\frac{1}{4}$ ") size which is stored in the FOB, which is located inside the process plant shed.

The plant was run continuously for large scale tests on Tummalapalle ore. About 50–60 tonnes of ore was crushed in the crushing plant for the large scale tests. The FOB discharges the ore to a ball mill-screw classifier grinding circuit located in the process plant. The ball mill was designed for a fresh ore throughput of about 200 kg/hr. The mill product, the classifier overflow product (COP) was designed to get pumped to a high rate 8 ft (2.54 m) dia. thickener.

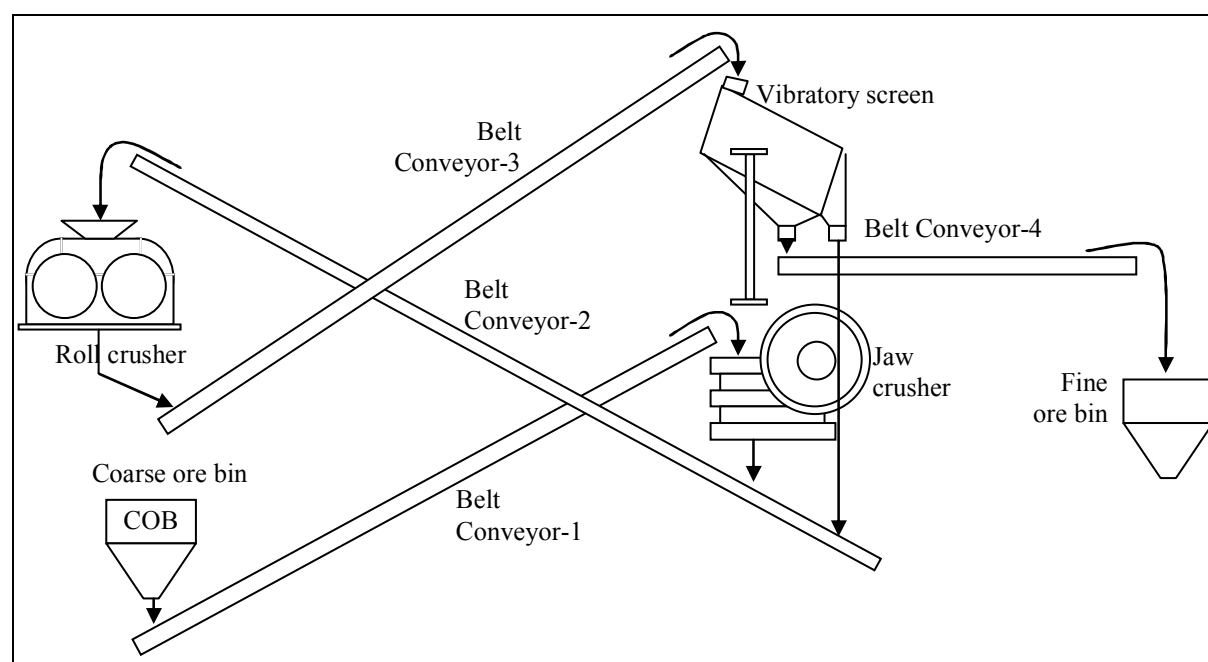


FIG. 1. Schematic view of the crushing plant at TDPP, Jaduguda.

4.2. Alkaline pressure leaching

For carrying out the alkaline pressure leaching studies on Tummalapalle uranium ore, two pressure reactors — one batch type and the other continuous type — were designed and procured.

The batch reactor is a 850 l capacity dished-end cylindrical shaped vertical pressure leaching reactor. Agitation is provided with impeller operated through a variable frequency drive (VFD). The design temperature and pressure of the reactor are 180°C and 15 kg/cm² (g) respectively. The reactor contents are heated and cooled by internal cooling coil. Slurry is discharged from the dished-end bottom of the vessel through a flush bottom valve. In all the experiments the slurry is filled to the extent of 45–50% of internal volume, keeping the remaining space for over-pressurization. A sketch of the batch reactor is shown in Fig. 2.

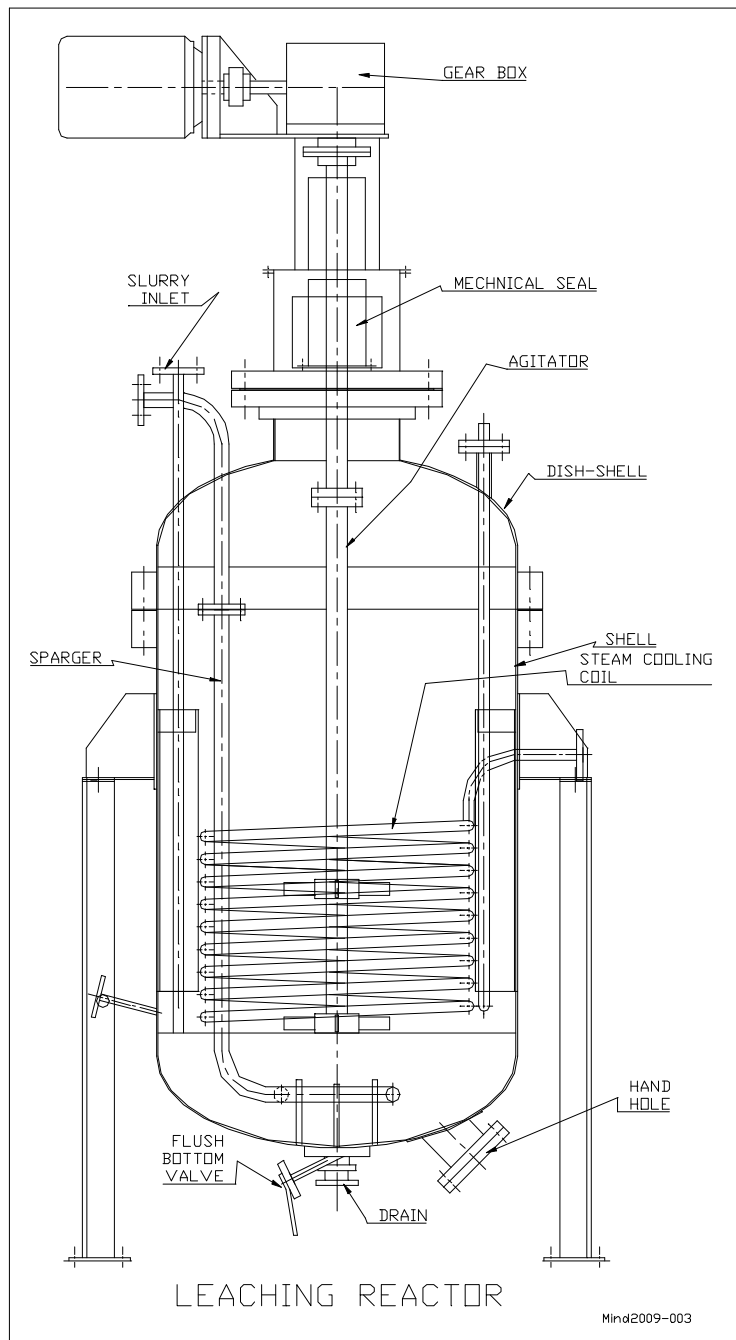


FIG. 2. Sketch of the batch pressure leach reactor.

The batch experiments were carried out with 300 kg of dry ore per batch. After transfer of the ore feed slurry, already conditioned with the required quantities of reagents, was heated to 80–90°C to drive out the air cover and then the vent is closed. The system is pressurized with industrial oxygen to 7–7.2 kg/cm²(g) and thereafter the content temperature is increased to 125–130°C by increasing steam pressure in the coil. After leaching the system is cooled by introducing cooling water in the coil. Once the leach slurry cools down to 40°C, the oxygen pressurization is cut off and reactor pressure is released through the vent. Sampling of the slurry during operation was taken through a side discharge using two stage pressure reductions and cooling arrangement.

In order to carry out leaching in continuous mode a 'Cigar' type horizontally mounted continuous pressure leach reactor (CLR) with a total internal volume of 850 l was designed and procured. The reactor had internal partitions to get 3 compartments with arrangements for agitating the slurry in each compartment with an agitator assembly. The material of construction of the reactor is Inconel 600. The reactor is jacketed outside (SS 304L) for external heating as well as cooling.

The internal chamber of the reactor is divided into three compartments by internal partition plates with weir plate arrangements to provide for smooth overflow of the slurry from one compartment to the other. Minor variations in the partition height and hence the volume of the internal compartments were possible by adjusting the weir plates. Agitation is provided in each of the three compartments operated through a variable frequency drive (VFD). The design temperature and pressure of the reactor are 180°C and 14 kg/cm² (g) respectively.

The feed slurry is fed in the first compartment and the unidirectional inter-compartmental transport is maintained by overflow through the weir plates. The design prevents by-pass from one compartment to the other and the slurry is allowed to have the nominal residence time governed by the slurry flow rate. The slurry discharge from the third compartment is through a dip tube. Provision exists for draining of the slurry from the individual compartments during shut down. Sampling of the slurry during operation is facilitated through a side discharge using two stage pressure reductions and cooling arrangement. In all the experiments the slurry is filled to the extent of 45–50% of internal volume, providing the remaining space for over-pressurization with gases. A sketch of the continuous pressure leach reactor is given in Fig. 3.

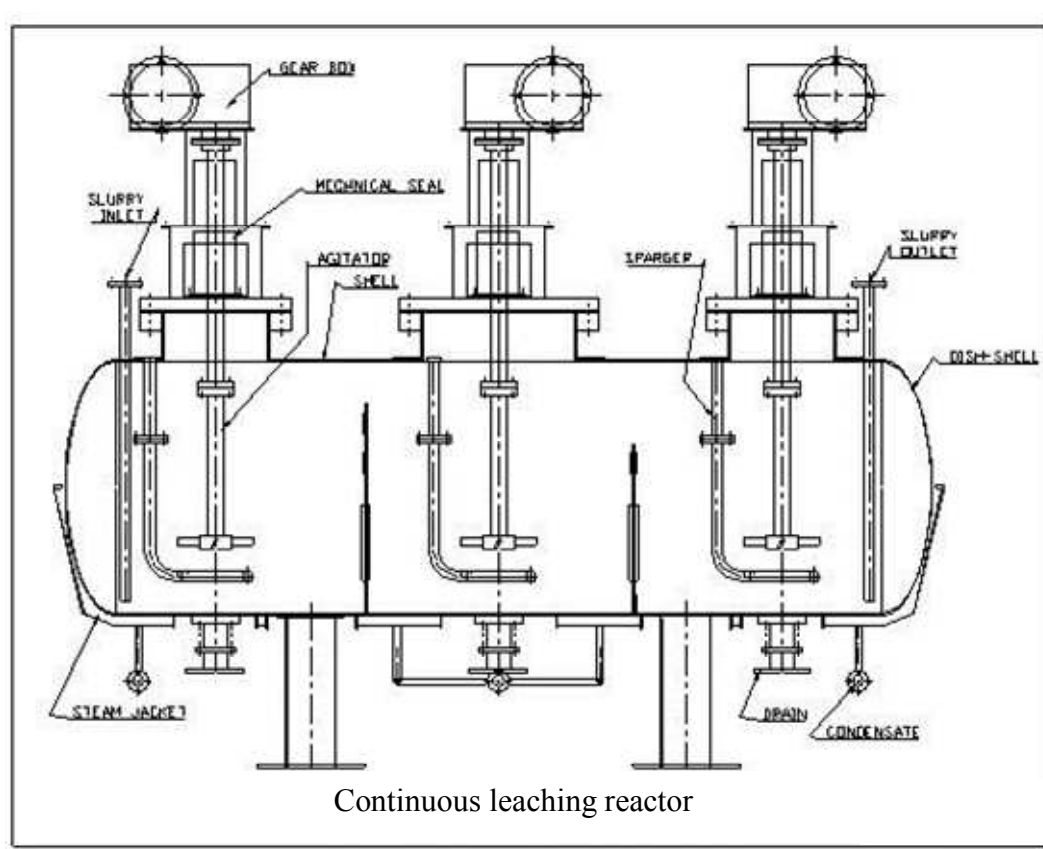
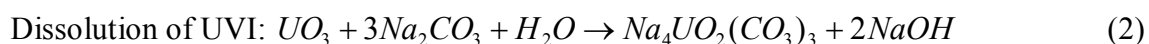
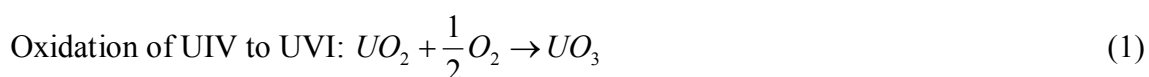


FIG. 3. Sketch of the continuous pressure leach reactor (CLR).

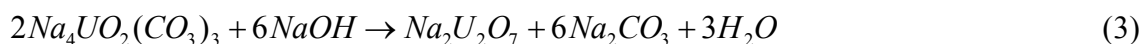
The batch and continuous reactor is provided with instrumentation for measurement and control of temperature. In the case of continuous leach reactor the feed and discharge of the slurry from the pressure reactor are controlled by two separate interlocks. The solenoid valve in the feed-line opens only if the pressure of input slurry is more than the reactor pressure. The discharge of slurry takes place through a dip tube which is in line with a pneumatically operated control valve. The opening of the control valve is interlocked with the level in the third compartment. The level in the third compartment is monitored with a differential pressure transmitter (DP) which sends signals to the control valve.

The CLR is fed continuously with feed slurry at pre-set feed flow-rate with the aid of a screw-pump. The screw pump is operated through a VFD controlled motor for finer and accurate control of the slurry flow rate. The impeller agitation speed in each compartment is set at desired value such that there is no short-circuiting of slurry from one to the other and the overflow over the weir is quiescent. The reactor contents are maintained at 125–130°C under 7.2 kg/cm² (g) over-pressures. The discharge flow-rate of the reacted slurry is matched with feed flow-rate such that there is no build-up in any compartment. The pipes feeding into the CLR and the discharge pipe from the CLR are insulated to check heat losses.

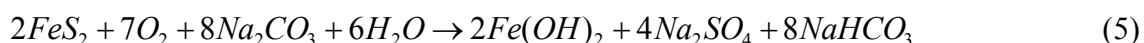
The essential chemical reactions during leaching operations are summarized below.



Prevention of back precipitation of dissolved uranium by sodium hydroxide formed by the buffering action of sodium bicarbonate,



Dissolution of sulphide minerals (pyrites), silica and alumina are given by,



Heat recovery using a spiral heat exchanger (SHE): For efficient utilization of heat energy during leaching, heat recovery from the leach slurry existing the leach reactor with incoming slurry to the reactor is essential. This assumes even more importance while processing low grade ores. Heat recovery studies were therefore carried out in the case of continuous leach reactor. Although many types of heat exchangers are available for the purpose, the spiral heat exchanger was adopted for this purpose, due to its various advantages. Similar heat exchanger has been used in one of the recently opened mills at Namibia. The pressurized leach slurry from the CLR is taken into heat recovery system for bringing down the temperature of the slurry prior to its de-pressurization. A Spiral Heat Exchanger (SHE) of spiral channel width 8 mm and plate width of 40 mm along the exchanger axis (cross

sectional area 0.0032 m^2), 8 m^2 heat transfer area and 8 l slurry holding capacity in each of the channel has been for heat recovery. The functional view of the SHE is schematically shown in Fig. 4. The SHE has ports for receiving (i) the cold feed slurry and (ii) the hot leach slurry discharged from the CLR. The smooth and curved channels result in lower fouling tendency inside the channel. Even if any localized fouling occurs the reduction in channel cross sectional area increases the fluid velocity which scours the fouling. Needless to say — the lower floor space occupied by the entire unit is an attractive design feature. After the exchange of heat from hot leach slurry to the cold feed slurry, the feed slurry goes to CLR and the hot leach slurry is discharged into a filter feed surge tank which is in line with horizontal belt filter. In-line temperature probes are mounted on cold and hot slurry feeding and delivery lines for measuring the temperature.

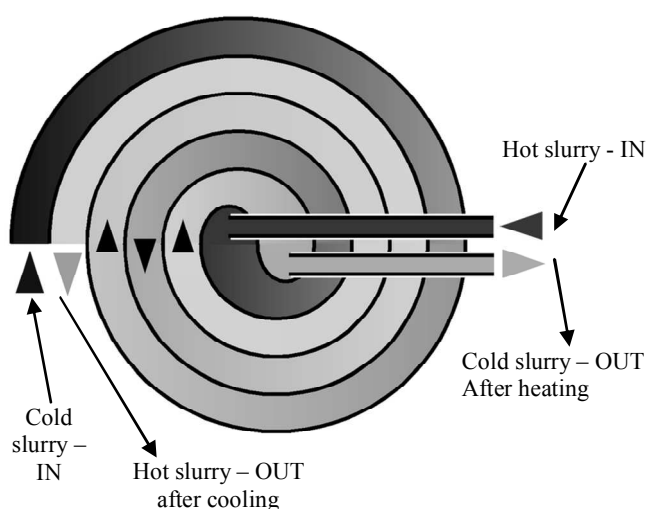


FIG. 4. Functional view of the spiral heat exchanger (SHE).

Solid-liquid separation of the leach slurry using a horizontal belt filter (HBF): The slurry from the pressure reactor was filtered in a Horizontal belt filter (HBF). In the batch mode leaching tests, after the leaching operation the cooled leach slurry is pumped using a vertical sand pump into a surge tank. The surge tank feeds the leach slurry into the feed box of HBF. On the other hand the leach slurry from the CLR passes through the SHE and discharges into the sump pump.

The horizontal belt filter has 2.5 m^2 filtration area with 4 stage counter-current washing facility using a synthetic filter cloth. A water ring vacuum pump provides requisite vacuum over the filter bed length. The SS filtrate collection launder has internal partitions to prevent intermixing of different filtrates viz. cloudy-filtrate, leach filtrate, different wash-water filtrates. Similarly intermixing of wash water between the stages on the top of the filter cloth was prevented by dams positioned alongside the wash-water delivery pipes. Instrumentation is provided for on-line measurement of cake thickness and varying the pumping rate of filtrates or wash solution. The functional arrangement of the pilot plant model HBF is schematically shown in Fig. 5.

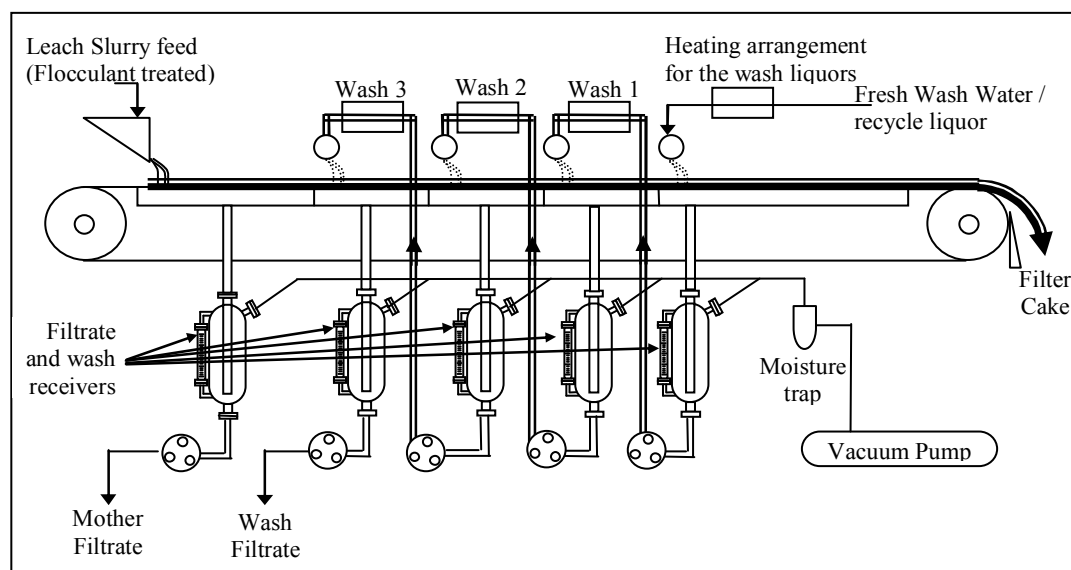


FIG. 5. Schematic view of the horizontal belt filter with four stage counter current wash arrangement (Cloudy port and chamber are not shown for clarity).

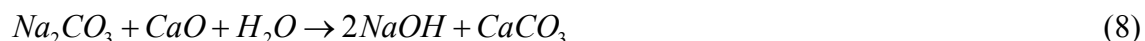
The leached slurry is fed on to the filter cloth at pre-set flow-rate through a pulp distributor. The leach residue was washed counter-currently in four stages, with fresh plain wash-water in the first stage. Each of the filtration zones were followed by dewatering zones for trace removal of solution from the cake. Counter-current washing helps in removal of dissolved uranium values from the filter cake and also maximizes the solute concentration. The leach filtrate and wash filtrate were collected into separate containers for further processing. The filter cake forms the leach residue, which is rejected as tailings. The filter cake is discharged at the end of the filtration-cum-washing-cum drying using knife discharge. The leach residue, collected in a launder is mixed with water and flows into to the tailings tank.

The leach slurry is dense because of high pulp density; and the liquor in the slurry is highly viscous because of the large amount of dissolved solids and alkaline content.

Yellow Cake Precipitation: The dissolved uranyl carbonate complex present in the leach filtrate is precipitated in the form of sodium diuranate (SDU — the yellow cake) using sodium hydroxide (caustic lye). Since the leach filtrate obtained from horizontal belt filter is turbid in nature it is further clarified using fine pore filter cloth in a Neutsche Filter and clarified leach liquor is taken for precipitation. Commercial caustic lye flakes were first dissolved in water to remove the muck and other insoluble extraneous matter. The insolubles were removed by filtration. The concentrated caustic lye filtrate solution was added to leach filtrate in controlled manner under constant agitation. After the required contact time the yellow cake slurry was filtered in a Nutsche Filter and SDU was collected as solids and the rest as filtrate (SDU Barren). The SDU cake was washed with plain water and the washings were collected separately. The washed SDU was dried and stored as product. The barren liquor was processed for reagent regeneration and recycle.

Reagent regeneration from the SDU barren: During the precipitation stage caustic soda (NaOH) was added in excess of stoichiometric requirement to decompose the sodium bicarbonate present in the leach filtrate. The SDU barren obtained by filtration of the SDU slurry contained substantial amount of sodium carbonate, sodium sulfate produced by the oxidative dissolution of the pyrite and other sulphide minerals and small amount of sodium hydroxide remaining after SDU precipitation. Since considerable amount of sodium is lost from the system by way of generation of sodium sulphate, conservation of sodium in the form of carbonate is very essential for the overall economics of the process flow-sheet. Also from the environmental considerations, disposal of the SDU barren containing many reagent chemicals will have several restrictions. The SDU barren liquor is, therefore, subjected to a series of chemical treatments for re-generation of the two leachants — sodium carbonate and sodium bicarbonate. The series of steps involves three essential steps, namely (i) causticization, (ii) crystallization and removal of sodium sulphate and (iii) carbonation, which are described below

Causticization: Causticization of SDU barren with commercial grade lime (CaO) to convert the remnant sodium carbonate to sodium hydroxide. The calcium carbonate sludge generated as reaction product is a waste product. Some of the radioactivity build-up due to recycle process is eased out in the causticization process as radium and uranium too undergo chemical reaction to certain extent with calcium hydroxide resulting in insoluble calcium diuranate and calcium-radium product. All these insolubles are separated by filtration of causticized slurry of SDU barren. Causticization was carried out in a 250 l capacity SS 304L reactor having provision for external heating with steam. CaO was added to the SDU barren in slurry form. The chemical reaction during causticization is given as:



Since the reaction of Ca(OH)_2 with Na_2CO_3 is exothermic in nature, the heat requirement for the reactor contents to attain 80°C was very minimal. After a specific reaction time the reactor contents were cooled and filtered in a Nutsche filter. The calcium carbonate sludge was separated out from the causticized SDU barren. The sludge was washed with plain water and the washings were collected separately. The calcium carbonate sludge is meant for disposal alongwith the final plant tailings (leach residue).

Removal and Recovery of Sodium Sulphate: The causticized SDU barren solution contains sodium sulphate, sodium hydroxide and small concentration of sodium carbonate and uranyl carbonate. High concentrate of sulphates may inhibit mutual solubility of carbonates and bicarbonates and may affect uranium leachability when it is recycled to leaching stage. It is therefore essential to separate sodium sulphates. This has been done by freeze crystallization and filtration to obtain Glauber salt ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) in the solids and mother liquor in the filtrate. Sodium sulfate is not only a by-product of this process but its recovery reduces the concentration of the total dissolved ions in the recycle liquor which has been observed to yield positive effects on the leachability as well as rate of solid-liquid filterability.

The crystallization unit consists of a chilling unit having a storage tank, compressor and mono block pump and crystallizer of 1 m^3 capacity with an agitator to stir the solution. The crystallized sodium sulfate slurry was fed to pan filter having filtration area of 1 m^2 by gravity to carry out filtration under vacuum.

Carbonation: The sodium hydroxide in the SDU barren are re-converted to sodium carbonate/sodium bicarbonate by purging carbon dioxide gas through it. The NaOH present in

the liquor is converted first to Na_2CO_3 and on continuation of the carbonation step further, NaHCO_3 is produced as per the chemical reactions given below.



The causticized SDU barren solution after removal of excess sodium sulphate is recycled back to prepare fresh ore slurry. The carbonation was carried out by purging of CO_2 through a sparger provided in the feed preparation tank. Industrial grade CO_2 was used at controlled flow-rate through a heater and flow-meter. The sodium hydroxide in the liquor gets first converted into sodium carbonate and on continued passing of carbon dioxide sodium bicarbonate is formed.

Tailings disposal: The filter cake from HBF which forms the major constituent of solid waste from the process was allowed to fall from the HBF by gravity to a 1 m^3 capacity rubber lined agitator tank. The leach residue solids were re-pulped with plain water and pumped to centralized tailings treatment plant of UCIL, Jaduguda for disposal.

5. PILOT PLANT TESTS AND OBSERVATIONS

The general flow sheet was developed based on the bench scale tests carried out at the laboratory of Mineral Processing Division, Hyderabad. These tests included optimization of most of the process parameters for leaching, such as mesh of grind, temperature, contact time, reagent dosage, various types of oxidants, elevated pressure and temperature large scale tests using the parameters generated on laboratory scale/bench scale carried out at TDPP, Jaduguda. The engineering parameters, such as effect of agitation, residence time in the CLR and total pressure and oxygen partial pressure, mode of oxygen injection, types of impeller etc., on leach recovery, heat exchanger studies on SHE, filtration studies on the HBF were carried out and required design data were collected. The circuit used for leaching in the CLR is given in Fig. 6.

One of the important aspect that needed to be studied was the effect of recycle of the processed SDU barren to the ore grinding stage on the overall grinding efficiency. The result is shown in Fig. 7, wherein it may be seen that the grinding rate becomes slower with recycle of reagentized liquor and this need to be considered while designing the grinding mill circuit.

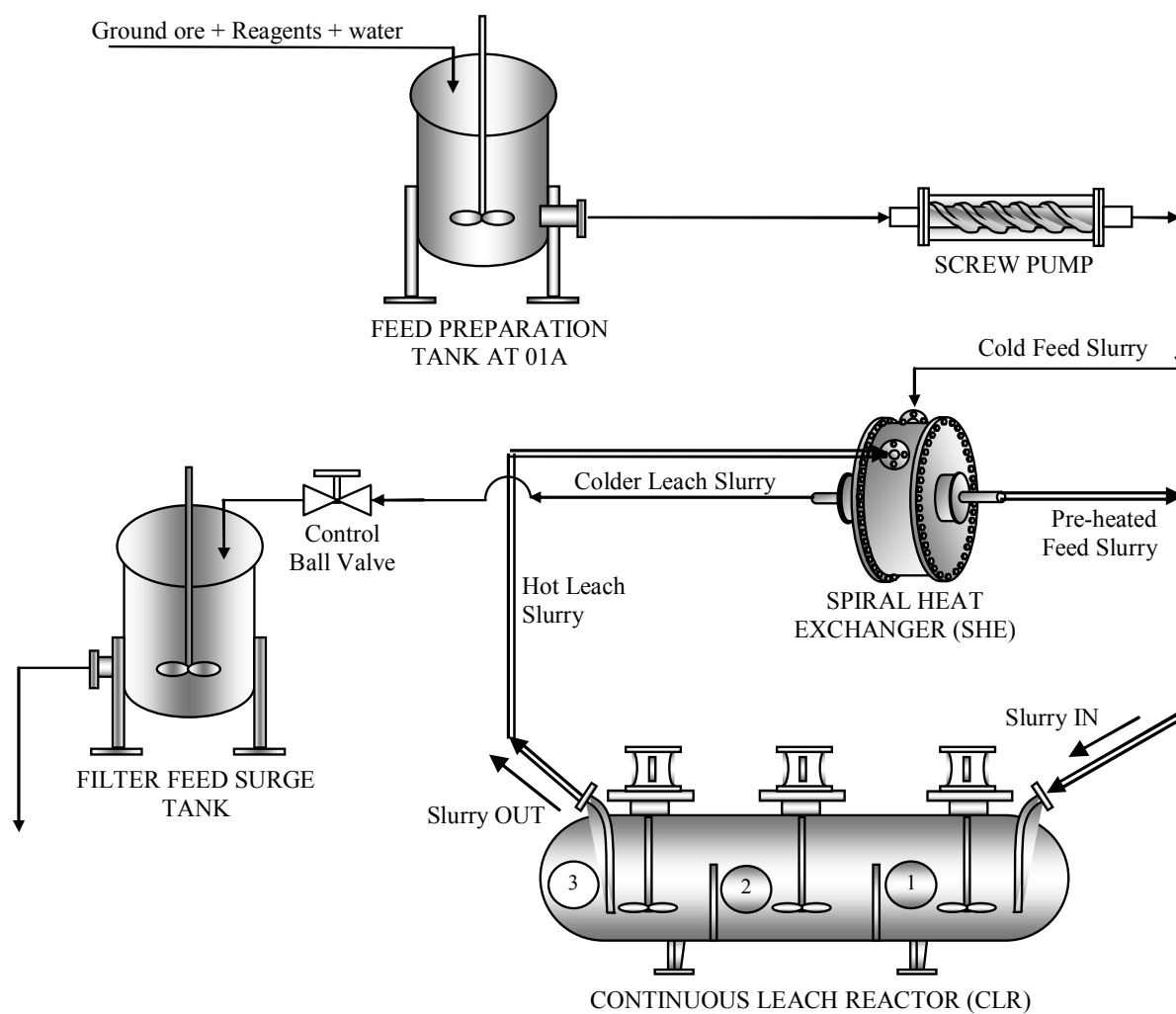


FIG. 6. Circuit used for leachability studies in the CLR.

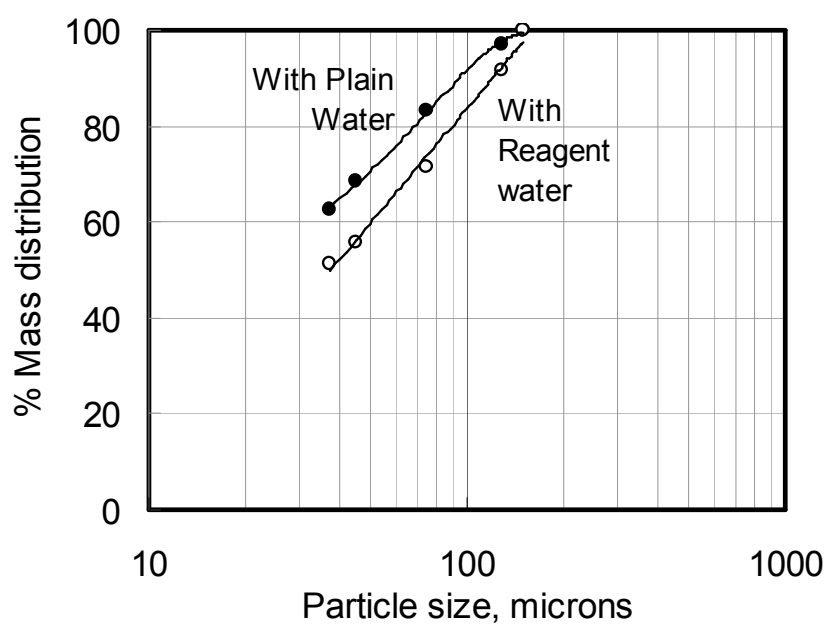


FIG. 7. Absolute cumulative mass distributions of Tummalapalle ore with plain and reagentized recycle liquor.

Further, higher viscosity and density of the liquor in the slurry not only lowers the grinding rate but also the rates of filtration of the neutral ore slurry as well as the leach slurry. Efforts were made to improve the rate of filtration by controlling the belt speed, cake thickness. Residence time distribution (RTD) studies were carried out using a radio tracer and the data was analyzed with the help of N-CSTR models assuming the standard functional form of gamma distribution for the RTD.

The tests in the batch pressure reactor confirmed the contact time of 4–6 hours required for obtaining a leach recovery of 80%. However, the leaching in CLR indicated that longer durations are required to get a similar recovery. There was practically no significant difference between the two modes of oxygen addition, by direct injection through a sparger tube or by just maintaining an oxygen overpressure in the reactor. Heat transfer calculations indicated that the overall thermal efficiency worked out to be 94%. The heat transfer coefficient was evaluated based on the pilot plant studies at two different slurry flow rates through the SHE. Similarly the filtration rates of the feed and discharge slurries were evaluated and the rates were optimized by proper control of the operating variable and also by using hot water washing. The filtration tests carried out on the HBF under actual process conditions led to a number of observations. The rate of filtration could be enhanced significantly depending upon the process conditions. Granulometry of solids was found to have a profound effect on the rate of filtration. The rate of filtration with solids grind of 72% by weight in -200 mesh was $666 \text{ kg}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ while the rate with 84% by weight -200 mesh leached solids gave about $450 \text{ kg}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ with flocculant addition. Comparison of loss of dissolved U_3O_8 along with the leach residue in hot- solution wash and wash at ambient temperature clearly indicate that washing with hot-wash solution is more efficient. It was observed that use of hot water reduced the loss of dissolved U_3O_8 . The washing efficiency with a wash displacement ratio of 1:1 of leach residue with hot-solution was about 98%.

The precipitation of sodium diuranate from the leach liquor was carried out at ambient and elevated temperatures and also with and without seeding. The optimal precipitation time, required for maximal uranium recovery was determined. A precipitation efficiency of 95–97% could be obtained with leach liquors assaying 1.2–1.5 gpl of U_3O_8 . The final technological process flow sheet developed for extraction of uranium from Tummalapalle ore is given in Fig. 8.

About 50 tonnes of Tummalapalle ore was processed in the pilot plant during a number of campaigns and the data was analyzed and the design parameters were evaluated for detailed engineering design of the industrial mill, planned by Uranium Corporation of India Limited at Tummalapalle.

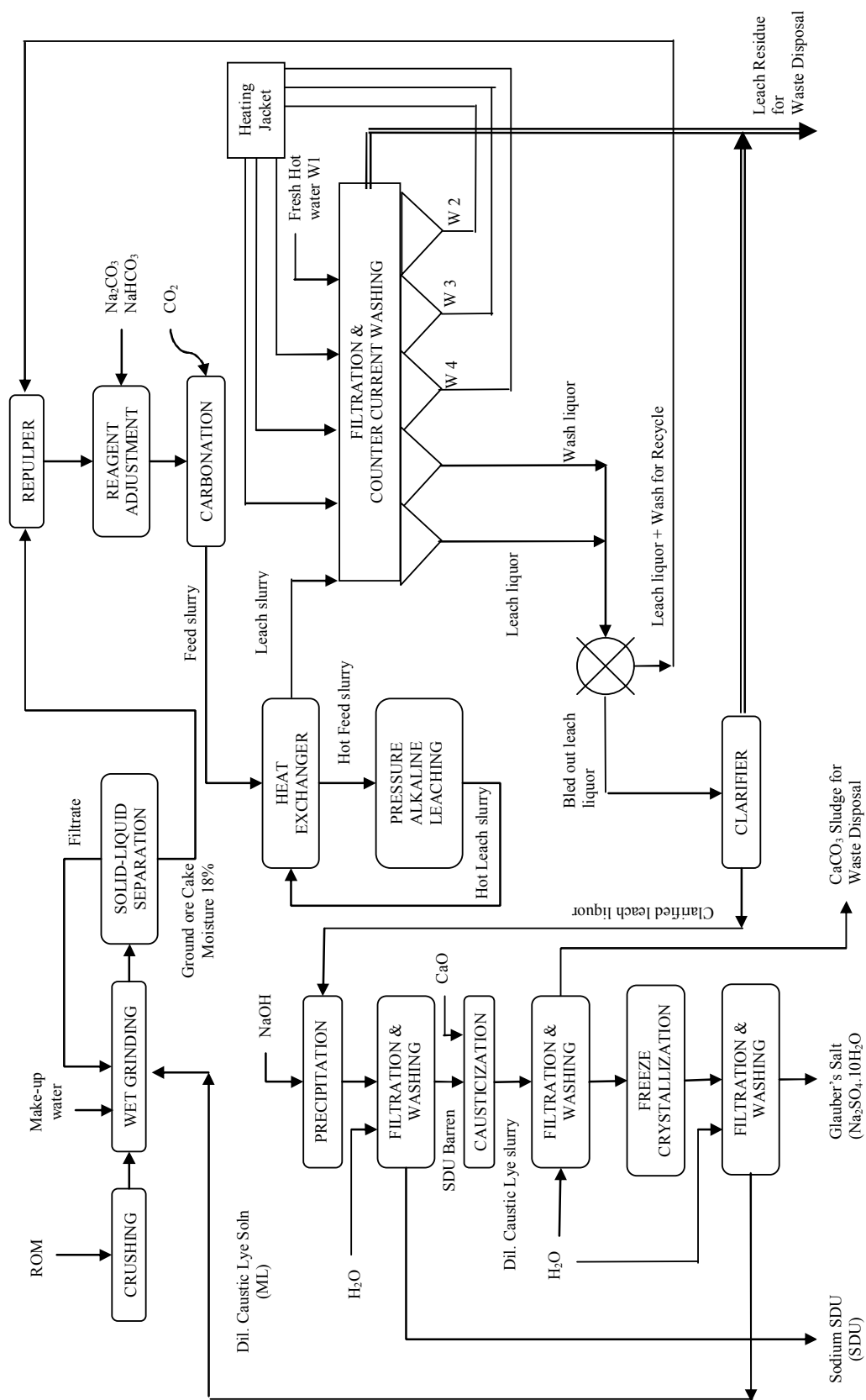


FIG. 8. Technological flow-sheet for processing Rummalpalpe uranium ore.

6. CONCLUSIONS

In view of the growing demand for uranium in the country, India has plans to open up new mines located at the Singhbhum Shear Zone as well as other locations in the country. In order to generate the engineering data and scale up parameters for mill design, a pilot plant was set up at Jaduguda. Detailed experimental studies on alkaline pressure leaching route were carried out on Tummalapalle uranium ore in the pilot plant to demonstrate the process and generate useful design data. Already large scale tests have commenced on uranium ore from Gogi, Karnataka through the alkaline leaching route.

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ENVIRONMENTAL REMEDIATION AND RADIOACTIVITY MONITORING OF URANIUM MINING LEGACY IN PORTUGAL

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Abstract

The main legacy site of uranium mining and milling in Portugal, located near the town of Canas de Senhorim, contained around 15 million tones of solid waste in various mill tailings and spoil heaps. Approval of an environmental remediation plan for this area was followed by the start of engineering works, including the transportation of several wastes to the main tailings pile, re shaping and contouring the waste heap and placing a multi layer cap. These works were mostly performed in 2006 and 2007. During part of this period, monitoring of radioactivity was performed in the surface air, surface waters from the area including the monitoring of the small river that receives drainage from the mill tailings area, and agriculture products. This paper presents the results of measurements of the main alpha emitting radionuclides of uranium series in water and compares them with previous data for the region. Implications for the radiological protection of the population are discussed.

1. LEGACY AND REMEDIATION WORK

During the 20th century in Portugal about 60 mines were exploited for radium and uranium production. The entire industrial sector discontinued activities in 2001 leaving a total of about 60 million tons of mining and milling waste accumulated at several former mine sites. Following the end of ENU Company 'activities and concerns of the population with uranium waste, an environmental remediation initiative was approved by the Government for abandoned mines including uranium mines. As remediation work for radioactive mines had not been planned ahead by the ENU Company, this initiative was funded by the State. Inventory of former mine sites and waste was made and remediation plans were elaborated by the State owned mining holding company EDM under the supervision of an inter-ministerial commission [1] [2]. Environmental remediation work at uranium mines started in 2005 at the Urgeirica Mine, near Canas de Senhorim, and Vale da Abrutiga Mine, considered as priority sites. So far, the environmental remediation work at former uranium mine sites was funded with 12 MEuros and it should be implemented by the year 2013.

Remediation work in Urgeirica was completed by the EDM Company in 2005–2007. Waste in milling tailings and low grade ores remaining there as well as waste from the decommissioned uranium ore chemical treatment plant were concentrated in one single place (Barragem Velha). Slopes of the piles were smoothed, drainage ditches were dig, and the waste pile was covered with clay and sand layers, textile geo-membrane, soil and vegetated with grass. The mine water treatment plant was improved, automated, and will continue in operation to treat mine water and leakage collected from the waste pile.

Treated mine water and surface runoff following rains, are drained into a stream nearby, Ribeira da Pantanha, flowing into the Mondego River. Furthermore, seepage from tailings and acid mine water from the underground mine is likely to infiltrate the local aquifer and may spread into groundwater resources of the region [1] [2].

We used the measurement of radionuclides from uranium series in surface water of this region to make a preliminary assessment of the dispersal of radionuclides from mine and milling heaps during environmental remediation works.

2. MATERIALS AND METHODS

Surface water samples (5–10L) were collected along the path of the creek Pantanha, upstream and downstream of the discharge point of treated mine water and drainage from waste ponds (Fig 1). Water samples were collected also in the creek Vale de Gato that does not receive effluents from the mine and from the waste dumps (Fig 1). Water samples were filtered in situ through large diameter, 0.45 μm pore size, nitrate membrane filters, using stainless steel filter holders, peristaltic pumps and a portable power generator. Filtered samples were acidified to $\text{pH} < 2$ and filters with suspended matter stored for later analysis in laboratory. Water physical-chemical parameters were measured in situ with a portable multi parameter probe. Filtered water and suspended matter samples were analyzed after addition of isotopic tracers ^{232}U , ^{229}Th , ^{224}Ra , and ^{209}Po . Following radiochemical separations, radionuclides were plated on stainless steel discs and silver discs for Po, and radioactivity on the discs measured by alpha spectrometry [3]. Analytical quality control was performed through the analysis of IAEA certified reference materials and periodic participation in analytical inter comparison exercises.

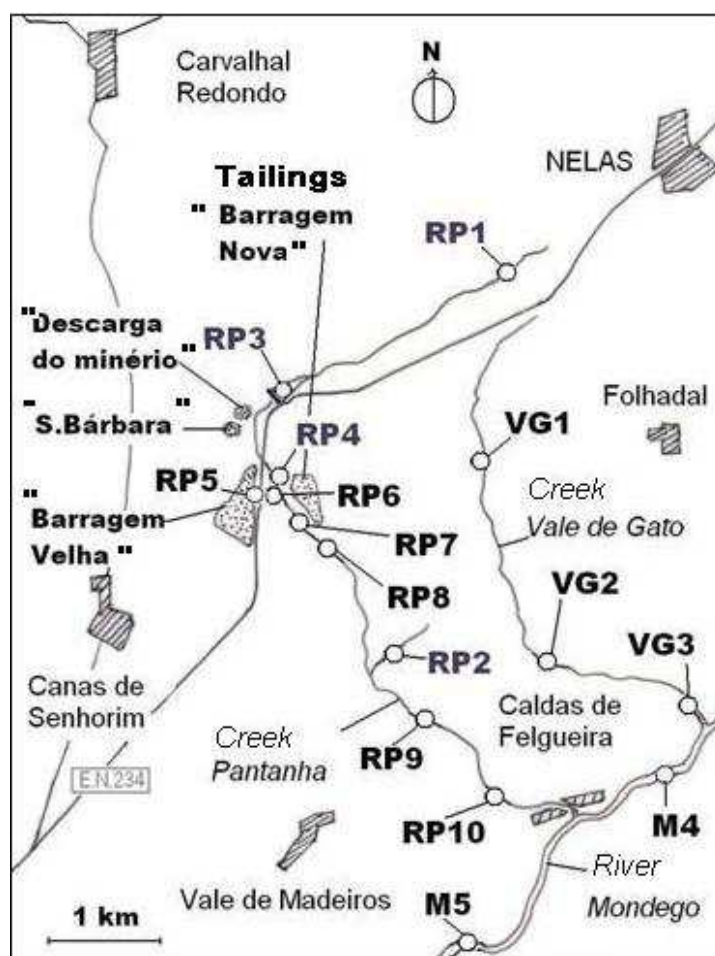


FIG. 1. Region of Urgeiriça-Canas de Senhorim (Portugal) with indication of the main milling tailings, rivers and sampling stations.

3. RESULTS AND DISCUSSION

Analysis of filtered surface water samples from the creek Pantanha indicated an enhancement of uranium isotopes (^{238}U , ^{235}U , and ^{234}U), ^{230}Th and ^{226}Ra in the area near the mill tailings (Table 1). This is due to contributions by surface runoff and by seepage of rainwater flowing through the waste piles. Enhancement of uranium isotopes in the creek water was 1 000 times the concentrations measured upstream the zone of waste piles. Downstream, the concentrations decrease but in the river Mondego, a main river receiving the discharge of the creek, the enhancement was still measurable some 10 km far from the waste piles. In the same surface waters, concentrations of dissolved ^{226}Ra and ^{210}Po were enhanced also, but by a factor of 10–100 times in comparison with concentrations measured upstream the discharge from waste piles. Enhanced radionuclide concentrations, especially those of ^{226}Ra and uranium, were significantly correlated with concentrations of sulphate ion resulting mainly from the H_2SO_4 used in the ore leaching [3]. Enhanced radionuclide concentrations in suspended matter samples were measured in the same zone and can be compared with background concentrations of stations RP1, RP2 and VG1-3 (Table 2).

TABLE 1. RADIONUCLIDE CONCENTRATIONS IN THE SOLUBLE PHASE (mBq L⁻¹ \pm 1 σ) IN SURFACE WATER SAMPLES. (RP), CREEK PANTANHA (RP); CREEK VALE DE GATO (VG); RIVER MONDEGO (M)

Station	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Po
RP1	8.9 \pm 0.3	9.4 \pm 0.3	0.78 \pm 0.08	8.0 \pm 0.7	9.2 \pm 0.2
VG1	6.7 \pm 0.3	6.8 \pm 0.3	0.74 \pm 0.09	12.9 \pm 1.2	7.1 \pm 0.2
VG2	7.0 \pm 0.2	7.7 \pm 0.2	0.91 \pm 0.18	6.7 \pm 0.4	9.8 \pm 0.3
VG3	8.6 \pm 0.3	9.0 \pm 0.3	1.5 \pm 0.1	5.2 \pm 0.3	11.3 \pm 0.3
RP2	7.1 \pm 0.4	7.8 \pm 0.4	0.42 \pm 0.11	6.7 \pm 0.9	23.2 \pm 0.9
RP3	135 \pm 5	129 \pm 4	2.6 \pm 0.2	33.4 \pm 1.8	12.0 \pm 0.3
RP4	464 \pm 15	472 \pm 15	4.7 \pm 0.3	13.8 \pm 0.9	6.6 \pm 0.2
RP5	(42 \pm 1) \times 10 ³	(41 \pm 1) \times 10 ³	(1.3 \pm 0.1) \times 10 ³	247 \pm 16	137 \pm 7
RP6	(22.6 \pm 0.8) \times 10 ³	(22.2 \pm 0.8) \times 10 ³	691 \pm 31	99.8 \pm 3.5	18.7 \pm 0.8
RP7	(5.5 \pm 0.6) \times 10 ³	(5.3 \pm 0.6) \times 10 ³	2.7 \pm 0.3	125 \pm 14	19.7 \pm 0.8
RP8	(4.4 \pm 0.2) \times 10 ³	(4.4 \pm 0.2) \times 10 ³	2.5 \pm 0.4	103 \pm 6	174 \pm 9
RP9	874 \pm 48	873 \pm 48	5.6 \pm 0.6	78.5 \pm 3.4	21.5 \pm 0.9
RP10	253 \pm 8	262 \pm 8	4.6 \pm 0.5	66.2 \pm 3.5	22.3 \pm 0.9
M4	7.2 \pm 0.2	7.7 \pm 0.2	1.8 \pm 0.2	6.1 \pm 0.4	7.6 \pm 0.3
M5	20.0 \pm 0.5	21.1 \pm 0.5	1.4 \pm 0.1	3.3 \pm 0.5	6.3 \pm 0.3

TABLE 2. RADIONUCLIDE CONCENTRATIONS ($\text{kBq kg}^{-1} \pm 1\sigma$) IN SUSPENDED MATTER FROM CREEK PANTANHA (RP), CREEK VALE DE GATO (VG), AND RIVER MONDEGO (M)

Station	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Po
RP1	0.64 ± 0.02	0.68 ± 0.03	0.32 ± 0.02	0.46 ± 0.04	0.84 ± 0.03
VG1	0.77 ± 0.03	0.77 ± 0.03	0.30 ± 0.02	0.64 ± 0.05	1.1 ± 0.2
VG2	1.54 ± 0.03	1.64 ± 0.05	0.70 ± 0.03	0.83 ± 0.04	2.1 ± 0.2
VG3	1.29 ± 0.04	1.36 ± 0.09	0.54 ± 0.03	0.89 ± 0.06	1.76 ± 0.05
RP2	0.62 ± 0.02	0.64 ± 0.02	0.23 ± 0.02	0.27 ± 0.02	3.7 ± 0.10
RP3	11.1 ± 0.3	10.1 ± 0.3	1.44 ± 0.07	3.7 ± 0.05	7.2 ± 0.2
RP4	23.3 ± 0.7	23.4 ± 0.6	4.6 ± 0.07	1.29 ± 0.06	4.5 ± 0.2
RP5	0.92 ± 0.04	0.94 ± 0.05	0.38 ± 0.04	0.81 ± 0.04	0.92 ± 0.05
RP6	10.5 ± 0.3	10.3 ± 0.3	0.72 ± 0.04	1.43 ± 0.06	4.4 ± 0.1
RP7	21.3 ± 0.6	21.1 ± 0.6	0.53 ± 0.06	0.59 ± 0.02	2.05 ± 0.07
RP8	1.04 ± 0.06	1.02 ± 0.06	1.72 ± 0.09	0.26 ± 0.03	2.6 ± 0.2
RP9	21.7 ± 0.6	21.4 ± 0.6	2.0 ± 0.1	0.94 ± 0.04	3.14 ± 0.09
RP10	13.5 ± 0.5	13.5 ± 0.5	2.9 ± 0.2	1.81 ± 0.09	4.8 ± 0.1
M4	0.73 ± 0.02	0.79 ± 0.02	0.54 ± 0.02	0.47 ± 0.02	1.01 ± 0.03
M5	2.71 ± 0.08	2.71 ± 0.08	0.86 ± 0.05	1.07 ± 0.10	1.41 ± 0.05

Radionuclide concentrations determined in underground mine water (pH 4) collected through the main shaft, contain about 2 Bq L^{-1} of ^{238}U and about 1.4 Bq L^{-1} of ^{226}Ra , thus much higher than measured in surface waters [4] [5]. Due to the low pH and low oxygen content of this mine water, uranium is likely reduced to U(IV) and U concentrations in the dissolved phase are much lower than those in the solid phase. Determinations made in surface waters (Tables 1, 2) in oxic conditions are likely to follow a different solid -water partitioning pattern and more uranium dissolves as U(VI).

Although concentrations of naturally occurring radionuclides in natural waters are not constant, clear enhancement of absolute concentrations and modification of radionuclide concentration ratios are observed in the area of uranium mines and milling facilities. Enhancement of radionuclide concentrations in these waters likely occurred as the result of leaching of milling waste piles by rainwater, or underground in situ leaching with sulphuric acid. Change of radionuclide ratios may give indication on the source of radionuclides. In the case of Urgeiriça mine, U series radionuclides dispersed in surface waters come mainly with seepage from milling tailings and displayed concentration ratios $\text{U/Ra} \gg 1$. Seepage from this source also infiltrates surface wells located close to the tailings. However, water in wells at distance from the tailings, displaying enhanced radionuclide concentrations and with U/Ra ratios close to unity, was likely contaminated with acid mine water originating in the underground galleries, as indicated also by the low dissolved oxygen concentrations (not shown).

Radionuclide concentrations reported herein and measured during remediation works in the Urgeiriça area are comparable to concentrations measured in previous years. Those works, on one hand did not increase the discharge of waste containing radioactivity into the river

system and, on the other hand, did not show immediate reduction in contamination levels in comparison with previous years [4] [5]

4. CONCLUSIONS

Milling wastes disposed on surface contain high concentrations of uranium series radionuclides, especially ^{226}Ra [2]. Surface runoff and leaching of milling tailings by rain water strongly enhanced radionuclide concentrations in the water of the creek Pantanha that is a tributary to the Mondego River. Enhanced radionuclide concentrations in solution and particulate matter of this river system were measurable during about 10 km downstream although, at larger distances, radionuclide concentrations in water return to near background values due to dilution. Concentrations reported were similar to those measured in previous years and were not enhanced by remediation works. With the cover of tailings now in place it is expected that radionuclide concentrations in surface water streams will decrease rapidly. The follow up of radioactivity in the environment and in these streams in particular, will be monitored during several years.

From the uranium mining legacy, the lessons to learn include the need for forward planning of radiation protection measures for the complete mine life cycle in order to minimize the exposure of the public to ionizing radiation and to toxic metals, and to reduce the environmental impact and environmental remediation costs of mining and milling waste. Today, this is an essential societal requirement, and public trust for future uranium mining is probably also built on the success of remediation of uranium legacy sites.

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HUMAN RESOURCES DEVELOPMENT
(Session 6)

INTERNATIONAL TRAINING CENTRE, WNU — SCHOOL OF URANIUM PRODUCTION (THREE YEARS EXPERIENCE)

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Abstract

Following a joint meeting of the IAEA, OECD/NEA Uranium Group and the World Nuclear Association, in 2004 the shortage of skilled professional staff to support the expansion of the global uranium industry was a major topic of discussion. As a consequence of the concerns expressed at that meeting, in 2006 the World Nuclear University-School of Uranium Production was set up with the cooperation of the DIAMO State Enterprise at their site in the Czech Republic. The facility is now up and running and provides a range of technical training activities to help strengthen the skills base amongst all uranium producing countries, both current and future. The paper describes the history of the school so far and the range of activities on offer.

1. INTRODUCTION

In the middle of the first decade of the 21st century a new fresh wind in nuclear energy generation improved the demand in nuclear fuel supply and of course the refreshing in uranium prospection, exploration and mining as well. But the serious problem has appeared because of a significant lack of well skilled professionals that limited any new development in this industry. This disproportion resulted from more than twenty years depression in the uranium market. A lot of professionals left the mining industry due to their age or finding new working positions in another industry. The international organizations interested in organization of uranium production and involved in the dissemination of best practices in peaceful utilization of nuclear energy (IAEA, OECD/NEA, WNA) identified this problem various meetings and proposed to establish an international training center with the aim of compensating for the shortages and to improve knowledge in developing countries.

2. HISTORY OF THE “SCHOOL” PROJECT

In 2004 year during the Joint meeting of Uranium Group (UG) (IAEA, OECD/NEA) held at Straz pod Ralskem, Czech Republic, the first indication of the lack of skilled professionals appeared. About nine months later, in June 2005, at the IAEA Uranium Symposium in Vienna the first significant discussion took place about the necessity to organize an international training center focused on the Uranium Mining Life Cycle. The contributors to this discussion were various international organizations including IAEA, OECD/NEA and WNA/WNU. Their high level of experience in organizing previous UG meetings led to decision to request DIAMO, State Enterprise, Czech Republic, to develop this project.

In April 2006, the constitutional meeting was held in Prague. All the above mentioned counterparts approved the DIAMO project and recommended to start the development of the first training courses. The International Training Centre, since that time called, “World Nuclear University — School of Uranium Production” or “WNU-SUP” is operated by DIAMO, State Enterprise under the auspices of the World Nuclear University, London, UK.

The main aspects that have been evaluated in DIAMO project can be defined as:

- Over 60 years of experience in uranium mining;
- Existing and functioning mining infrastructure in a unique environment;
- Access to renowned universities;
- Centrally-located and easily accessible from all over the world;
- Reasonably priced living expenses within the Czech Republic.

3. THE “SCHOOL” MISSION AND PROCEDURES

The WNU School of Uranium Production mission can be defined as “to provide world-class training on all aspects of uranium production in support of expanded, environmentally-sound and sustainably developing uranium mining throughout the world”.

The methods and procedures that should be used to fulfil the School mission can be expressed as follows:

- To educate students in all aspects of the uranium production cycle including exploration, planning, development, operation, remediation and closure of uranium production facilities;
- To improve the state of the art of uranium exploration, mining and mine remediation through research and development;
- To provide a forum for the exchange of information on the latest uranium mining technologies and experiences — best practices;

All School activities are open to all organizations and individuals interested in the tasks of the uranium mining life cycle. There are two main avenues for application:

- Direct commercial contract;
- Fellowship based on a Technical Cooperation (TC) Project between IAEA and a counterpart country or region.

Beside these two ways any other co-operation can be implemented based on national or multinational activities, workshops or technical meetings.

During the last three years different types of courses have been developed to provide crosscutting information on general aspects of the uranium mining life cycle and explain and demonstrate specific aspects of different operations. Courses that are currently available are organized following requests from applicants. The long term courses are usually organized twice a year in the spring and autumn semesters. Other short courses, or so called scientific visits, are available throughout the year.

Courses in service:

In Situ Leach Mining (both alkaline and acid):

- Operators course (4 weeks);
- Executive course (2–5 days).

Exploration:

- Four weeks combined course on U deposits exploration and sandstone type deposits mining (ISL preference).

U mining and milling residues remediation:

- One week course on waste rock piles and tailings pond remediation, environmental monitoring and radiation protection.

Alkaline Milling (Processing):

- One week course focused on mineralogy, technological requirements and processing of uranium ores, tailings and water management, radiation and environmental protection and monitoring. Practical demonstration at alkaline mill GEAM Branch.

Other potential courses:

- Conventional (underground) Mining;
- Mine and Mill Water Management and Treatment;
- Heap Leaching;
- Best Practice in Uranium Mining Life Cycle.

Typical teaching approach for so called „OPERATORS“ courses is six hours of teaching + two hours of review and discussion daily. Field visits to sites in relation to theoretical lessons are organized each week or on request. The „EXECUTIVES“ courses consist of from three to five days programmes for mid-level managers with some experience in mining and for governmental policy-makers/administrators. Special presentations and discussions (face to face) of topics defined by participants represent the typical approach. Topics of lessons are mostly oriented towards strategic planning, feasibility studies, capital and operational costs.

Beside the professional training the „School“ organizes for the students weekend social events that include trips to surrounding areas, sightseeing and visits to local specific traditional production facilities. Any individual activities like swimming, tennis, table tennis, gym, biking or hiking in the local surroundings are available for students every day.

4 THE „SCHOOL“ EXPERIENCE

Since 2006, more than 50 participants have taken part in 10 different types of training courses. The „ISL OPERATORS“ course was run in September 2006 with seven attendees — six of them from China under the IAEA TC project and one Pakistan Atomic Commission commercial participant. Three „EXPLORATION“ courses for China, Argentina, Latin America, Egypt and Bangladesh IAEA TC Projects were performed in the period between autumn 2007 and spring 2009. An „ISL EXECUTIVES“ two weeks scientific visit under the IAEA-Argentina TCP was held in autumn 2007 in Prague and Straz p.R.. A tailings ponds remediation executives ‘scientific visit under the IAEA — Tadjikistan TCP was arranged in autumn 2007.

A special one week technical visit of an Indian specialists group was held at Rozna Uranium mill for recognizing and consultation of alkaline milling process on a commercial basis in September 2006. In 2008 year a significant co-operation with a Chinese partner has been established. A special training course of „DIAMO ISL experience at the Straz deposit“ has been developed for them. Fourteen participants from BOG/CNNC took part in this course in November 2008.

Beside the positive sounds in „School“ project there are a few limitations in the number of training courses and number of participants. One of the most important is a long time period in IAEA fellowships administration that results from a relatively complicated system of fellowships approval. The system of „request — offer — acceptance of offer — approval“ going from national authority of requesting country through IAEA to national authority of host country, then to supplier of the training and back by the same way takes several months. It happens that some applicants cannot be included to next running of the requested training although free places in the course are available.

5. CONCLUSIONS

The WNU School of Uranium Production has operated for the last three years. Current experience shows that this type of relatively short training courses is well suited to the needs of developing countries and regions and some specific operators, executives and regulators requests. The main source of the participants is those recruited through the IAEA fellowships based on TC Projects. Beside this way, the School develops commercial contracts with specific organizations with the aim to gain a wider range of participants.

THE URANIUM RECOVERY INDUSTRY AND THE CURRENT NUCLEAR RENAISSANCE — A HEALTH PHYSICISTS PERSPECTIVE

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Abstract

Concurrent with the recognition that nuclear generated electricity must play an increasing role in worldwide energy supply and in consideration of the new nuclear power plants ordered or planned, the demand for uranium needed to fuel these reactors has already outpaced supplies. Accordingly, the price of uranium (typically expressed as US\$ per pound U_3O_8 equivalent) had increased significantly in recent years. As a result, numerous new and reconstituted uranium recovery projects are being developed in the United States and in other countries that possess considerable uranium ore reserves (e.g., Canada, Australia, Kazakhstan, Mongolia, Namibia, and others). It should be noted that in the United States, the current reactor fleet of 104 operating units, which generate 20 percent of the US's base-load electricity, requires approximately 55 million pounds of U_3O_8 per year, but only about 4–5 million pounds per year is produced domestically. That is, over 90 percent of current demand, ignoring anticipated increase in requirements in the near future as new plants come online, must come from foreign sources. Domestic uranium production over the last 10 years reached a low of about two million pounds in 2003 and has been increasing steadily since then. Uranium recovery as defined in this paper encompasses conventional uranium mining and milling as well as in situ recovery techniques and the recovery of uranium as a byproduct from other processes, such as phosphoric acid production. Following a brief history of uranium recovery in the US, the paper describes the basic methods and technologies associated with conventional uranium mining, conventional uranium milling and In Situ Recovery (ISR). The “health physicists perspective” is introduced into these discussions by providing summaries of the various radiological environmental monitoring and operational health physics programs that are required for these facilities. Applicable regulatory guidance and associated “best health physics practices” developed at these facilities are described. Finally, the paper concludes with discussions of recent and current trends in human capital as related to the availability of health physicists and other radiological scientists required to replace and aging workforce and staff the “nuclear renaissance”.

1. INTRODUCTION

Uranium recovery encompasses conventional uranium mining and milling as well as in situ recovery techniques (Figure 1) and the recovery of uranium as a byproduct from other processes, such as phosphoric acid production. Concurrent with the recognition that nuclear-generated electricity must play an increasing role in worldwide energy supply and in consideration of the new nuclear power plants ordered or planned, the demand for uranium needed to fuel these reactors has already outpaced supplies. Accordingly, the price of uranium (typically expressed as US\$ per pound U_3O_8 equivalent) has increased significantly in recent years. As a result, numerous new and reconstituted uranium recovery projects are being developed in the United States and in other countries that possess considerable uranium ore reserves (e.g., Canada, Australia, Kazakhstan, Mongolia, Namibia, and others).

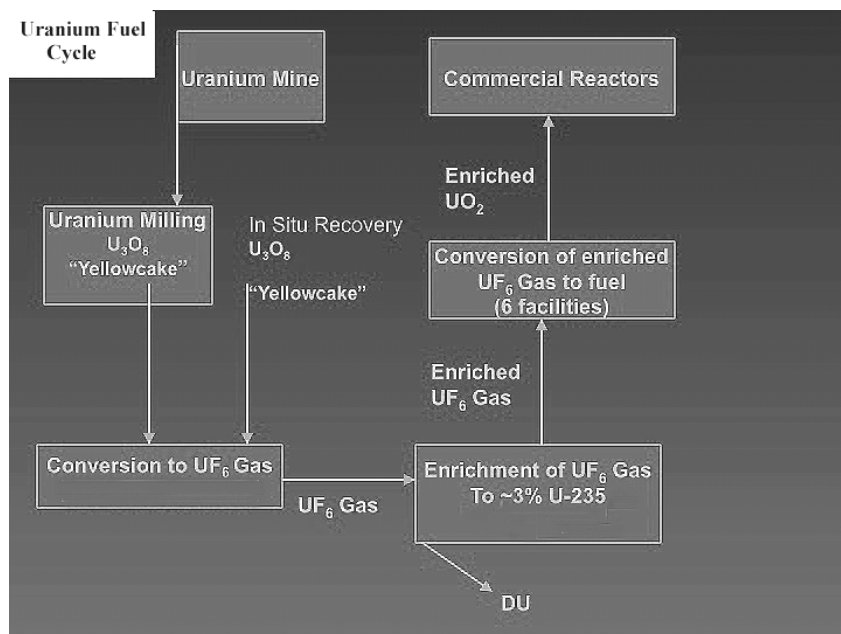


FIG. 1. Uranium fuel cycle.

This imbalance between supply and demand is depicted in Fig. 2. It should be noted that in the United States, our current reactor fleet of 104 operating units, which generate 20 percent of our base-load electricity, requires approximately 55 million pounds of U₃O₈ per year, but only about 4–5 million pounds per year is produced domestically. That is, over 90 percent of our current demand, ignoring anticipated increase in requirements in the near future as new plants come online, must come from foreign sources. Domestic uranium production over the last 10 years reached a low of about two million pounds in 2003 and has been increasing steadily since then.

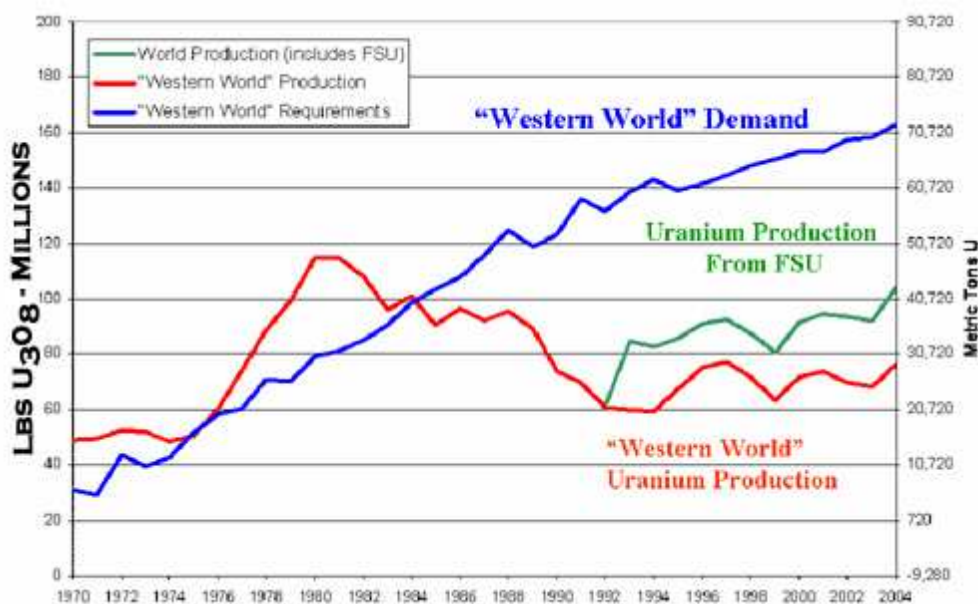


FIG. 2. U₃O₈ production versus demand (www.uraniumproducersamerica.com/supply.html).

2. HISTORY OF URANIUM RECOVERY IN THE UNITED STATES

In the United States, the mining of ore that contains uranium goes back to the early part of the 20th century. At that time the interest was not in uranium per se, but in other minerals associated with it, namely vanadium and radium. Interest in uranium began in earnest in the years immediately following World War II with the passage by the U.S. Congress of the McMahon Act (more commonly known as the Atomic Energy Act [AEA], signed by President Truman in August 1946), which created the United States Atomic Energy Commission (AEC) and established the U.S. government as the only buyer of uranium (for the nuclear weapons program). The government's uranium ore procurement program sent thousands of prospectors crawling over the "Colorado Plateau" (the four corners area of the states of Utah, New Mexico, Arizona, and Colorado). This ore was processed at a number of sites—collectively known as the "MED (Manhattan Engineering District) Sites"—and remediated decades later under the Formerly Utilized Sites Remedial Action Program (FUSRAP) still ongoing today. AEC incentives ceased in 1962, and private companies established mining and milling operations on a much larger scale than those early efforts.

As the commercial nuclear power industry developed in the late 1960s and early 1970s, the federal government was no longer the exclusive buyer of domestically produced uranium. U.S. production and uranium prices peaked in the early 1980s. Shortly thereafter, domestic demand for uranium ore declined as the commercial nuclear power industry fell far short of its expected growth and in response to, and low cost of, much higher-grade Canadian and Australian deposits that began to dominate world markets. Planning and construction of new U.S. commercial nuclear power plants came to a halt and the domestic price of uranium dropped dramatically, and the U.S. faced an oversupply of uranium despite demand remaining about constant through 2003.

As a result of the market conditions described above, the uranium recovery industry will benefit directly from the "nuclear renaissance" of today and into the near future. The U.S. Nuclear Regulatory Commission (NRC) Uranium Recovery Branch estimates that over the next few years, it expects to receive over 30 source material license applications for new and/or upgraded uranium recovery facilities [1] (see Table 1). Similar new project development is also taking place in the historical uranium recovery districts in NRC Agreement States (e.g., Texas and Colorado).

TABLE 1. NEW SOURCE MATERIAL LICENSING ACTIONS ANTICIPATED IN NEXT FEW YEARS (*IN SITU RECOVERY).

Facility	Quantity
New ISR* Facility	14
New Conventional Mill	7
Combined ISR Conventional	1
ISR Expansion	7
ISR Restart	1
Conventional Restart	1
TOTAL	31

3. OVERVIEW OF CONVENTIONAL URANIUM MINING TECHNIQUES

Conventional mining generally refers to open-pit and underground mining. Open-pit mining is employed for ore deposits that are located at or near the surface, while underground mining is used to extract ore, typically of higher grade (concentration of uranium in the ore expressed as weight percent or ppm), from deeper deposits. Conventional uranium mines are not regulated under the AEA since the raw ore is not considered “source material”⁴ under the Act and therefore is not a “licensed material.” The health and safety aspects of conventional uranium mines are regulated at the federal level by the Mine Safety and Health Administration of the U.S. Department of Labor and by respective state agencies with responsibility for health, safety, and environmental protection associated with mining.

4. CONVENTIONAL URANIUM

Uranium mills (and in situ recovery facilities [ISRS]) are “licensed facilities” since they produce source material as defined under the AEA. Accordingly, licensing requirements and management of uranium mills are defined in NRC’s 10 CFR 40, *domestic licensing of source material*, and commensurate requirements of agreement state regulations. After the ore is crushed and ground to a uniform particle size, the uranium is extracted from the ore and subsequently concentrated via combinations of leaching (acidic or alkaline), solvent extraction processes. It is then precipitated into the final yellowcake product, which is then dried and packaged for transport to a conversion facility.

5. IN SITU RECOVERY FACILITIES

ISRs (also referred to as in situ leach or uranium solution mining) are rapidly becoming a preferred method around the world for uranium recovery. This is primarily because of lower capital costs, fewer manpower requirements for operations, smaller land-use footprints, and environmental advantages over conventional mines and mills. However, applicability of this technology is generally limited to very specific geological, hydrological, and geochemical conditions. ISR processes in the United States typically involve the circulation of groundwater, fortified with oxidizing (typically gaseous oxygen) and complexing (e.g., carbon dioxide) agents into an ore body (referred to as “the lixiviant”), solubilizing the uranium in situ, and then pumping the solutions to the surface where they are fed to a processing plant (very similar to a conventional mill, without the need for ore crushing, grinding, and leaching). The uranium dissolved in solution returning from underground is first concentrated in an ion exchange circuit, stripped from the ion exchange resin via an elution process and then precipitated into yellowcake, dewatered, dried, and packaged as the final U_3O_8 product in an identical manner as in conventional mills. Fig. 3 shows the basic approach to in situ uranium recovery.

⁴ In general terms, “source material” means either the element thorium or the element uranium, provided that the uranium has not been enriched in the isotope ^{235}U . Source material also includes any combination of thorium and uranium, in any physical or chemical form, that contains by weight one-twentieth of one percent (0.05 percent) or more of uranium, thorium, or any combination thereof that is processed for its uranium and/or thorium content.

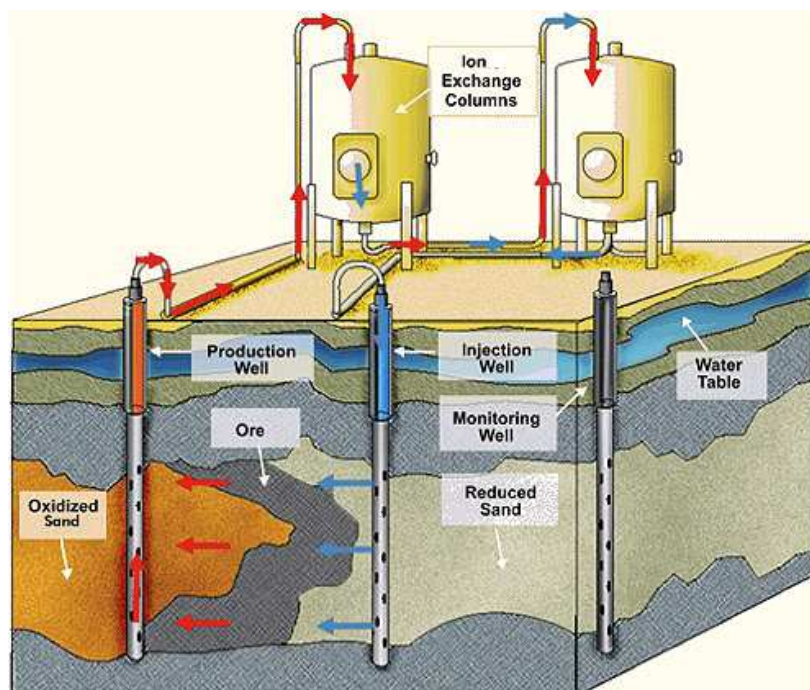


FIG. 3. Basic approach to in situ uranium mining.

6. ADDITIONAL URANIUM RECOVERY TECHNOLOGIES THAT MAY BE REVISITED

In the 1970s and into the 1980s, uranium was also recovered as a byproduct of copper and phosphate production. I was the radiation safety officer for a uranium recovery plant that was collocated at the world's largest open-pit copper mine, near Salt Lake City, Utah. Our uranium plant received a portion of the copper recovery circuit liquor and, through ion exchange and subsequent traditional uranium milling processes as described above, produced 50 000–100 000 kilograms per year of yellowcake. Similarly, I had corporate radiation protection oversight responsibility for one of the several uranium recovery facilities in the phosphate lands of west central Florida. This facility received a portion of the phosphoric acid production plant stream and, through traditional uranium milling processes, also produced a similar rate of yellowcake. Regarding uranium's well-known occurrence in phosphate rocks, it seems reasonable to assume that uranium companies are again or shortly will be re-evaluating the potential uranium reserves inherent in this material and the associated economic viability of recovery.

7. ENVIRONMENTAL MONITORING AT URANIUM MILLS AND ISRS

Comprehensive environmental monitoring programs must be conducted at uranium recovery facilities to (1) establish the preoperational radiological baseline against which potential future impacts can be assessed and (2) demonstrate compliance during operations to public exposure standards (e.g., 1 mSv/y per 10 CFR 20.1301) and to ensure effluent releases are maintained ALARA. These programs are typically performed in accordance with NRC Regulatory Guide 4.14 (NRC 1980). Uranium and, therefore, its progeny are naturally occurring, and levels in environmental media can vary considerably from place to place depending on local geology, hydrology, and geochemistry. Accordingly, measurements are made of direct radiation (cosmic plus terrestrial) and of uranium-series radionuclides in air

(long-lived alpha-emitting particulates and radon gas), in surface and groundwater, and in soil, vegetation, and meat, milk, and fish as may be applicable at a given locale. Key elements of the preoperational baseline program are continued during plant operations and also typically include effluent monitoring (radionuclide particulates and radon releases from ventilation systems and yellowcake dryer stacks).

8. OPERATIONAL HEALTH PHYSICS PROGRAMS AT URANIUM RECOVERY FACILITIES

Uranium Mines: The environment underground potentially exposes workers to two primary sources: (1) internal exposure from inhalation of ^{222}Rn and its short-lived progeny in breathing air (the “radon daughters,” ^{218}Po , ^{214}Bi , ^{214}Pb , and ^{214}Po) and (2) external exposure from close proximity to higher-grade uranium ore. Needless to say, ventilation and diligent air sampling programs are critical in maintaining internal exposure ALARA and, in higher-grade mines; occupancy times in some areas underground often must be managed and controlled. As indicated previously, the Mine Safety and Health Administration (MSHA) regulates worker health and safety in mines in the United States. MSHA regulations currently require documentation of internal exposure (typically in working level⁵ months (WLM) of radon daughter exposure relative to a standard of 4 WLM/y) and external exposure relative to a 5 rem/y (50 mSv) standard. However, at the present time, MSHA does not require conversion of WLM of exposure to a committed effective dose equivalent (CEDE) nor the addition of internal and external exposure into an expression of the total effective dose equivalent (TEDE). At open-pit mines, internal exposure is usually minimized since excavation is in the open air and dust suppression technology is applied typical of large civil engineering construction projects.

Uranium Mills and ISRs: Operational health physics programs in conventional mills and ISRs are very similar and are generally consistent with any nuclear material facility that produces standard industrial uranium compounds of natural enrichment⁶ and include:

- Airborne monitoring for long-lived alpha emitters (uranium, thorium), primarily in ore crushing, drying, and packaging areas including combinations of grab sampling and breathing zone sampling;
- Radioactive material area ingress/egress control programs and surface-area contamination surveillance and control throughout plant areas;
- Respiratory protection programs if necessary, typically only necessary in ore crushing, product drying, and packaging areas;

⁵ A working level (WL) is the total potential alpha energy dissipated in one liter of air from the decay of the short-lived daughters in equilibrium with 100 pCi/L of radon (approx. 3.5 Bq/l), equivalent to 1.3×10^5 MeV/liter of air; a working level month (WLM) is exposure to a concentration in air of one WL for a working month of 170 hours. It is generally assumed that 1 WLM = 12.5 mSv (1.25 rem) so that 4 WLM/y = 50 mSv (5 rem)/y. Note however, that ICRP 65 (ICRP 1994) equates a WLM to 5 mSv (500 mrem), which may be conservative.

⁶ Natural enrichment means the mixture of the three naturally occurring isotopes of uranium as it occurs in nature, which is, on a mass basis, 99.3 percent ^{238}U , 0.72 percent ^{235}U , and 0.005 percent ^{234}U . Due to differing half-lives, and therefore different specific activities, on an activity basis these ratios are 48.9 percent ^{238}U , 2.2 percent ^{235}U , and 48.9 percent ^{234}U . By “definition,” the specific activity of natural uranium is 0.67 $\mu\text{Ci/g}$ (10 CFR 20, Appendix B, Table 1, footnote 3).

- Bioassay programs appropriate for the uranium products to which employees are potentially exposed. It must be noted that product-specific solubility characteristics can have metabolic implications for bioassay [2] [3] [4]. Higher solubility results in faster pulmonary clearance and, therefore, less pulmonary dose and vice versa. Typically, only urinalysis is performed with in vivo lung counting in response to confirmed intakes above specified action levels;⁷
- Airborne monitoring for radon and progeny as dictated by specifics of facility design;
- External exposure monitoring, primarily in areas in which large quantities of uranium concentrates and/or byproduct material are processed, packaged, and/or stored;
- Internal audit and quality control programs to ensure execution of safe work practices, regulatory compliance, and ALARA.

Internal exposure is documented by recording the derived air-concentration hours (DAC-hrs) of exposure to long-lived alpha emitters (uranium, thorium, radium), exposure to radon progeny in working level months, and bioassay results. External exposure is documented from personnel dosimeters (thermo-luminescent or optically stimulated designs). Committed effective dose equivalents (CEDE) resultant from internal exposures and the total effective dose equivalent (TEDE) as the sum of internal and external exposure are typically calculated using methods described in, e.g., NRC Regulatory Guide 8.30, *Health Physics Surveys in Uranium Recovery Facilities*, 2002 [5].

Over the years, the NRC has issued a number of helpful regulatory guides specific to uranium recovery facilities, providing a solid basis and foundation for “good health physics practice.” Typically, the agreement states accept these as appropriate to demonstrate compliance to their own regulations commensurate with, e.g., NRC’s 10 CFR 20 and 10 CFR 40. Examples include:

- 8.30 — Health Physics Surveys in Uranium Recovery Facilities;
- 8.31 — ALARA Programs at Uranium Recovery Facilities;
- 8.22 — Bioassay at Uranium Mills;
- 3.56 — Emission Control Devices at Uranium Mills;
- 3.59 — Estimating Airborne Source Terms for Uranium Mills.

9. THE HUMAN CAPITOL CRISES IN HEALTH PHYSICS

In the U.S., a projected shortfall in sufficiently educated radiation safety professionals has placed a burden on industries using radiation to support energy, security and health needs including the uranium recovery industry. This national shortage is primarily due to several decades of stagnancy of the nuclear industry in U.S. and globally, little incentive for students to pursue health physics and related radiological science university programs, the large number of radiation safety personnel reaching retirement age and a general lack of funding for academic research and educational health physics programs. Recent assessments sponsored by the Health Physics Society and the USNRC have addressed the circumstances of labor

⁷ Over my career I have had the opportunity to have been the radiation safety officer at six different uranium recovery facilities that produced products of varying solubility depending on specifics of process chemistry and the drying temperatures used (e.g., Task Group on Lung Dynamics class D/W as well as Y—ICRP 1972). However, modern mill designs dry the final uranium product at much lower temperatures than in the past, producing more soluble products.

resources in the health physics, related radiological and nuclear science professions [6] [7]. The results of these studies are summarized here.

Fig. 4 presents the increasing age profile of radiological scientists and engineers in the U.S. and demonstrates that currently, about 70 % of this population is near or in excess of 50 years of age. Fig. 5 shows the decreasing trend in health physics graduates from the mid-1990s until early in this decade. However, the data of Table 2 suggests this trend has been somewhat reversed in the last few years with increased enrollments and graduates thru 2010. Accordingly, some current trends in the health physics and radiological science labor market are summarized as follows:

- The number of undergraduate and graduate degrees are increasing relative to the previous few years;
- Enrollments continue to increase therefore more graduates are expected;
- Modest growth is expected in total number of new health physics positions available;
- Over 200/year new job opportunities are being created for graduate level health physicists;
- However, significant need exists for replacement due to attrition as more are retiring;
- Approximately 2:1 ratio is expected in the number of job opportunities vs. number of new graduates.

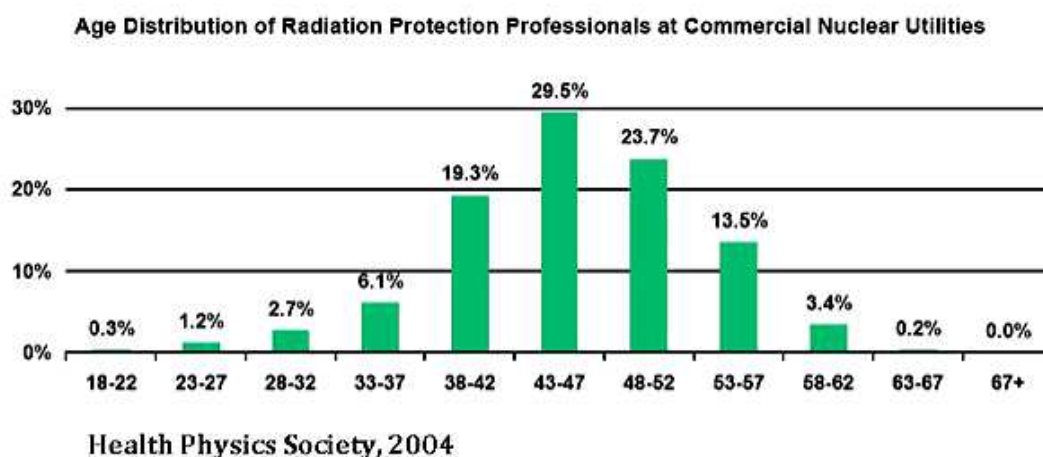
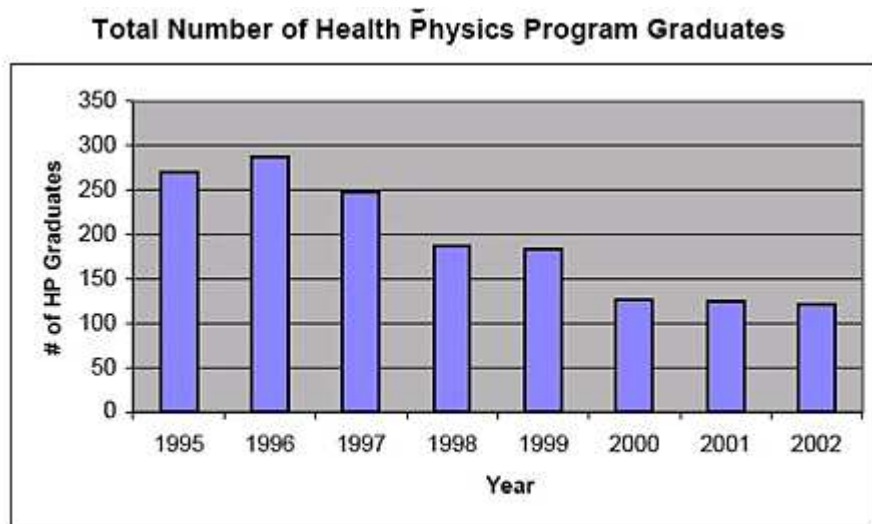


FIG. 4. Age distribution of radiation protection professionals at commercial nuclear power plants.



Health Physics Society, 2004

FIG. 5. Number of health physics program graduates had been declining.

TABLE 2. NUMBER OF ENROLMENTS AND DEGREES ARE DEMONSTRATING INCREASING TREND

Health physics enrollments, degrees, and estimated available supply			
Year	Total enrolments	Total degrees	Estimated supply of new graduates
1999	478	192	109
2000	393	136	81
2001	447	131	60
2002	425	137	73
2003	505	154	80
2004	568	132	60
2005	624	169	81
2006	639	173	83
2007 estimated		~195	~95

2010 estimated		~205	~100

ORISE, 2007

10. CONCLUSIONS — OPPORTUNITIES FOR HEALTH PHYSICISTS IN THE EXPANDING URANIUM RECOVERY INDUSTRY

Hopefully, this broad overview suggests that numerous opportunities for health physicists and radiological scientists are emerging as a result of the rapid ongoing expansion of the uranium recovery industry. Not only are there opportunities to support the health physics and related environmental-assessment and monitoring programs of operating plants, but also the preoperational licensing process is arduous and can take several years. During this preoperational period, baseline radiological monitoring programs must be designed and implemented and source material license applications and numerous other permits must be prepared. These regulatory submittals must describe, in some aspects in considerable detail, the intended operational health physics and training programs and provide results of fate and transport modeling efforts to estimate off-site public exposure during operations, radiological design aspects to ensure incorporation of ALARA principles into the facility design and layout and for effluent control, and descriptions of the planned operational environmental monitoring program. After the doldrums of the last 20 plus years, it is again an exciting time at the front end of the uranium fuel cycle.

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COOPERATION WITH EMERGING COUNTRIES IN ADVANCED MINING TRAINING PROGRAMMES INVOLVING AN INDUSTRIAL PARTNER

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Abstract

After about 20 years at a low level of activity the global uranium mining industry has been enjoying a significant expansion since about 2003. However, it is apparent that the “quiet” period has led to a shortage of new staff coming into the industry, many middle ranking and skilled professionals have moved to other industries and many of the remaining staff is fast approaching retirement. Many organizations are looking at ways to address this situation as quickly and effectively as possible, including governments, industry and the IAEA. This paper describes one training programme that has been developed, and is currently being implemented, as a joint venture between the uranium mining company AREVA NC and the Centre for Advanced Studies of Mineral Resources, which is located at the School of Mines in Ales. France.

1. INTRODUCTION

The Maputo Declaration on the development of Geosciences in Africa emphasizes that Africa, with its wide range of natural resources, is in a significant position to contribute to its own development and that of other regions of planet Earth. The development of Geoscientific knowledge can help Africa to learn from its past mistakes in the environmental management of our Earth’s system in order to improve the quality of life for its people (Maputo, Mozambique, 5 July 2006).

We believe and share the vision that promoting wider geoscience education and contributing to the capacity building of regional centers of excellence in geoscience scientific and research infrastructure, will improve awareness by the African peoples of the need for sustainable management of the environment and of the continent’s natural resources to combat poverty by the development of mining activities.

This communication outlines a successful example of public-industrial partnership and networking in advanced mining training programs between the CESMAT and AREVA.

2. CESMAT

The **Centre for Advanced Studies of Mineral Resources (CESMAT)** is a Higher Education Institution in France whose function is to train and produce the upper management personnel working in mining, throughout the world. The program of study is comprised of seven separate year-long study programs, a network of some 2 300 former students from a hundred countries with whom regular contact is maintained, and a permanent think-tank unit that concentrates on the training of mining sector managers (Tables 1 and 2).

CESMAT has a lightweight and flexible structure, with thirty-three years of experience in dispensing innovative training that is based on an exchange of experiences between professionals. The Centre provides a program that is veritably tailored to the students’ home

country working conditions. The guiding principle for CESMAT is that cooperation and training hold a special position in French policy concerning relations with mineral producing countries. Using this as a base, the Centre fulfils the long-term mission confided to it by the Ministry of Industry, which is to establish a network of relations with producing countries.

The Centre was initially established to encourage exchanges among the various sectors of technical mining expertise; CESMAT has constantly kept abreast of international developments and of new problems encountered by the industry. Therefore, seven programmes have been progressively developed on minerals prospecting and processing, resources evaluation, open cast mining techniques, mining economics, impact of mining on environment, management of closure of mining activities and the role of the State.

These programmes bring together ten to twelve engineers or geologists who have already had some professional experience. For non-French speakers, a language-training phase of three months may precede the programs. The following specializations are currently being offered:

- Ore Prospecting and Mineral Processing — Nancy School of Geology — CESEV;
- Treatment of Industrial Evolutions and Changes — CESTEMIN;
- Geo-statistical Analysis of Ore Deposits — Paris School of Mines — C.F.S.G.;
- Open Cut Mining Operations — Paris School of Mines — CESECO;
- Economic Analysis of Mining Projects — Paris School of Mines — CESPROMIN;
- Mine Safety and Environments — Alès School of Mines — CESSEM;
- Mines Public Administration — Paris School of Mines — CESAM.

Teaching is done both by Institute professors and by public and private sector industry experts. These instructors rely heavily on technical visits and on practical case studies. One specific component is the student research project mentored by specialists in the field, which is oriented directly to circumstances in the student's home country. During this time, the Secretary General conducts personal interviews with each student to gauge satisfaction levels and to gather input that may be useful in developing program content in the future.

The participation of students in each program is attested to by means of an official certificate. In some cases, this may be accompanied by a diploma from the host school.

Tuition for the courses, which costs around 15 000 €/year, may be covered by CESMAT for students affiliated with public or private mining organizations from foreign, mineral producing countries.

Scholarships are also available from French organizations, sources in the student's country of origin, or international organizations such as the EU, UNESCO, UNDP and others.

CESMAT has also built partnerships with mining companies (VALE in Brazil, CODELCO in Chili and AREVA in France) which contribute to sponsoring trainees for living costs during their studies in France. Also, AREVA is developing uranium exploration and mining in many countries and has signed cooperation agreements with the governments of these countries to provide them technical and financial support for capacity building in partnership with the French school of mines.

3. AREVA'S INTERNATIONAL COOPERATION AND TRAINING PROGRAMS

In the framework of its international cooperation policy, AREVA offers training programs to the government institutions of emerging countries and for employees of AREVA abroad through the AREVA Mining College:

3.1. Cooperation with emerging countries for government institutions:

As mentioned previously, AREVA is developing uranium exploration and mining in many countries and has signed cooperation agreements with the governments of these countries to provide them with technical and financial support for capacity building in partnership with the French school of mines (GEM/EMA and CESMAT).

AREVA has signed agreements with local governments in order to promote education and improve capacity building in emerging countries.

AREVA will, in connection with CESMAT, propose a personal project dedicated to uranium. The trainee will also learn French for 3 months prior starting at GEM/CESMAT

AREVA will sponsor trainees for travel and living costs during their studies in France for one or two years.

If already employed, the trainee at the end of the training should return to his or her institution. Local authorities have a priority to offer a job to young graduates. If the candidate does not receive a proposal, AREVA will do their best to offer the graduates work locally

Other existing or future possible areas of cooperation:

- Visit of a Government delegation to AREVA;
- Exchange program in education and research;
- Development of a Master's degree at the local university;
- Recruitment in MEng / MSc (2 years training);
- Upgrading of a local laboratory in order to achieve the standard needed for setting up the Master degree.

TABLE 1. PARTICIPANTS BY COUNTRY IN 2008/9 AND 2009/10

Activity	2008–2009	2009–2010	Total
Namibia	6	13	19
South Africa	2	2	4
Mongolia	2	0	2
Gabon	0	3	3
Republic of Central Africa	0	4	4
Senegal	0	3	3
Total	10	25	35

The total investment represents 1 Million € in 2 years, funded by French government (50%) and AREVA (50%).

— **Training for AREVA employees: why a Mining College?**

Present boom and growth:

- Development of exploration properties and acquisitions;
- New mining projects (Niger, Namibia, South Africa, Canada, Kazakhstan...);
- Increase capabilities in present operating sites (Katco, Somair).

Large deficit in required human resources:

- Recruitment is active and ongoing (666 in 2006, 1 000 in 2007 of which 200 engineers and managers) many of them are at junior levels.

Lagging interest in mining related courses in universities resulting in less graduates.

— **Mining College: how does it work?**

Through a curriculum of professional training modules and work exposure.

Each curriculum consists of:

- Training modules specific to various pertinent business activities — technical subjects (geology of uranium, sampling, mining techniques, mineralogy...);
- In-the-field internships/visits to various sites;
- Generic topics (occupational safety, environment, management, etc.).

The modules are taught by:

- Internal experts — both active and retired AREVA employees;
- External experts from prestigious engineering schools (GEM School of Mines). Active and retired university professors, consultants...).

The curriculum runs over a three-year period.

— **Curriculum: which one?**

- Exploration Geologist;
- Mine Geologist (geological control);
- Mine Engineer;
- Ore Processing;
- Mill Maintenance;
- Mine Maintenance.

An example: exploration geologist (Figure 1):

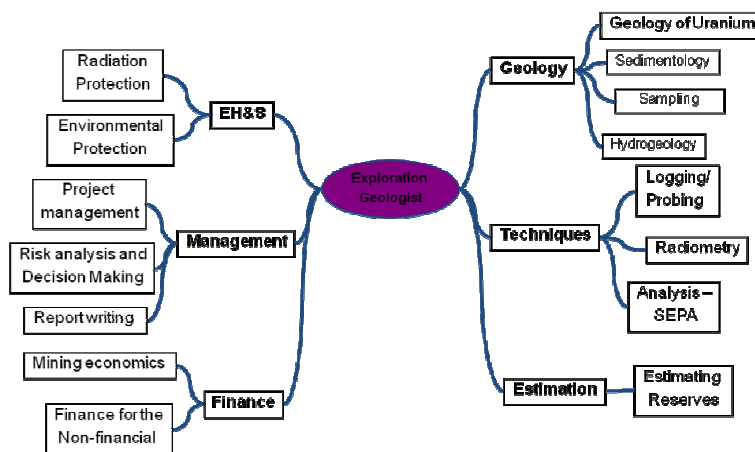


FIG. 1. Exploration geologist.

— Rules and financing

Eligibility for registration:

- <3 years' experience <30 yrs. old;
- Some obligatory modules but also a choice of modules in line with the job profile (Manager, participant, Mining College staff);
- Distribution of schedule of sessions.

Financing:

- All costs borne by the Mining BU (800 K€ in 2008);
- Air travel (economy class);
- Once a student has been registered, curriculum and attendance are obligatory.

— 2009 Mining College participants

Exploration Geologists	103
Mine Geologists	16
Mining Engineers	30
Ore Processing	23
Maintenance	12
Specialized curriculum*	08
<u>TOTAL</u>	<u>192</u>

* For Industrial Engineers, Mechanical Engineers...

TABLE 2. PARTICIPANTS BY COUNTRIES AND ACTIVITY — MAY 2009

Activity	Canada	Central Asia	Australia	Jordan	Areva RSA	Niger	France	Total
Exploration	19	17	2	4	32	16	13	103
Mine geologists	5	3			1	3	4	16
Mine engineers	5				2	14	9	30
Ore processing.	3	3				6	11	23
Maintenance		3				8	1	12
Customized							8	8
Total	32	26	2	4	35	47	46	192

4. CONCLUSIONS

The Cooperation between GEM/CESMAT and AREVA with overseas governments promotes a high level of education and capacity building which is necessary for both local institutions and AREVA locally.

There are positive benefits arising from the creation of a network in order to share experience.

PANEL DISCUSSION

The panel discussion was opened by C. Ganguly who pointed out that the panel members had been selected to ensure an in-depth coverage of the major issues that had been discussed during the technical session of the symposium. After the Chairperson's opening address each panel member was invited to make a short presentation as part of the scene setting for the discussions.

The panel members were:

G. Grandey, Chairperson	Canada
T. Geer	USA
S. Kidd	World Nuclear Association (WNA)
F. Killar	Nuclear Energy Institute (NEI)
A. Boytsov	Russian Federation
R. Gupta	India
H. Fosstroem	IAEA

G. Grandey's opening address was entitled "Building success in troubled times". His main theme was what actions the industry participants could take to support each other through the present period of a relatively rapid expansion of all aspects of the nuclear industry, while taking into account the general global economic situation. He was followed by opening statements from each panel member. It was noted by several speakers that in general the mainstream uranium industry had been little affected by the drastic changes in the economic climate. In particular it was observed that electricity is required by almost everyone and, despite a recession, overall demand for electricity continues to grow, albeit at a slower rate than before. This thread was taken up by a number of the speakers during the discussions.

Another common theme amongst the opening remarks by panel members was the general desire to have improved security of energy supply and "cleaner" energy as part of efforts to offset climate change and how this was driving exploration in a growing number of countries. Thus a frequently discussed topic was the supply of uranium to feed all the proposed Nuclear Power Plants (NPP) that had been mentioned throughout the symposium; speakers observed that several companies are looking to participate in joint ventures, especially with China and Russia. Over the next ten years more than 2 billion pounds of uranium will be used and it is already known that current mine production is less than the existing demand and it is expected that 20% of the demand will be met from new and expanded mining operations.

To ensure an ongoing uranium supply, exploration will need to continue and there was much debate about the shortages of skilled and experienced staff throughout the whole of the nuclear fuel cycle, in general, and the uranium production cycle specifically. A number of times the point was made that fluctuation in uranium prices will continue to have an impact on the level of exploration activity. As part of the impact of these exploration and mining activity expansions a number of people observed that there will need to be upgrading of regulatory processes to deal with the increases in activity throughout the uranium production and nuclear fuel cycles; and this again would require increased access to suitably trained and experienced human resources.

A major obstacle in the expansion of supply and demand will be the issue of raising funds to pay for exploration and project development. The panel noted that the structure of the uranium industry is changing rapidly and there is growing interdependence between existing players and a realisation that new mines are needed so that production may get closer to demand, new partnerships and joint ventures will become more common in the future. It was agreed that while all producers are trying to improve their environmental performance in all stages and phases of the uranium production and nuclear fuel cycles, an overall improvement in standards was still to be achieved in some areas. In particular work to achieve reductions in, and prevention of, social impacts and improvements in social acceptance are programmes high on the agenda of all modern uranium producers.

The panel commented that the IAEA should also be encouraging the adoption of its safety standards by the nuclear industry and explaining how this may help address the concerns in some quarters of the community; the IAEA should also work to ensure harmonisation of standards.

There was some discussion of the concern expressed by some speakers over the current gap between supply and demand in relation to the supply of raw material for nuclear fuel, but one observer noted that the level of new activity reported at meetings such as URAM 2009 seems to confirm the need to at least maintain the present level of activity.

However, it was agreed by all present that development should be undertaken in a balanced manner and the industry has to reduce risks and also ensure that there are no new legacies created, for example in the uranium mining resurgence. The idea of stewardship is being more widely adopted in parts of the uranium industry and there is a growing trend for downstream users and buyers of uranium to visit mines to check on their environmental credentials and ensure they are dealing with “clean” quality mining companies.

The panel noted that all those who participate in the nuclear industry, be it uranium production or nuclear fuel cycles, need to be part of the same team working together. There is a great increase in interest in the industry and all participants have a part to play.

S. Kidd looked at the future of the industry from the point of view of the advantage it has over the price of fuel. Nuclear power generation is more costly than other methods in all areas except the price of the fuel. The uranium production cycle is worth about US \$20 billion annually; but this is a small sum in comparison with the costs of gas and coal for power generation; for example, with coal 50% of the price of the coal delivered to the power plant may be for transport, consequently power plants need to be located near the source of fuel. Uranium, on the other hand, can be mined in remote areas and it is relatively small volumes of yellowcake that need to be transported for fuel fabrication and delivery to an NPP. Thus the advantage is apparently small but in truth highly significant and thus extremely important.

One speaker represented a primary producer of uranium and he said their concern was how to meet the future demand for their product. He believed that there is currently enough production capacity and that there are enough resources for the present. Whilst the present established and larger producers seem to be able to command premium process for their product the economic crisis has had an impact on the smaller, junior companies. Despite the demise of many of the smaller companies that have sprung up in the years since 2004, two have gone on to develop into established uranium producers — Paladin and Uranium One.

From examination of the supply and demand analyses, especially that done by WNA, A. Boytsov concluded that 2025 would be the outer limit of uranium production expansion. This would mean further resources need to be discovered within the next 20 years. And so new

production facilities should be created and maintained. Again a major concern was ensuring that the uranium market price would remain attractive to developers as well as being profitable and stable. He concluded by noting that the present lead time for opening new uranium mines is about 15 years on average, and that this is far too long in the current situation.

In another discussion it was noted that the two nations with the greatest ambitions for the development of nuclear power are currently China and India, but neither country has sufficient uranium production capacity to meet domestic demand. Therefore, both countries have a serious need to improve uranium production in the long term and to assure the stability of that production.

Amongst all the talk of expansion of production one speaker added a note of caution, observing that there is a shortage of young professionals in the nuclear industry and that this was an area where he thought the IAEA could play an important role in training. Young professionals need opportunities to gain experience to complement their training and perhaps IAEA could help Member States developing uranium mining and related activities to build up a cadre of trained personnel to be ready for the major development push that many of the meeting participants see as an inevitable development for the future.

The meeting was advised by H. Forsstroem that there are three areas where the IAEA could be especially helpful in the present situation: capacity building; support for new members of the industry both in nuclear power and mining; and improving the acceptability of the nuclear industry to the community at large. These are topics into which the IAEA is putting a major effort in the near-term plans for both the Regular Budget and Technical Cooperation programmes in many areas.

One questioner noted that the global nuclear expansion was not apparently being severely affected by the financial crisis and seems likely to expand as predicted by many speakers. The speaker went on to remark that URAM 2009 had shown that the uranium community was ready to expand and develop.

F. Killar replied that the whole of the nuclear supply chain was near capacity at all stages and we should be careful to think of the whole cycle in the context of expansion. Long term there may be mining issues. A. Boytsov commented that by 2025 many existing uranium mines would be depleted and so planning was needed now for the longer term future. S. Kidd said that knowledge transfer and teaching of new younger people was vital to support development. Fuel is important but the industry needs to look at ways of improving public education about the nuclear fuel cycle and uranium mining to overcome prejudice and fear based on not having all the facts. H. Forsstroem said there were plenty of challenges to come and the three pillars of the IAEA: Safety and Security; Science and Technology; and Safeguards and Verifications would all be required to overcome these challenges.

S. Kidd came back to remark further that there is no mismatch between nuclear fuel demand and electricity expansion. One issue is the time taken to get a new power plant built and licensed, if this could be brought down to less than 10 years it would be good and the same applies to the development of uranium mines. One problem is that while the industry is accustomed to very long term planning, the public tend to have a shorter time horizon when looking at decisions. A. Boytsov commented that the supply issue for mining was based on conservative assessments and some very large mines were being planned around the globe, e.g. Cigar Lake, Elkon, etc. We need to be aware of the economic situation and avoid early depletion.

H. Forsstroem commented that technology and safety go hand-in-hand and should not be separated to improve an economic balance. The industry has to remain safe and effective in order to remain acceptable. F. Killar concluded the discussion by noting that it is necessary to always consider the nuclear fuel cycle as a whole. The gap between supply and demand is primarily in the uranium mining area and the industry is currently very dependent on secondary sources of supply; it will be necessary to find new sources of supply before too long. There needs to be consistency in regulation and encouragement of private industry interaction to complement IAEA activity.

The second question was about the pricing of uranium which is unlike many commodities as only 15% of uranium trades on a spot market and so uranium producers are faced with a complex mixture of strategies and economics. There is a marked lack of transparency in the present pricing and marketing of uranium, especially on long term price indicators. The speaker wanted to know if this contributes to increasing demand by sending erroneous signals to producers.

The panel responded by saying that utility companies value stability of price as much as miners. Low uranium price does give a market advantage in the energy production arena especially against coal where up to 50% of the price may be transportation costs. However, indicators are just that, useful but have little influence on the market price; demand from nuclear power utilities is long term, constant and committed. It was noted that the industry has to be aware of speculation in relation to uranium pricing, noting the example of what had happened only recently in 2007. If assumptions are made about long term plans in China and India then this may help stabilise long term prices.

The theme changed with a question about thorium and plutonium based fuels and if the panel thought they would be viable in the 2020–2023 time frame. R. Gupta replied first saying that India has only modest uranium resources but was looking at thorium as an alternative since that is a much larger resource. H. Forsstroem continued by saying this was like the chicken or the egg dilemma. Thorium is regarded as a long term adjunct to uranium by many. India was isolated from the main nuclear community for some time and so looked for other options. Uranium has not been considered to be a limited supply and so thorium continues mostly to be a secondary consideration. He thought thorium is unlikely to be of importance before 2020 but it might be useful in 30 years' time. However, the research and development would need to be started now. S. Kidd commented that the Generation IV reactors, beyond LWR had been accelerated in development by today's renaissance of the industry. Many of today's new build reactors will come on line over the next 10 years and after that thorium may be more important-but research and development should begin today. He also thought that this was unlikely to happen unless there is a very great expansion in reactor development. T. Geer agreed with S. Kidd and said that there would be no new reactors for thorium until significant development resources become available. There would need to be a policy validation e.g. in India, before thorium programmes would be developed by others. The disposal of excess weapons grade plutonium is troublesome despite the obvious benefits of the programme. F. Killar concluded the response by saying that USA utility companies will be reluctant to try a new system while they are selling electricity successfully with existing technology. The problem will be to get someone to go first and show that it works and is economically viable.

In the next question it was observed that nuclear power is a multiple activity programme but until very recent times there had been little new activity in uranium mining and reactor construction. Where did the panel think this industry would find the necessary skills and

trained people and how would this be managed on a global scale? S. Kidd began the reply by saying that maybe the questioner was too pessimistic. In the early 1950s and 1960s the nuclear industry began from nothing but was soon established. If nuclear power is the answer to many current problems then we will eventually develop all we need. France built 5–6 reactors per year in the 1980s, perhaps China will be able to do the same. H. Forsstroem agreed saying that education is growing and we need to be sure that the newcomers are trained before the older workers retire. He stated again that knowledge and experience transfer are going to be important activities for at least the next ten years. F. Killar agreed and said that the NEI was concerned about the aging workforce and skills loss etc and was taking an active stance. He estimated that 50% of today's workforce will be retired inside 10 years or maybe less and so NEI is working with the authorities to develop programmes to meet predicted skills needs. He noted that there is a shortage of nuclear engineers and new courses are starting up; but in reality not too many new specialist engineers will be required, many of their skills are shared with other engineers. He did note however that for health physicists the situation is grave as there are skills shortages in all areas and training programmes are being developed but perhaps not quickly enough to meet demand. A. Boytsov added that this was indeed an issue in Russia, especially in the mining sector. The new Elkon mine may need 6 000 skilled persons covering all disciplines. He noted that there are skills shortages in the Russian Federation and new training programme are being developed to overcome the difficulties in the human resources sector.

The next questioner commented that as history tends to repeat itself, how could the industry be sure it will do better in the future in terms of cost overruns for new projects?

T. Geer began the response by saying that the selection of known and proven technology and design, links with other users and maintenance of standard designs to keep licence applications as similar as possible would help improve performance all round. He explained that the use of common parts to streamline supply chains and avoiding excessive customisation and exchanging more lessons learned were being applied in the USA and Europeans are watching to see what they can learn.

G. Grandey said there were two risks that had to be appreciated. Namely, regulatory expectations, which had grown considerably since the last major round of activity and also QA/QC systems that are now in place throughout the industry and should be seen as an integral part of a company's culture to help meet modern regulatory expectations.

The next questioner, C. Macdonald asked if there was confusion about gaps in supply: is the gap in supply or in commitment by companies? It seems there is no shortage of resources but plenty of uncertainty in the market.

From the floor it was observed that previous nuclear development had been with strong government support but the current IAEA model for regulatory development was not optimal and would not support rapid growth in the industry. It was suggested that a new emphasis was needed and that licensing processes should be streamlined. The fact that nuclear engineering brought overwhelming benefits to society should be remembered and used to encourage people to make this industry a career choice. After 50 years of experience in developing nuclear resources, we should be able to speed up the pace of development, for example in Canada making licensing a new plant a one step process not a two-step one.

F. Killar began the panel's response by saying he agreed that a one step process would be better. However, he added that the increasing use of standard designs, early site selections etc. were all steps that were speeding up the approvals process and reducing the risks of

projects being delayed; the use of a pre-approved standard reactor design is another factor to be considered in this context. He believed that the licensing process could be reduced though these improvements so that by 2012–2013 it could take as little as three years. Now that a standard design is effectively 80% approved with only site specific details to be licensed one really could look forward to 3 year licensing times. He concluded by saying that eventually he could envisage an 18 month licensing time schedule.

T. Geer agreed that early site approval was an accepted practice now and this did save a lot of time and money. Now that there is a strong market demand, licensing is being streamlined but with no loss of integrity. A speaker from NRC (USA) commented that the use of standard designs was very helpful for NRC and certainly at the moment in the USA every effort was being made to standardise applications to the maximum extent possible.

A participant from Niger asked that if one had many uranium exploration targets in remote and poorly accessible areas how would the panel tackle a 10 year plan, which seems to be the current development time for a new mine. It seemed to the speaker that mining companies backed away when market prices fell and so he advocated more transparency in uranium pricing and purchasing. There were also concerns over relatively short mine lives and poor provision for remediation. He also favoured a high uranium price to maintain development interest

G. Grandey replied first, saying that although the uranium production cycle is a long term industry price mechanisms are not very long term with the present situation of a spot and term market and as both these prices are less than 10 year terms, looking ahead more than 10 years is difficult. He pointed out that uranium is unlike base metals in that there is no “hedge” but he agreed the industry needs to try and do better on long term pricing. T. Geer continued saying that if there was a national policy and the fuel was for domestic reactors then the present situation made more sense. A long term investment in enrichment facilities could be considered but if a country is simply mining uranium for sale then it is not the same. He concluded that complex pricing will remain until the supply and demand situation stabilises and very long term prices can be agreed upon. F. Killar said that utilities sell electricity and buy their fuel in an open market; sometimes they are able to have longer term deals on pricing but in the long term more market stability is required. Also he reminded the meeting that uranium has only one use so there is little flexibility in sales. H. Forsstroem concluded the answer by noting that there was a difference between private and state enterprises in regards to pricing. He remarked that if there was a lot of new private investment in uranium mining and nuclear power this should stabilise the situation.

A speaker from Brazil said that they were planning to increase their uranium production operation by a factor of 2–3 times over the next 3 years or so, which is why they had requested an UPSAT mission. He suggested that other producer nations should also request UPSAT missions as it may help with the acceptability question.

In replying G. Grandey observed that compared to most base metals, which are freely traded and which is cost effective, uranium has two issues. Firstly, many nations want to retain the uranium and control it, so there can be no free trade. Secondly, there is a “uranium renaissance” at the moment but many governments still maintain that development of uranium resources is unacceptable. This creates concerns in the search for stability in long term supply. Uranium does have some particular qualities but it is essentially another metal and people need to be helped to understand this. G. Ganguly remarked that uranium is a dual use material with the potential for weapons use and so free trading may create some problems. H. Forsstroem said that acceptance of uranium mining by society generally was still an issue but

there is often resistance to the development of any new mine. The legacy issue is a reality, especially with uranium mines. However, today's uranium industry has done much to improve standards and modern uranium mines are amongst the world's best run operations. He concluded by reminding the meeting that the main issue is to communicate these facts to the community at large better than we do at present.

S. Kidd said that the WNA was working to remove the emotion from the uranium debate as much as possible. Uranium could be sold long term but he believed daily trading would also be required. T. Geer commented that the global community considers CO₂ to be a problem and once they realise that renewables are not going to be the complete answer to future energy needs then nuclear will be required as an integral part of the "energy mix". For these reasons society will need to be swayed and learn to realistically balance the risks of nuclear against those of energy shortage and climate change.

G. Ganguly brought the session to a close by saying that the nuclear renaissance had raised many issues which had been discussed in the session. He reminded participants that this is not the first time nuclear has started activity- before we started from zero but now there is a wealth of experience although there is a serious need to grab and retain that experience now before all the knowledge holders retire! Also more effort should be put into stewardship and stakeholder communication at all levels and good practices are to be encouraged at all times. The IAEA will be aiming to assist newcomers to the uranium production cycle but today's major players must stand prepared to assist the juniors to develop successfully and not bring the industry into bad favour with the community. The newcomers and young professionals are there and they are up to the challenge but it is important that all partners in the industry cooperate and keep arranging meetings such as URAM-2009 to promote knowledge exchanges and networking to help smooth the progress of this latest upsurge in activity.

CONCLUDING REMARKS OF THE SYMPOSIUM PRESIDENT

F. Dahlkamp, Germany

Ladies and Gentlemen,

It has been a week of informed presentations and first class discussion on the current state of the uranium industry. I hope you have all enjoyed the exchanges and I would like to thank the contributors and the participants for their efforts.

The uranium supply issue has been debated at length. Going back in history mining has been an industry that supplied people with commodities when the price was right. In the case of uranium it appears there are no special technical issues that cannot be managed but only issues of politics and public acceptance.

In the area of uranium resources there seem to be issues that are more academic than practical. The questions of terminology and transparency need to be resolved, especially when they are together. As Hans Forsstroem said, 'We would perhaps be better off going back to more practical terms'.

As I remarked in my opening address there are still two major outstanding issues. Firstly, we must address the need to ensure proper knowledge transfer from the aging and retiring workforce to the newcomers who will be managing the expansion of the industry. Secondly, we need to work harder at linking the various factions within the uranium production cycle and improve the industry's communications with the community and indigenous people. If this has happened in part as a consequence of this symposium then that will be a sign of success.

I wish to thank the IAEA and the organisers for this symposium and I leave you with a traditional German miners' greeting for a safe return and look forward to seeing you at the next symposium in three or four years' time.

"Glück Auf"

LIST OF OTHER PAPERS AND PRESENTED POSTERS

SESSION 3: URANIUM EXPLORATION and GEOLOGY

Metasomatic Uranium Mineralization of the Mount Isa North Block

A. Otto, J. Jory, J. Thom, E. Becker

The Main Geological Types of Uranium Deposits in Argentina

L. Lopez

Uranium Prospection in Uruguay

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Uranium and REE Resources of South Eastern Desert of Egypt

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