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Establishment of Uranium Mining and Processing Operations in the Context of Sustainable Development

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ESTABLISHMENT OF URANIUM MINING AND PROCESSING OPERATIONS IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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FOREWORD

Mining is an industry that has long been associated with causing significant environmental impact, and uranium mining has been no exception to this belief in the past. There are legacy sites arising from uranium mining on every populated continent which are sources of contamination and pollution and are the centre of adverse public attention and concern. Since the 1970s, the world community has taken greater notice of environmental issues and legislation to protect the environment and improve the environmental management performance of all industries, including mining..

As public concerns over climate change and the potential adverse impacts of modern life styles on the environment have grown, so has the potential for the increased use of nuclear energy as a source of power come under increased scrutiny. The nuclear fuel cycle begins with uranium mining, and thus any increase in demand for nuclear power facilities and programmes can only come about following an increase in uranium mining activity, which supplies the basic raw material. Thus, after a relatively quiet period in the industry's history, uranium mining has seen an upsurge of activity since 2003. This activity includes increased production from currently operating mines as well as exploration and exploitation of new resources and a return to previously uneconomical resources. All of these developments need to incorporate management systems that take into account both improved environmental management, in line with current standards, and application of the principles of sustainable development.

The IAEA supports the exploitation of nuclear resources for peaceful means and has the task of providing Members States with guidance on how to best develop nuclear energy resources. Part of that guidance comes in the form of published reports in the IAEA Nuclear Energy Series, of which this publication is one example.

This report provides stakeholders with practical information and historical examples of experience gained from the introduction of uranium mining and processing operations in specific areas and the subsequent effects of mine closure. In addition, recommendations are offered to the primary stakeholders; namely government agencies, mining and processing companies, local communities, and environmental protection groups.

The IAEA acknowledges the valuable contributions of the consultants in the preparation of this report. The IAEA officers responsible for this report were C. Ganguly and P. Waggitt of the Division of Nuclear Fuel Cycle and Waste Management.

EDITORIAL NOTE

CONTENTS

SUMMARY

This report focuses on the criteria necessary for the sustainable development of uranium mining and processing operations in the context of the four cornerstones of sustainable development, namely:

— Environment;
— Social issues;
— Economics, and;
— Governance.

The criteria for ensuring sustainable development within each of these four areas is outlined, and the subject of legacy issues and timescales over which an industry should be considered sustainable are discussed.

A sustainable industry is one that balances environmental, social and economic requirements. Concentration on only one aspect is certain to cause conflict with the others. For example, focusing exclusively on environmental protection can make an operation unprofitable and a failing business will lose shareholders and be unable to develop and meet its social obligations. However, the emphasis on particular aspects will vary with the specific operation and its local physical and social environment. Proper governance will have in place the structures required to permit achievement of an appropriate balance.

As the world's population continues to grow at a rapid rate, so too does the demand for electricity. Nuclear power has for the past two decades generated approximately 15–16% of the global electricity supply, and is seen as an attractive potential alternative to fossil fuels.

Uranium is the basic raw material for manufacturing nuclear fuel. Therefore, to fuel currently operating and forthcoming nuclear power reactors it is fundamental to ensure a sustainable supply of uranium.

ENVIRONMENTAL ISSUES

To ensure that the environmental aspects of sustainable development are respected, an operator must:

— Promote responsible stewardship of natural resources and the environment, including remediation of past damage;
— Minimize waste and environmental damage throughout the whole supply chain;
— Exercise prudence where impacts are unknown or uncertain, and;
— Operate within ecological limits and protect critical natural capital.

Tailings, waste rock and water management have been, and will continue to be, the most challenging areas in terms of achieving good environmental performance. If uranium mining and processing operations are to be regarded as sustainable then management achievements in these areas must be of the highest order. In this regard, the lessons of the past appear to have been learned, with almost all current operations having well developed management plans in place at startup, which continue to be an integral part of the operating strategy, evolving with changing circumstances as development proceeds throughout the life of the project.

In some respects, the effectiveness of these plans to satisfy the expectations of sustainable performance is still being assessed. The Nabarlek mine and mill in Australia, which commenced operation in 1979, is at present the only example of a conventional operation which has started up and been decommissioned according to plans developed at startup and refined as part of the operating strategy. However, other sites such as the Collins Bay A zone and D zone pits at Rabbit Lake in Canada are well down this path.

There are also operations that commenced in the 1950s for which decommissioning and closure plans were not well formulated at startup, but which achieved acceptable closure through the application of appropriate technologies and standards. Examples include the Mary Kathleen mine in Australia, the Eldorado Nuclear Beaverlodge site and operations in the Elliott Lake region, both in Canada.

The ability of the industry to embrace a high level of environmental performance during operation is also reflected in the records of the Ranger uranium mine, surrounded by the World Heritage listed Kakadu National Park in Australia, and the high grade operations at McArthur River/Key Lake and McClean Lake (Canada), which have addressed and overcome new challenges with regard to mining and waste management.

The current generation of operators has also demonstrated a willingness to address evolving environmental sustainability standards during operation. Prime examples are improvements to tailings deposition methods in Australia and Canada, introduction of new technologies and systems for water management at Ranger and Key Lake, and process modifications to alleviate or eliminate the impact of ammonia used in production at a number of sites.

Despite the impressive performance of the above examples, legacy issues arising as a consequence of earlier environmental standards that fell well short of responsible industry practice at the time still impact perceptions of the current uranium mining and processing industry. While good progress has been made in some states, problems requiring attention still need to be resolved in several states to create broader confidence in governance and its acceptance of social responsibilities.

SOCIAL ISSUES

The social aspects of sustainable development must:

- Ensure the fair distribution of the costs and benefits of development for all those alive today;
- Respect and reinforce the fundamental rights of human beings, including civil and political liberties, cultural autonomy, social and economic freedoms, and personal security;
- Sustain improvements over time, by ensuring that depletion of natural resources will not deprive future generations;
- Optimize utilization of human resources by developing competences, improving training and exchanging know how.

It is clear that mining operations can have both positive and negative economic and social impacts on communities. Mining can provide employment and business opportunities to local communities. However, improperly managed mining activities can adversely impact the environment and the local population, and in the worst cases result in displacement of local settlements.

Proper management of these community issues can avoid potential social problems to the mutual benefit of both the communities and mining operations. Experience has shown that successful companies have developed strategies to handle the impact of mining and processing on communities and the environment, a key element of which is discussing issues with the local community. It is clear from the Australian and Canadian cases that sustainability is closely related to participation of neighbouring communities in decisions affecting them, and that a trilateral dialogue between the three main stakeholders — the community, the company and the government — is essential.

This contrasts sharply with cases in the past when some States brought thousands of people to work in remote areas in so-called 'combinates',which were then abruptly dissolved, leaving a population stranded in an alien and contaminated environment.

Although developed countries have produced strategies to handle the impact of problems on local communities, in many cases developing countries do not have such strategies. Hence, it is important that assistance be made available to them to develop such tools.

A key result of studies is the conclusion that companies must obtain a 'social licence' based on consultation and participation between primary stakeholders, and that appropriate policies and strategies must be adapted to the realities of an operation.

ECONOMIC ISSUES

The economic aspects of sustainable development must:

— Maximize human well-being;
— Ensure efficient use of all resources, natural and otherwise, by maximizing returns;
— Identify and internalize environmental and social costs;
— Maintain and enhance the conditions for viable enterprise.

Sustainable development of uranium mining and processing operations requires identification and response to economic constraints of the industry. In many market based economies, uranium mining and processing operations are corporate profit centres, whereas in some developing countries these operations are viewed as a source of economic exchange.

Decades of mining and processing experience have resulted in the evolution of a relatively mature industry in which the key components of economic development are relatively well recognized. These components range from technical details associated with mining and milling, through to business models applied by specific companies, and to national development policies. All should be carefully integrated, for as is common in many industries, the uranium mining and processing industry is highly competitive on an international basis.

Sustainable development should reflect the increasing globalization of world trade and the increasing expansion of free market principles to more national economies. Decades of experience have demonstrated the non-sustainability of mining and milling operations of centrally planned economies. A central premise of this report is that mining and milling operations should be inherently profitable on a project-by-project basis. Individual companies and countries can approach this profitability concept in various ways. However, it is postulated that the improper consideration of global markets, such as by providing state subsidies, will ultimately jeopardize the sustainability of any particular operation. Government intervention can lead to business practices that are not globally competitive, with the potential that a change in government policy will render a mining and processing operation obsolete, leading to serious social and environmental disruption.

Specific elements of major importance to the sustainability of mining and milling of uranium include the open nuclear fuel market, industry profitability measures, ore deposit characteristics, the regulatory environment, availability of resources, and investment and taxation. These should be integrated with social, environmental, and governance factors in order to ensure sustainability of operations.

Governance

The governance aspects of sustainable development must:

— Ensure transparency by providing all stakeholders with access to relevant and accurate information;
— Ensure accountability for decisions and actions, which are based on comprehensive and reliable analysis;
— Encourage cooperation in order to build trust and set shared goals and values;
— Ensure that decisions are made at the appropriate level, as close as possible to and with the people and communities most directly affected.

To ensure sustainable development of uranium mining and processing operations, a system of governance is required to define the roles, rights and responsibilities of all stakeholders (governments, companies, investors, labour unions, communities, international institutions and non-governmental organizations). This allows for the weighing of costs and benefits, as well as compromises reached on the development and operation of uranium mines in order meet competing demands.

Timeframe for sustainability

Current uranium resources recoverable at US $130 per kg or less are about 5.5 Mt, representing about 90 years of consumption at current rates. A modest expansion of nuclear power programmes with no further increase in uranium reserves will significantly reduce this time.

A further consideration is continued technological development. General usage of electricity in developed countries started approximately 100 years ago. Electricity generation has seen tremendous development, particularly in the past 50 years. It is difficult to predict what system of power generation might be in operation in the next 100 years. Thus, it is reasonable to consider the range of 100 years as an objective for a sustainable uranium industry.

It is fundamental to appreciate, however, that sustainable remediation of uranium mining and processing facilities will require planning for stewardship over significantly longer periods of time, and potentially in perpetuity.

LEGACY ISSUES

Many uranium mines were developed during and after World War II for strategic reasons. In most cases these projects proceeded without an appropriate level of concern for environmental issues because production was the major priority. These sites were frequently abandoned at the end of mine life with little or no remediation.

Most of these operations preceded any environmental protection legislation by several years. Many of these sites, particularly in Europe and Asia, have not been remediated and still present significant environmental hazards. If public perception of the uranium industry in general and the nuclear power industry specifically is to be improved, then it is imperative that these legacy sites be decommissioned and remediated in accordance with the four cornerstones of sustainability.

1. INTRODUCTION

For more than 20 years, nuclear energy has been generating about 15–16% of the global electricity supply [1]. In recent years, there has been a rising expectation that nuclear energy can meet increasing demands for power generation in an economic manner, without adversely impacting the environment. Nuclear energy can also supply process heat for desalination of sea water, production of hydrogen, and district heating. Nuclear reactors derive energy from the fission of ^{235}U, an isotope of natural uranium which is the basic raw material for nuclear fuel. Uranium and its daughter products as shown in Fig. 1 are radioactive and, to varying extents, hazardous to health. Hence, a comprehensive review of uranium mining and processing, from exploration and feasibility studies, to commissioning and operation, and finally to closure, decommissioning and remediation, is essential to understand the criteria for sustainable development.

Uranium is recovered through underground and open pit mining, in situ leach operations (ISL), and as a by-product of mining for other commodities (e.g. gold, copper and phosphate mining). The environmental issues of significance are site specific and will vary with the type of operation and its location.

1.1. ENERGY DEMAND

Sustainable development of uranium mining and processing operations and nuclear power generation must first be considered with regard to global energy demand. As a point of reference in 2008, 64% of worldwide electricity generation came from fossil fuels, 16% from nuclear fission, 19% from hydroelectric schemes and only 1% from other renewable sources [2].

Access to electricity and modern energy services is a necessary requirement for economic and social development. Over the next two decades the investment required for new power generation capacity in developing countries will amount to approximately $20.1 trillion [3]. However, energy industries in many developing countries are in urgent need of reform. The reform process includes commercialization and privatization of state owned utilities, and opening of markets to private investors as well as the changing of price policies.

FIG. 1. Lichtenberg open pit.

TABLE 1. URANIUM–235 DECAY SERIES

Isotope	Half-life	X ray energies (kV)
U–235	7.038×10^8 years	16.2 (31%) 90.0 (3.56%) 93.4 (5.81%) 105.2 (2.01%)
Th–231	25.5 hours	16.7 (96%)
Pa–231	3.25×10^4 years	15.7 (44.8%)
Ac–227	21.6 years	—
Th–227	18.2 days	15.2 (42%) 85.4 (1.86%) 88.5 (3.06%) 99.8 (1.06%)
Fr–223	22 minutes	15.2 (23.9%) 85.4 (1.69%) 88.5 (2.8%)
Ra–223	11.43 days	14.3 (24.5%) 81.1 (15%) 83.8 (24.9%) 94.6 (8.59%) 97.3 (2.8%)
Rn–219	4 seconds	13.4 (1.01%)
Po–215	1.78 milliseconds	—
Pb–211	36.1 minutes	—
Bi–211	2.15 minutes	12.2 (1.02%) 72.9 (1.25%)
Po–211	0.52 seconds	—
Tl–207	4.79 minutes	—
Pb–207	stable	—

1.2. NUCLEAR POWER

Nuclear power is a technology that generates electricity with little consumption of hydrocarbon fuels, and a correspondingly small release of greenhouse gases (GHGs) to the atmosphere. The life cycle assessment of nuclear energy versus other current sources used for electricity production reveals comparatively low greenhouse gas emissions.

As of December 2006, some 435 nuclear power reactors with a total capacity of some 372 GW(e) had been installed in 30 countries [1]. A reliance on nuclear power is demonstrated by the 15 countries that depend on nuclear power for at least a quarter of their electricity, with the greatest being Lithuania (80%), France (78%), Slovakia (57%), Belgium (55%), Sweden (50%) and Ukraine (45%) [4].

1.3. URANIUM SUPPLY

In 2006, eight uranium mining countries accounted for about 93% of world uranium production [1], and in total 39 603 tonnes of uranium (t U) were produced through mining. Currently, the uranium demand-supply picture is distorted by a number of temporary factors. Prior to 1985 world uranium production exceeded consumption in electric power generation. Governments had accumulated large stockpiles of uranium for national security purposes and utilities were responding to a perceived future shortage of uranium by purchasing uranium in 15 year advance contracts. By 1985, uranium consumption had increased to equal production and has been exceeding production by an increasing amount ever since. As excess stocks of uranium became known and changes in the political situation in the former Soviet Union and China allowed low priced uranium into the Western market, the price of uranium tumbled, marginal operations were shut down and little new investment was made in the uranium industry. However, recent concerns over security of supply have resulted in a significant, although variable, increase in uranium price, greatly enhancing the conditions required for investment in both plants and exploration. In 2006, world uranium mining production (39 603 t U) provided about 60% of world reactor requirements [1]. The remainder of the demand was met through secondary sources, such as civilian and military stockpiles, uranium reprocessing and re-enrichment of depleted uranium. However, after 2013, secondary sources will decline in importance [1]; by 2025 secondary sources may provide only 4–6% of market requirements [5]. Based on this scenario, new uranium production capacity will be needed within a few years.

Recycling is an important component of metal supply industries. It has been suggested that perhaps 85% of the copper ever produced is still in use [6]. In a free market, economics decide whether new or recycled metals are used. Recycling generally involves effort and energy consumption, with an associated cost. It stands to reason that when the cost of finding and developing new ore bodies exceeds the cost of recycling, more metals are recycled. In the case of uranium, a portion (<2%) of the uranium is destroyed by fission to release the energy that is converted into electricity. However, by reprocessing used fuel and converting the heavy elements back into reactor fuel, it is possible through many cycles to extract the remaining energy from uranium. Similarly, the large stocks of depleted uranium, which are stored as tailings from uranium enrichment, represent a large energy resource that could be utilized in breeder reactors. At present it is cheaper to bring new uranium into the system but used reactor fuel and depleted uranium inventories should not be disposed of in a manner that would prevent future generations from accessing these energy sources.

1.4. SUSTAINABILITY

The Brundtland Report [7] states that “humanity has the ability to make development sustainable — to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs”.

The original Brundtland definition can be broken down into four conditions for sustainable development:

— Material and other needs for a better quality of life have to be fulfilled for people of this generation;
— The process should be as equitable as possible;
— While respecting ecosystem limits, and;
— Building the basis on which future generations can meet their own needs.

Expanding on the Brundtland admonition, not only should this generation not totally deplete resources that will be vital to future generations, but the environment must not be adversely impacted so as to leave the earth, or significant portions of it, with severe constraints on future human use. This imposes constraints on the manner in which exploration, development, and extraction of uranium ore bodies should proceed.

Sustainability of the industry depends on improved recovery techniques, proper remediation, and continued exploration and development of new ore bodies as older ones are depleted. As the easier exploration targets are developed, exploration techniques require development to find and exploit more difficult targets.

At the end of mine life, decommissioning and remediation of facilities are required. This does not necessarily imply a return of the site to the original pre-discovery condition, but the site should be left in a safe, environmentally acceptable condition that will not create problems for future generations, and preferably have potential for subsequent use.

1.5. STRUCTURE

This report is structured around the four cornerstones of sustainable development, which are environment, economics, social issues and governance.

The section discussing environmental issues describes various exploration, mining and processing practices, and how decisions made relating to these practices can have a substantial impact on the environment. The social impact (both positive and negative) of mining operations is discussed in the subsequent section.

The next section of this report analyses the economics of mining and processing uranium in a free market system; recognizing that external factors can have a significant impact on the sustainability of any particular operation. The final dimension of sustainability discussed is the system of governance, which is required to define the roles, rights and responsibilities of governments, companies, investors, labour unions, communities, international institutions and non-governmental organizations.

The issue of legacies resulting from historic and often state subsidized operations and how they affect sustainable uranium production operations is discussed in the context of the four cornerstones of sustainability. This section is supported by summary case histories to illustrate the sustainability cornerstones, with full case histories located in appendices.

Finally, this report provides recommendations to achieve sustainable development for uranium mining and processing operations.

2. ENVIRONMENTAL ISSUES

Environmental issues include the plant footprint, tailings and water management, and recycling. Additionally, the issues of decommissioning and mine closure are discussed with examples from case studies in Australia (provided in appendices). Discussion in this section illustrates that the key to environmental sustainability is an active approach to environmental management throughout the life of an operation, beginning at the exploration and planning stage, and continuing through the life of the operation to remediation and final closure. Despite the acceptable performance of new mines, legacy issues arising from past inappropriate or non-existent environmental standards still adversely impact the perception of the current uranium mining and processing industry.

Sustainable development requires responsible environmental management, with continual improvement based on [8]:

— Environmental assessments prior to operation;
— Ongoing efforts to reduce environmental risk and impact;
— Enhanced environmental monitoring to study ecosystem interactions;
— Research into the long term behavior of waste facilities.

All components of uranium mining and processing operations impact the environment to a greater or lesser degree. The key to sustainable environmental management is to develop a plan that considers the complete life cycle of a uranium operation, which includes:

— Exploration;
— Feasibility studies;
— Construction;

— Operation;
  - mining;
    — waste rock management;
    — ore stockpile management;
    — mine water management;
  - processing;
    — tailings management;
    — process water management;

— Decommissioning;
— Remediation;
— Closure.

This section discusses approaches that can be used in each stage of the mine life cycle.

2.1. EXPLORATION

Collection of baseline data must commence at the earliest possible stage of an exploration programme in order to provide sufficient information to develop environmental impact statements and assessments. Ideally, baseline data should be collected for at least three years prior to commencing operations; however, an appropriate timeframe will be site specific and dependent on the relevant regulatory regime. Data sets required will be site specific, thus examples of baseline data include, but are certainly not limited to the following:

— Hydrological and hydrogeological conditions;
— Flora and fauna surveys;
— Climate;
— Soil surveys;
— Archeological and heritage surveys;
— Anthropological surveys,
— Contaminated site assessments.

Preliminary exploration techniques for uranium deposits are relatively non-intrusive, and are similar to exploration techniques used for other mineral deposits. In the preliminary stage of exploration these techniques typically include collection and analysis of soil and surface rock samples, vegetation and water sampling, and airborne and surface geophysical surveys.

The next stage of exploration includes drilling, trenching, test pitting, and occasionally setting up pilot plants or other test facilities. These activities have the potential to be sufficiently disruptive to the environment that specific precautions need to be taken, in particular to protect surface water and groundwater. For example, exploration drilling can pierce aquifers and precautions must be taken to prevent cross contamination of water between aquifers. Appropriate management of surface runoff and subsurface disturbance is important as this will minimize the potential for release of any harmful elements.

There is extensive industry experience for most types of uranium deposits, and case histories should be consulted for more detailed insight and guidelines. Additionally, during the exploration phase, a range of environmental and social issues are likely to evolve.

2.2. FEASIBILITY

Issues to be considered during the planning and feasibility stage of a project include the mining method, size, location and footprint of the proposed operation.

Factors that impact the footprint of a uranium operation include:

— Climatic conditions;
— Hydrological and hydrogeological conditions;
— Location and setting;
— Annual and total planned throughput;
— Ore body size;
— Ore grade (which has a direct influence on the ore stockpile area, plant size and volume of the tailings retention facility);
— Mining method (open cut, underground, heap leaching, *in situ* leaching), which impacts the size of waste rock stockpiles;
— Water release criteria (e.g. if water cannot be released large retention and/or evaporation ponds may be needed);
— The nature of the process flow sheet (for example replacement of a CCD circuit by RIP would significantly reduce plant size).

Such feasibility studies may be conducted in such a way as to assist the process of final decision making by financiers without their having to make binding investment decisions. Much of the information collected in the feasibility stage is used as a pre-requisite to the final investment decision and in the preparation of the environmental impact assessment process (EIA), which culminates in the preparation of an environmental impact assessment statement (EIS) for submission to regulatory authorities. It is quite often the case that the EIS is published initially as a draft and made available to regulatory authorities and other stakeholders for comment. Once all the issues raised through this public consultation process have been addressed by the mining company to the satisfaction of authorities, detailed design work may proceed. This can include further drilling to better estimate the mineral resource and facilitate optimization of the mining plan.

Often there may be statutory minimum time periods for the various stages of the EIA process. These usually oblige the authorities to react within a certain time and provide direction as to the acceptability or not of the draft EIS. Rarely are the proponents of a project required to respond to documents in accordance with a pre-set timetable. This enables them the flexibility to carry out additional studies or planning tasks without a time pressure other than one they may impose on themselves. One very important component of the EIS should be the scope and financing of the remediation plan for the whole project. Preparing for such issues before the mine is built ensures that the risks of creating a new legacy site are minimized.

2.3. CONSTRUCTION

Once the EIS has been finalized and the project has been authorized to proceed, the detailed design and construction phase of the project may begin. This begins with the completion of any final data collection and then preparation of detailed designs for the mine and associated infrastructure. This may include roads and airstrips depending on existing facilities at the location and the chosen operating conditions for the mine. For example, the details of components such as well fields for water supply, housing construction (if there is to be a mining camp on site) and waste rock stockpile design can only be finalized at this point.

Often the project may have a temporary accommodation camp and supporting infrastructure at the site for the duration of the construction phase. Such facilities need to be included in remediation plans, especially the allowance for financing their remediation, even if they are to be built into the final development of the project. The labour force required for construction is likely to be larger and more diverse than the permanent labour force required to operate the mine. During construction there may be many skills essential to construction which are not normally found in a mine labour force; these can include specialized building trades workers, larger numbers of semi-skilled labourers, etc. Once the construction phase is complete and the mine is ready to be commissioned there may be some social issues to be addressed if excess labour has to be let go from the site, as is often the case. Planners and managers need to be aware of this issue and have an appropriate strategy in place for dealing with the downsizing and restructuring of the construction work force into the mine operating work force.

Once construction has been completed and various components of the mine tested then the whole project can be commissioned. Often mining will have commenced before construction of the processing plant is complete so that stockpiles of material are ready to be used in the startup and commissioning of the processing plant. Once the plant is working satisfactorily, production is usually gradually increased until design throughput is achieved. This is often referred to as 'ramping up' production. At this point the project is fully operational.

2.4. OPERATIONS

2.4.1. Mining

Uranium ore is recovered primarily by conventional open pit and underground mining and uranium in solution is recovered by in situ leaching (ISL) [1]. The expected distribution of production between these various methods in 2007 was open pit 23.7%, underground 37.7%, ISL 27.7%, by-product recovery 8.4% and 2.5% by other methods including heap leaching of ores recovered from open pit mines [1]. All three main recovery methods impact the surface and subsurface environment, albeit to different degrees. These impacts can be minimized through careful planning and thorough environmental assessment at the outset of exploration activities and during feasibility studies. Of specific concern in the uranium industry is the potential for contamination by uranium and radioactive decay products, as well as the potential for acid rock drainage (ARD) and metal leaching. These contaminants of concern (CoC) can be released to the environment via a number of pathways including air, surface water, and groundwater, with potential adverse impacts on mine workers, the local population, and the receiving environment.

Groundwater and surface waters must be appropriately monitored both before and during operations to provide data enabling actions to be taken to prevent or minimize contamination and adverse impacts on the receiving environment. This reflects the importance of collecting sufficient baseline data in order to place monitoring results in the context of the baseline data and determine whether any adverse impact has in fact occurred. The groundwater and surface water around an ore body may naturally reflect elevated concentrations of some elements. However, mining activity may accelerate natural processes, including oxidation, reduction, ion exchange, microbial activity, and changes in concentration of dissolved gases, which can lead to substantial increases in CoCs in surface and groundwater.

Waste rock

Waste rock from open pit and underground mining requires special consideration to establish the potential for ARD and metal leaching. Waste rock containing sulfides (even at very low concentrations) can oxidize and release heavy metals and radioactive decay products. Waste rock associated with oxide ore deposits also has the potential to release contaminants and radioactive decay products. Uranium deposits and the waste rock associated with them encompass a wide range of mineralogy and geochemistry. While generalizations of their properties can be made, substantial variations do occur, even within an individual deposit. Hence, the ore and waste rock must be properly characterized prior to mining to assess the particular type and potential concentration of contaminants. Characterization at this time allows for identification of potential environmental impacts and provides the opportunity to change flow sheets and materials handling plans in order to minimize these identified impacts at the lowest possible cost.

Environmental protection

Precautions must be taken to protect mine workers and the environment. The most significant potential hazards are exposure to dust, airborne radioactive decay products, radon gas, and radiation. These hazards are of particular concern for underground high grade mining operations. However, open pit and ISL operations have similar hazards. There are well established industry procedures and guidelines for radiation protection and monitoring and appropriate implementation of these will protect workers from specific hazards associated with uranium mining.

The significance of long term impact and liability of waste rock piles has historically been overlooked and underestimated by the mining industry. The change in approach that has occurred in Canadian uranium operations is well summarized in literature [8] and serves as a model for all future operations, particularly for high grade deposits with reduced waste rock volumes. The emphasis is very much on planning and prevention, rather than the unsustainable process of having to manage long term contaminated seepage and runoff.

Long term management plans for waste rock must be based on pre-mining geochemical characterization tests to understand relevant potential contaminant source terms and concentrations.

This approach has seen a transformation from surface stockpiling of unsegregated, uncharacterized waste to comprehensive handling based on ARD and metal leaching potential of the rock. Problematic material is now segregated on lined pads pending secondary handling. It can be reused as backfill or to dilute ore during processing. An example of this approach is the McArthur River mine. Potentially problematic material (rock containing >0.03% U_3O_8 or net neutralizing capacity (acid: neutralizing potential ratios of 1:<3)) will be stored on lined pads at McArthur River. This material will either be used for underground backfill or transported to the Key Lake mine for final placement in existing, approved disposal areas. Inert waste rock will be placed on the surface in approved, unlined sites [9].

2.4.2. Processing

The establishment of criteria for best environmental practice in processing can be considered in three stages. The following paragraphs consider these three stages, commencing with flow sheet options, which are most readily addressed by individual operations. The second stage will most likely involve a methodology choice by the proponent during development planning, while in the third stage the industry in general must embrace all the life cycle issues of a plant.

The basic uranium processing flow sheet has not changed substantially over the last 50 years [10]. However, there has been a continual improvement in overall environmental performance, particularly in regard to planning for closure both prior to and during operation. The following lists the predominant environmental sustainability performance factors:

- Energy consumption;
- Reagent consumption;
- Water;
  - Source;
  - Consumption;
  - Recycle;
- Emissions, effluents and wastes, and;
- Transport requirements.

While unit operations and practices within the flow sheet may not always appear to impact environmental sustainability performance factors, this is not always the case. The following outlines key impacts of various flow sheet components where options for improvements can reduce adverse environmental impacts.

Crushing and grinding

Crushing and grinding are significant energy consumers, and performance must be assessed in terms of power consumption, uranium recovery, and the impact of particle size on settled tailings density, rate of tailings consolidation and water recovery. Grind size will also affect the usage of chemicals, such as flocculants/coagulants.

A fine grind size may also limit the underflow density in a counter current decantation (CCD) washing circuit, which may increase the wash ratio and overall water requirements. The problem of excessive fines can be overcome through by-passing fines around the grinding circuit [11]. This not only reduces energy consumption, but reduces the generation of slimes that are difficult to handle. Pool [11] describes how ENUSA's Quercus mill in Spain was designed and built on this principle. Note that a coarse grind size will reduce grinding power requirements, but may result in pumping and/or agitation difficulties, with a subsequent increase in energy requirements.

Leaching

Leaching is the main chemical reagent consumer in the milling process. In addition to dissolving uranium, leaching mobilizes a range of potential contaminants, apart from radionuclides.

Reagent addition (quantity) can be minimized by:

— Optimization of leach conditions to minimize dissolution of gangue (waste rock) components;
— Leaching at higher slurry density so the amount of acid needed to maintain free acidity is reduced.

Reagent addition (impact) can be minimized by substitution of cleaner chemicals.

Acid leaching is often the preferred processing route in conventional uranium milling, although alkali leaching has been tried for some specific ore bodies.[1] Currently, there is no viable alternative to sulfuric acid for acid leaching. Other commonly available acids increase milling costs, are more corrosive, and have greater potential to cause adverse environmental impacts. For example, pyrolusite (manganese dioxide) or sodium chlorate are typically used during sulfuric acid leaching to assist in oxidation. Pyrolusite consumes more acid than sodium chlorate and the product from the oxidation reaction, Mn^{2+}, has a potential environmental impact. However, the use of sodium chlorate can result in the buildup of chloride during water recycling, which can be very troublesome in water management systems and reduce operational efficiency in the long run.

Caro's acid, a specific mixture of sulfuric acid and hydrogen peroxide, has also been used successfully as an agent for uranium leaching [11]. It offers significant environmental advantages in that the residual reaction product is water. However, Caro's acid is subject to decomposition reactions and can be difficult to manage, which does limit its application.

Oxygen can provide suitable oxidation rates under some conditions, such as pressure leaching, and its use as a supplement in conventional acid leaching warrants more attention. Investigation of other oxidation options, such as bacterial leaching and external generation of acid or recycling of ferric sulfate could also be considered as possibilities to replace the addition of chemical oxidants.

Solid/liquid separation

Solid/liquid separation and uranium recovery are typically achieved through a counter current decantation (CCD) washing circuit. This process is simple, flexible and effective but is unattractive in terms of minimizing environmental impact, as a CCD circuit has a large plant footprint and high water requirements.

Alternatives to a CCD circuit include:

— Belt filtration and washing;
— A resin-in-pulp (RIP), or;
— Resin-in-leach (RIL) circuit.

CCD circuits have generally been preferred to filtration on the grounds of ease of operation and reliability, even though filtration has the advantages of reducing water usage and increasing the uranium concentration of the pregnant liquor. The filtration option after leaching has the potential of producing a highly dewatered filter cake (20 to 25 wt% water) that can be used directly to produce paste tailings.

Belt filtration has the ability to filter large volumes of solids. Wash volumes are comparatively low and produce only minimal dilution of the uranium leach solution. Belt filters have previously been used in the

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[1] The first new uranium mill to use alkaline leaching since Lodeve in France in 1981 (where autoclaves were required) is the Langer Heinrich mill in Namibia, which began operations in 2006. The main advantages of acid leaching over alkaline leaching are greater recovery of uranium and faster leaching kinetics, unless high temperatures and long residence times are used.

industry. However, not all tailings can be effectively dewatered on a belt filter, particularly clay rich ores, as the filtration rate may be too low to be practical. Such an ore could be readily treated by an RIP circuit.

In the RIP or RIL flow sheets, instead of separating the leached solids from the pregnant solution, a uranium selective ion exchange resin is added to the leach slurry to recover uranium directly[2]. An RIP process offers the possibility of improving uranium recovery[3], reducing water use and minimizing bleed liquor volume.

The RIP process was first used in the 1950s. However, advances in resins, the extensive Soviet Union experience, and improvements developed in the gold industry (with both RIP and carbon-in-pulp) indicate that the technology could improve the environmental performance of uranium extraction plants.

Uranium recovery from solution

In most conventional mills, uranium is recovered by solvent extraction (SX) using tertiary amines in mixer-settlers. The most significant potential environmental impact of SX is contamination of the aqueous process liquor by organics.

Although solvent is recycled, annual solvent losses can be equivalent to the total solvent inventory. Solvent loss occurs through evaporation, degradation, and solubility as well as by entrainment in raffinate and crud. Loss of raffinate can be minimized by the use of standard techniques for organic liquid recovery (e.g. carbon column, flotation), but crud losses are essentially unavoidable and are a function of the amount of solids in the feed liquor and the design of the mixer/contactor.

Pulse columns can offer advantages over mixer-settlers in terms of solvent losses. Pulse columns also have a smaller footprint and a lower total solvent inventory. However, columns cannot be used in all SX system designs because of kinetic and other process control considerations.

A comparison of performance over three years of pulse columns and a four-stage mixer-settler at Olympic Dam, Australia, found:

— Entrainment of solvent in the raffinate was lower for the columns, at 30% to 50% of that measured for the mixer-settlers;
— The columns suffered fewer mechanical failures;
— There were fewer problems with crud formation and emulsions generated by high silica concentrations in pregnant liquor for column operation, which reduced solvent losses, and;
— Evaporative and total solvent losses from the columns were lower.

For high grade leach liquors, SX (or ion exchange) can be replaced by a direct precipitation system. This system has a similar ‘front end’ to SX, which includes grinding, leaching and filtration. The ‘back end’ includes a partial neutralization step in place of the SX circuit, where iron and other impurities, but not uranium, are selectively removed, followed by direct precipitation of the uranium using hydrogen peroxide [12].

Precipitation of uranium

The chemistry of SX stripping and uranium precipitation circuits must be integrated. In a conventional flow sheet, stripping is accomplished using ammonium sulfate, and uranium is precipitated with ammonia solution. This has been accepted industry practice, although there is increasing pressure to limit release of ammonia to the environment, which may occur through co-disposal of ammonium sulfate bleed streams and tailings slurries. In some cases, uranium is precipitated as magnesium diuranate (MDU). Another option is the use of a strong acid strip/hydrogen peroxide precipitation process to produce uranyl peroxide. At some sites, such as Key Lake in Canada, ammonia is being recovered from waste streams and sold as ammonium sulfate fertilizer.

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[2] Uranium is eluted from the resin using typically 10% sulfuric acid or acidified sodium chloride, followed by direct precipitation.

[3] Ion exchange resins have the potential to minimise the effects of ‘preg-robbing’, i.e., to reverse adsorption loss of soluble uranium onto ore slimes and leaching debris/precipitates.

The transport, storage and use of liquid ammonia also pose potential significant environmental and safety risks. Accordingly, a specific ammonia disaster plan should be available in the event of a spill or leakage from storage tanks.

Drying/calcination of yellowcake

Ammonium diuranate (ADU) or MDU decomposes at ~ 800°C into a multiple hearth calciner, yielding a product which typically contains ~99% U_3O_8 (yellowcake). U_3O_8 can also be produced from uranyl peroxide using a strong acid strip/hydrogen peroxide precipitation process. The advantage with this process is that the peroxide requires ‘drying’ at a much lower temperature, typically 250°C. This operation has a much lower solids discharge to the stack than a multi-hearth calciner [13]. The energy requirement for low temperature drying is significantly less than that required for calcination (a reduction of 40% to 50%).

Handling of yellowcake product has the potential to generate a dust which is both chemically and radioactively hazardous. Worker exposure to dust is controlled by containment and isolation from the work environment. All phases of the drying operation must be maintained under negative pressure with exhaust gases passing through dust collection systems to avoid yellowcake losses.

2.4.3. Tailings and water management

Tailings and water management are integral parts of the overall operations development plan, and must include performance targets, as for other production and operating activities. It is essential that this plan is understood and followed during operations, and that the impact of any process changes on the management plan are evaluated and understood before such changes are implemented.

Tailings and water management are the most significant areas in which the uranium mining industry (and the mining industry in general) must improve performance, if the industry is to be regarded as sustainable.

Site conditions will dictate the most appropriate form of tailings storage, although there is now a clear trend towards in-pit disposal of tailings as compared to previously favoured above ground impoundments. In-pit tailings storage involves using hydraulic barriers and hydraulic bypass mechanisms to minimize groundwater contamination by minimizing interaction between tailings and the surrounding environment [8]. The concept is that tailings placed within the pit possess a lower hydraulic conductivity that the surrounding host rock and/or a pervious surround is constructed as tailings are placed in the pit.

An extension of this approach is the use of natural geological barriers and conditioning of tailings to control pore water chemistry, thereby reducing long term solute migration. Such a system was designed for the JEB pit at McLean Lake [14].

While in-pit disposal may provide a long term solution to storage and containment of tailings, it can create some problems during operations and extend the time subsequently required for dewatering and remediation. The challenge is to implement subaqueous deposition without significant segregation of fines (which adversely affects settled tailings density) and thus minimize the waiting time before rehabilitation can commence. In this respect, provision of an under drain to assist dewatering is often required.

Seepage of tailings water during operation, prior to dewatering, will occur. This may be controlled by minimizing highly permeable areas in pit walls, typically faults, through treatment to improve integrity. It is necessary to monitor wells to evaluate seepage conditions, but these can also be used to collect seepage for return to the process or the repository and/or to intercept clean groundwater.

Irrespective of the ultimate form of the selected tailings storage option, there is a need to demonstrate that the rate of release of potential contaminants is understood and does not result in adverse environmental impacts. Long term modeling must demonstrate that residual levels of discharge from tailings are compatible with the receiving capacity of the local environment and that such levels are sustainable solely on the basis of passive environmental controls [8].

Paste tailings

Deposition of paste tailings is an alternative approach which is gaining some favour, particularly disposal into underground workings. The paste usually comprises total tailings thickened to a substantially higher density than conventional tailings, but still fluid enough to be pumped without segregating into fractions. The higher content of solids makes it feasible to add a binding agent to increase the strength of the tailings and further reduce hydraulic conductivity (e.g. Portland cement).

Some advantages of paste tailings include [11]:

— Reduction in the required tailings storage volume;
— Reduction in geotechnical hazards associated with containment structures;
— Increase in siting and operational flexibility for storage facilities;
— Significant water conservation potential.

It can be argued that the use of paste tailings also offers a potential reduction in both short and long term environmental liability. However, the veracity of this argument depends on numerous site specific considerations.

Disadvantages associated with the paste tailings technology include:

— Increased capital costs;
— Complications in manufacturing a tailings paste with a consistent solids content;
— Transportion and deposition of the paste material.

Another tailings disposal method similar to paste tailings in its objectives is the concept of ‘dry’, or filtered, tailings disposal. This approach was used at the Zirovski Vrh mine in Slovenia, where belt-filtered tailings were trucked to a nearby disposal system.

Backfill

Requirements for above ground tailings storage can also be minimized by using the tailings to backfill underground workings (a conventional industry practice). At Olympic Dam, some of the coarse fraction of tailings is deposited underground as cemented aggregate fill. Following a mill expansion and upgrading of facilities, it is planned to increase the proportion of total tailings going underground from 5%, to approximately 20% [15].

The Eldorado Beaverlodge operation in northern Saskatchewan backfilled workings with a substantial portion of tailings throughout most of its operating life (1953-82). Tailings were wet-cycloned and the coarse (sand) fraction pumped underground for use as backfill. Over the life of the operation, between 40% and 45% of the total volume of tailings produced were used as backfill.

Water management and recycling

Water management and recycling are key operational issues for uranium mining and processing operations. The most important consideration must be appropriate catchment management such that uncontaminated water remains clean, and contamination of any water is minimized. Tasks that assist in achieving this objective include:

— Identification and, where appropriate, separation of catchments;
— Collection and treatment of mine water;
— Collection and treatment of runoff from waste rock piles;
— Collection and treatment of runoff from ore stockpiles;
— Collection and treatment of runoff from plant areas;
— Collection and treatment of seepage from tailings storage areas;
— Treatment of tailings slurry and other processing waste streams.

The extent of water treatment required will depend on the quantity and level of waste waters contaminants and the initial quality of local surface water and groundwater. Most important, however, is identification of and, where appropriate, separation of catchments.

A case study has been made illustrating improvements in water management as it relates to adverse environmental impacts with respect to ammonia. At Rabbit Lake, a strong acid, rather than ammonium sulfate, is now used to strip uranium from loaded solvent. This process, coupled with hydrogen peroxide precipitation of uranium and using magnesia for pH control, eliminated ammonia from the flow sheet. Alternatively, at Key Lake, ammonium sulfate crystallization and recovery from the bleed stream is used. The stream is treated in a quadruple effect evaporator-crystallizer. These new approaches were necessary, as ammonia was not readily removed from tailings water.

Eliminating ammonia as part of the processing procedure reduces its potential requirement and associated costs, as well as potential adverse environmental impacts involved in addressing this issue post-processing. For example, while the Ranger flow sheet was designed on the premise of evaporating excess water (i.e. not releasing water), accumulation of excessive quantities of water (containing 1 g/L ammonia) has prompted Energy Resources of Australia (ERA) to design, pilot test and install a water treatment process that incorporates two stages of softening followed by reverse osmosis (RO) treatment [17]. The ammonia content required a further treatment stage, involving travel through a multistage constructed wetland to achieve the target release quality for ammonia. The system was commissioned in 2006.

Important aspects of tailings storage/decommissioning are physical and geochemical properties relating to settled density, consolidation rates, and seepage rates. A factor often not considered in determining these properties is the impact of the neutralization process on sludge/metal precipitates. Modification of the tailings neutralization process may improve dewatering/consolidation rates of deposited solids.

Acidic tailings liquor

Residual acidic tailings liquor, which makes up the CCD underflow tailings slurry, presents some unique management and treatment requirements and is site/operation specific. Examples of current practices that have provided acceptable environmental performance include:

— Neutralization to pH10, and specific treatment to remove ^{226}Ra and As prior to discharge (Canadian practice);
— Neutralization to pH4 and recycling to the grinding process (Ranger);
— Softening of pH4 water to pH10, Ca removal, reverse osmosis, followed by wetlands treatment (proposed for treating excess Ranger water from above);
— Recycling of acidic tailings water to the grinding process (Rossing);
— Evaporation of acidic tailings liquor (Olympic Dam);
— Recycling of acidic tailings liquor to leaching (Olympic Dam).

The ability to recycle can be limited by buildup of contaminants, e.g., chloride, which may affect the performance of specific process steps.

Collection of contaminated runoff water is not without problems, and the volume can significantly increase the need for storage capacity. Strategies in use to minimize these problems include:

— At Ranger, runoff water is segregated on the basis of source and quality; depending on quality, clean water is discharged directly to the environment, used for spray irrigation or released through constructed wetland filters; water with a higher concentration of contaminants is directed to the tailings water system; as significant contamination of runoff water is usually restricted to a few specific elements. Consideration is being given to specific treatment and release, rather than increasing the volume to be managed through the tailings water system, and;
— In Canada, lined pads are used for ore stockpiles and storage of reactive waste rock (e.g. acid producing waste), also, dedicated collection and batch release and treatment systems are used for management of storm runoff water.

Control of leaks

At Ranger, the impact of leaks is controlled by use of a pipeline corridor containment ditch, which collects and directs any leakage material to a sump. At some Canadian operations a pipe-within-pipe arrangement is used. A concrete tunnel, referred to as an utilidor, has also been used instead of an outer pipe (e.g. Key Lake). At Key Lake a double pipe system (steel pipe within polythene pipe), located in a plastic lined ditch has been installed for transport of tailings slurry. A further option is to use flow variations to detect major leaks in all lines.

Water use

Mining and process operations must strive to minimize the volume of fresh water used per kilogram of uranium produced in order to:

— Conserve a precious resource;
— Reduce supply costs and water charges;
— Reduce the volume of effluent discharge, and;
— Reduce the cost of waste water treatment and/or storage.

In areas of high precipitation, where water supply is not generally an issue, runoff water can be used in place of fresh water. In arid areas, available water is often of poor quality (high in salts such as sodium chloride), which can affect the process and limit the scope for recycling.

Recycling tailings water (treated or untreated) has different drivers, depending on the local situation. The Rossing uranium mine in Namibia recycles acid water to the grinding mills because of a water shortage; Ranger recycles to reduce the amount of make up water that would be required from groundwater resources and to minimize the amount 'lost' through evaporation from ponds. Olympic Dam in Australia cannot recycle acid water to the grinding circuit because of process considerations, but can return this water to the leaching circuit; after grinding, the pulp is thickened to a high density, and then diluted with acid water before leaching [18].

Beneficiation

Beneficiation processes have not found wide application in the uranium industry, although they have been (radiometric sorting) applied successfully at a number of operations. Beneficiation has the potential to reduce adverse environmental impacts by using a higher average ore grade into the mill, resulting in:

— A reduction in some aspects of plant size;
— Reduced water consumption and effluent volumes, and;
— Reduced tailings volume.

Current radiometric sorting technology is only effective at particle sizes greater than 25 mm. Hence, radiometric sorting is often unsuitable due to the softness of many uranium ores.

The potential of beneficiation was illustrated for the proposed Kintyre project in Australia, where through a combination of radiometric sorting and heavy media separation, the size of the milling plant could be reduced by a factor of four, and a simple direct-precipitation flow sheet was planned. This project has yet to be built.

In situ leaching

ISL can be a cost effective process for the treatment of small, low grade deposits of suitable mineralogy and geological environment. The proportion of uranium being produced by this method is increasing every year [1]. Minimal land disturbance and no tailings generation are significant environmental advantages. Both acid and alkaline leaching are used, with the latter accepted as current best practice where the aquifer contains potable water. For both acid and alkaline processes, uranium is recovered from the leach solution by an ion exchange and precipitation route.

The potential advantages of an ISL operation are:

- Reduced land disturbance;
- No requirement for mine dewatering;
- No ore and waste rock stockpiles;
- Reduced plant footprint (as there is no requirement for crushing, grinding, leaching and solid/liquid separation);
- No requirement for tailings storage,;
- Reduced volumes of effluent for disposal.

ISL does have a number of disadvantages, including:

- Low uranium recovery and less efficient utilization of resources;
- Contamination of groundwater;
- Potential contamination of groundwater outside the well field area;
- Failure and/or damage of surface infrastructure (primarily pipe works) can result in the release of process solutions.

Heap leaching

The primary advantage of heap leaching is that it does not require grinding or solid/liquid separation, which can substantially reduce operating costs. However, in the uranium industry it is generally only used to supplement production at conventional mining and milling operations. An exception is the exclusive heap leach operation at Lagoa Real in Brazil [8], however the plant only produces 250 t U/year.

From an operational perspective heap leaching can appear to be cost effective. However, in terms of a mine life cycle perspective, which includes remediation, heap leaching often results in complications, the most obvious being the potential necessity of transferring all spent heap leach material to a below grade facility or long term in situ encapsulation requiring potentially complex cover systems. The issue in this latter case is to minimize leaching of CoCs from remediated heaps as a result of incident rainfall, thus preventing adverse impacts to receiving environment. Another disadvantage is that heap leaching is generally used for processing low grade ore deposits that are uneconomic to process using other methods. Hence, large quantities of waste material are generated relative to the amount of uranium produced using other processes. Although the capital and operating costs for a heap leach can be low, remediation costs per kg of U_3O_8 produced can be higher than for other processes.

By-product operations

Uranium is also produced as a by-product from the processing of other minerals, and from phosphate fertilizer manufacturing. These operations recover uranium, which would otherwise go to process residues, waste liquors or the primary product. As by-product recovery typically involves very little change to the primary flow sheet or process, this recovery of uranium does not generally increase potentially adverse environmental impacts.

As by-recovery processes concentrate uranium, areas of the process plant site will need to be subject to radiological protection controls and regulations appropriate to a conventional uranium milling operation.

Marine phosphorite deposits account for 80% of the world output of phosphate based fertilizer products, and 70% of this total is converted into wet process phosphoric acid, which is the basis for current uranium extraction processes. Marine phosphorites contain up to 150 ppm U but there are no uranium recovery circuits in operation at present [19]. However, under current economic conditions and due to a revived interest in uranium production, this situation is being re-examined by a number of companies with the potential to recover by-product uranium.

As it is currently not recovered during the fertilizer production process, uranium goes to the fertilizer product. Heightened future environmental awareness and regulations, or consumer concern, could require that phosphate producers remove uranium from fertilizer.

Copper ore deposits frequently contain elevated levels of uranium because of the similar geochemistry of the two elements in the formation of ore bodies. In some cases the deposit can be mined and treated to recover both metals. This is the current practice at Olympic Dam, South Australia, where the ore contains about 700 ppm U. Uranium has been recovered as a by-product in Arizona, USA, from copper heap leach solutions and at Palobora, South Africa, from copper processing, where uranium concentration was less than 100 ppm U.

Recycling of uranium containing wastes

Uranium refining by solvent extraction results in small quantities of uranium remaining in the raffinate or waste stream. The uranium concentration is too low to be readily recycled within the uranium refinery, but may be recovered by recycling to a uranium mill. For many years liquid raffinate was recycled from the Port Hope or Blind River uranium refineries to several uranium mills at Bancroft and Elliot Lake in Ontario, Canada. The mills benefited from the sulfuric acid levels in the raffinate, in addition to the uranium. Following closure of the last Ontario mill in 1996, raffinate has been shipped to the White Mesa mill in Utah, USA.

2.4.4. Chemical and radiation control

The processes and equipment employed in a uranium operation are generally no more hazardous or different than those used across a range of hydrometallurgical flow sheets. Similarly, many of the chemicals used are commonly handled in the mining and chemical industries.

Factors that can impact on safe chemical handling and radiation control include:

— Requirements to meet local employment targets (use of inexperienced personnel), and;
— High staff turnover rates (loss of experienced personnel).

Methods that can reduce chemical and radiological hazards include:

— Facilities designed with radiation safety as an important consideration;
— Operations setting target limits for radiation exposure that are well below regulatory limits;
— Remote mining and ore handling with computer control;
— Slurry transport of ore;
— Redesign of milling circuits;
— Control of radon by freezing and grouting techniques, also used to control ground water;
— Thorough analysis of jobs versus exposure times, supported by a radiation monitoring programme, and;
— Dual ventilation systems.

2.4.5. Transportation

Mining operations require transportation of reagents and supplies to the site and transport of product to the market. Hence, the operator must have emergency procedures in place to deal with incidents involving reagent spills.

Typically, ore haulage distances are short and confined to the mining lease area. Where transport beyond the mining lease area,or via public infrastructure is required, radioactivity of the ore is of concern in the event of spillage.

Yellowcake product is also a radioactive material, but its gamma radioactivity is significantly less than that of ore per equal masses of material, because most of the ore radionuclides remain with the tailings. The greatest health hazard is the toxicity of uranium as a heavy metal if ingested, not radioactivity. Yellowcake is transported in sealed 210 L drums, typically stacked inside shipping containers. Transport of yellowcake is considered to be a safe, straightforward operation with very low risk of environmental consequences. However, operators must be sensitive to public concerns over the transport of both ore and yellowcake and maintain an appropriate emergency response capability.

2.5. DECOMMISSIONING

In general, the primary functions of a remediation programme are to retard contaminant release, oxidation, and erosion rates. These rates must be reduced to a level such that the receiving environment can absorb and assimilate such occurrences without adverse impacts, or when impacts take place, they are low enough to be acceptable to the community.

A comprehensive mine closure plan will ensure that these objectives are met. There are a number of aspects, both technical and sociological, to be considered when developing a Mine Closure Plan. The mining industry and the broader community now recognise that mining is an interim or short term land use, and that permanent alienation of land for beneficial post-mining land uses is unacceptable and must be avoided whenever possible. Demonstrating successful remediation of mining and processing operations though implementation of a mine closure plan is of critical importance to the mining industry if it is to continue to hold its social licence to access and exploit natural resources.

Many impacts of inappropriate waste management or radiological materials handling are neither transient nor short term, and unless managed correctly have the potential to adversely impact the environment for decades if not centuries to follow. Waste rock and tailings management decisions, at least up to an advanced conceptual stage, must be made before a mine commences production. Informed decisions on various potential management strategies can only be made subsequent to developing an understanding of short and long term physical, radiological and geochemical properties of all materials streams generated during mining and processing phases. In addition, it is fundamental to have a complete understanding of the environmental setting of an operation.

It is absolutely critical that remediation planning is undertaken in a holistic manner; which means when planning for remediation of an individual aspect of an operation, that its interrelationship to other aspects of the operation are taken into account.

Remediation solutions are site specific and methodologies/designs from one site can rarely be transferred to another without modification. Usually this requires undertaking site specific investigations, since the physical and geochemical properties of mine wastes, geological conditions, hydrogeology, climate, and setting are unique to each site.

During the development of a mining project, starting from exploration and moving through all stages to closure of an economically depleted resource, it is essential that a mine closure plan be developed, and that it be amended parallel to any changes within the scope of operation, such that it continues to reflect the current state of the project. Development of a mine closure plan is an integral part of all phases of a mining project and should not be considered something that can be left until late in the resource exploitation phase. Maintaining a dynamic mine closure plan will maximise remediation options that can be considered while minimising the overall ‘life of mine’ cost. Correctly informed planning decisions can only be made after considering their impacts on the mine closure plan and on ‘life of mine’ costs.

‘Life of Mine’ costs are significantly different to operational costs; decisions on operational costs made without full consideration of their long term impacts often increases life of mine costs for apparent short term gain. ‘Life of mine’ encompasses all activities from initial exploration through to the long term post closure stewardship phase. It covers:

— Exploration;
— Project planning and feasibility studies;
— Development and construction;
— Mining and processing;
— Decommissioning and remediation;
— Post closure monitoring, and;
— Post closure stewardship.

Implementing remediation planning at the earliest stage of an operation's life allows for consideration of the maximum number of remediation strategies or options, while also allowing them to be implemented at the lowest possible cost. In recent years, there have been commitments or plans to deal with legacy issues, which have highlighted the significant cost penalties that are incurred when site remediation planning is not considered, and examined sites which are remediated progressively during the operational phase. For example, in the 'Title 1' tailings remediation programme conducted by the US DOE, cleanup costs for legacy abandoned uranium processing sites were approximately US $30 per kg U produced. By comparison, remediation of operating sites has cost approximately US $2.0 per kg U produced [11].

2.5.1. Passive water treatment methods

Sound closure planning of an operation can minimize and possibly eliminate sources of contaminated water during the decommissioning phase, *e.g.,* Nabarlek, Australia. However, poor practices — at virtually all historic uranium operations — have created a number of legacy issues, which have required development and application of passive water treatment methods. These methods are necessary, even though water treatment plants have also been built, as the lack of planning has resulted in small flows of contaminated groundwater (mainly seepage) that will persist for many years and cannot be economically treated by other processes.

The most comprehensive investigation of such techniques has been carried out in relation to Wismut sites with the aim of reducing long term treatment costs. Potential applications for innovative, cost efficient technologies were identified for:

— Replacement of conventional treatment plants, which become inefficient due to the decrease of the contaminant load in the feed water, such as mine waters;
— Treatment of low volume streams exhibiting an unchanged level of contamination over long periods of time, such as seepage from waste rock dumps and tailings ponds, which would require a separate conventional treatment leading to high specific costs dominated by labour costs; and,
— In situ remediation of ground water contaminated by mine waters or seepage from waste rock dumps and tailings ponds.

Wismut is testing feasibility of the following passive biological technologies for treatment of mine, ground and surface water [20, 21]:

— Constructed wetlands;
— Reactive permeable walls;
— In situ removal of contaminants by microorganisms.

Wetlands technology is also in use at other sites and has been extensively used at Ranger during the operating phase [18]. The materials being investigated for reactive permeable walls include:

— Foamed zero valent iron;
— Fine grained heavy spar bonded in a matrix of expanded Geopolymer®;
— A product created from expanding and linking powdery titanium hydroxide with vinyl acetate adhesive.

The third method proposed by Wismut involves the application of microbiological treatment of contaminated ground water *in situ*. The tests are aimed at removal and fixation of uranium and other toxic metals directly in the ground. The basic concept of the method is to initiate and enhance microbiological processes underground which support the reduction of dissolved uranium to form insoluble uraninite and effect the precipitation of dissolved toxic metals as metal sulfides through addition of nutrients [19].

A recent remediation programme in Hungary has also examined the use of zero valent iron for the removal of uranium from seepage, as well as more conventional lime based barriers [21].

New technologies have also been developed for decommissioning and remediation of in situ leaching operations, which also should deal with long term restoration of groundwater. Reference [11] reports the following examples:

— At the Ruth pilot plant in Wyoming, the introduction of hydrogen sulfide into a depleted well field was shown to reduce and/or precipitate a variety of metal ions;
— Cotter Corporation has installed a reactive barrier containing zero valent iron at its Canon City uranium mill to intercept molybdenum contaminated groundwater;
— Reverse osmosis and electrochemical water treatment technologies are finding increased application in ISL remediation projects.

Natural attenuation of contaminated groundwater is being considered an acceptable approach for cleanup in Kazakhstan [22]. This approach arose from studies showing that ore hosting media were resistant to intensive ISL impact. It was demonstrated at several sites that a slow but irreversible neutralization of leaching solution occurs in aquifers containing residual solution plumes after leaching has stopped. The process is based on the action of natural barriers, and barriers that result from mining itself.

The natural neutralization barrier is due to the presence of neutralizers (carbonates, chlorites, alkali earths and certain clay types) and the reduction barrier is characterized by the reducing action of carbon materials, pyrite sulfur, bitumen, organic substances, hydrogen and hydrogen sulfide in unoxidized rocks. An adsorption barrier is also formed when concentrations of phosphates and carbonaceous matter are high.

In comparison with active restoration using pump-and-treat and/or chemical precipitation technologies, natural restoration was estimated to be 10 to 100 times less expensive [22]. While natural attenuation has potential application, it is a slow process, taking tens of years, which may not be acceptable in areas where affected aquifers have other beneficial uses. An extension of this approach has been tested (and patented), in which residual acid leach solution is pumped from the well field and passed through an adjacent area of unoxidized rock. Total restoration time was from a few months to two to three years, depending on the size of site to be cleaned [22].

So-called natural attenuation has also been observed in tailings from conventional ore processing. Natural leaching of radium from aged tailings was observed to be limited by the rapid development of high surface secondary minerals such as smectite, iron oxy-hydroxides and gypsum, which can trap 95% of total radionuclides and associated heavy metals [23].

The US Environmental Protection Agency (USEPA) is reported to have adopted natural attenuation at a number of abandoned uranium mill sites in the US, where contaminated groundwater is considered unlikely to pose an active threat to the environment [20].

Development of these passive methods provides an added level of risk control for all decommissioning and closure operations, thereby enhancing sustainability.

2.6. CONCLUSIONS

Tailings, waste rock and water management have been, and will continue to be, the most significant areas in terms of environmental performance. If uranium mining and milling operations are to be regarded as sustainable, then performance in these areas will need to be of the highest order. In this regard, the lessons of the past appear to have been learned, with all current major operations having well developed management plans in place at startup, which continue to be an integral part of the operating strategy, evolving with changing circumstances as development proceeds.

In some respects, the effectiveness of these plans to satisfy the expectations of sustainable performance is still being assessed. The Nabarlek mine and mill in Australia, which commenced operation in 1979, is the only example where a conventional operation has started up and been decommissioned according to plans developed at startup and refined as part of the operating strategy. However, other sites such as the Collins Bay A zone and D zone pits at Rabbit Lake are well down this path.

There are also operations that commenced in the 1950s, for which decommissioning and closure plans were not well formulated at startup, but application of appropriate technologies and standards have enabled acceptable closure to be achieved. Examples include the Mary Kathleen mine in Australia, and Eldorado Nuclear's Beaverlodge site and operations in the Elliott Lake region, both in Canada.

The ability of the industry to embrace a high level of environmental performance during operations is also reflected in the records of the Ranger uranium mine, surrounded by the World Heritage listed Kakadu National

Park in Australia, and in the high grade operations at McArthur River/Key Lake and McClean Lake mines in Canada, which have addressed and overcome new challenges regarding mining and waste management.

The current generation of operators has also demonstrated a willingness to address evolving environmental sustainability standards during operation. Prime examples are improvements to tailings deposition methods in Australia and Canada, introduction of new technologies and systems for water management at Ranger and Key Lake, and process modifications to alleviate or eliminate the impact of ammonia used in the process.

Despite the impressive performance of the above examples, legacy issues arising from environmental standards that fell well short of responsible industry practice at the time still impact perception regarding the current uranium mining and milling industry. While good progress has been made in Germany and Hungary, the problems requiring attention in Russia, the former Soviet Union and other states still need to be resolved in order to encourage broader confidence in governance and social responsibilities.

There is evidence that concern for environmental protection is now worldwide, and that regulations have changed to reflect higher expectations of government bodies and society in relation to environmental protection standards. The key to environmental sustainability is an active approach to environmental management throughout the life of an operation, beginning at the planning stage.

3. SOCIAL ISSUES

Today, in general, most large mining and processing operations are concentrated in areas which are thinly populated. Before mining, the land had often been used by nomadic aboriginal populations, who often may not understand the impact of mining nor the value and use of the metals exploited. These issues are debated and several case histories from Africa, Australia, the United States of America and Canada are discussed. These illustrate that although there are often substantial social and economic benefits to local communities resulting from mining operations, they must be sustainable to be successful.

3.1. INTRODUCTION

Mining operations can have both positive and negative economic and social impacts. Mining can provide employment and business opportunities to help local communities become prosperous. Conversely, improperly managed mining and processing activities can contaminate the environment and have serious adverse social impacts.

Displacement or disruption of settlements by mining operations can cause long lasting resentment and conflict. Communities can lose their land and their access to natural resources. Community institutions and relations can also be disrupted

Another significant impact of mining activity can be the migration of people into an area where a mine represents the most important economic activity. Migration effects may extend far beyond the immediate vicinity of the mine and can lead to social conflict when ‘outsiders’ from different cultural or ethnic groups move into an area. In the past, the worst cases occurred in mining centres of the former Soviet Union, where so-called combinates with workforces of more than 10 000 and associated communities were built over time and then abruptly dissolved in 1990, leaving residents in mining towns stranded in a contaminated area without employment. Even now in many places, the issues of closure and remediation have not been addressed due to a lack of both financial and technical resources. Solving these problems will strongly influence the acceptance of new production facilities and adoption of nuclear energy in some countries.

Today, large uranium mining and processing operations are concentrated in the following areas:

— Athabasca Basin in Saskatchewan, Canada;
— Stuart Shelf of South Australia (Olympic Dam);
— Alligator Rivers Region of Northern Territory, Australia;
— Chu-Sarysu and Syr-Darya sedimentary basins in Kazakhstan.

Most of these locations are thinly populated and the land is owned or occupied by indigenous peoples.

Proper management of community and indigenous issues can minimize social problems to the mutual benefit of both communities and mining operations. The more successful uranium mining companies (Cameco, Areva, RTZ, BHP-Billiton, *etc.*) have developed strategies to manage the impact on local communities and the environment. It is normal practice to discuss the impact of mining and processing with local communities and landholders before activities are started. The process is often defined in project assessment regulations, and development of an Environmental Impact Statement (EIS) usually requires a social impact assessment.

Developing countries often do not have regulations covering the environmental impact of uranium production. The World Bank, the IAEA and governments of some industrialized countries offer training courses for political decision makers to help address such shortcomings.

Social impact assessment is currently the most widely applied tool used to address the impact and mitigation of social issues associated with mine development. An environmental impact assessment generally includes an evaluation of the costs and benefits of a proposed project, to determine whether or not the project should proceed. Continuing dialogue through the assessment, development and operation of a mining project is essential. This requires a forum of the principal stakeholders with a clear role, and it must be appropriately housed and financed, and fully supported by all members.

3.2. COMMUNITY ACCEPTANCE

The concept of sustainable development applies as much to the host community as to the planned mining development. A sustainable development plan must evolve for any community that will be affected by mining; it is likely that the community will require outside assistance and resources in order to develop such a plan. If mining operations are to help communities work towards sustainable development, communities need to be able to participate effectively in decision making processes for establishing mining and milling operations. Enabling communities to effectively participate in the decision making process will generally require a comprehensive communications and education strategy in order to provide participants with sufficient understanding of the issues in order to be able to make informed decisions.

Mining operations in remote locations typically have to construct new infrastructure or upgrade existing infrastructure to support the demands of mining and processing operations. Typically this will include the following items:

— Airstrips;
— Roads;
— Water supplies;
— Sanitation systems;
— Electricity supplies.

These improvements in infrastructure can often have the unintended side effect of leading to an increase in the local population through the arrival of new settlers. Designing this infrastructure solely with mining objectives in mind may create dissatisfaction among the local population. With planning and community consultation during the feasibility stage, infrastructure can be designed so that it can benefit the community both during the mining phase as well as after closure, with minimal capital cost to the community. However, it must be remembered that infrastructure should not be left behind after closure unless there is a willingness and ability (particularly financial) on a community's part to undertake ongoing management of the infrastructure. The issue of financial resources for ongoing management and maintenance of infrastructure can sometimes be addressed by a mining company setting up a trust fund solely for this purpose. Development of infrastructure can also facilitate other forms of economic activity, such as tourism.

An example of an effective policy involving community stakeholders is Teck Cominco's Red Dog operation in Alaska; greater details regarding this operation can be found in the case studies section of this document. Teck Cominco believes there are five elements to sustainable development, which are:

— Empowering people;
— Respecting community values, culture, and traditional economics;
— Developing and internalizing capabilities;
— Equity in benefit sharing;
— Protecting the environment.

3.3. INDIGENOUS COMMUNITIES

A significant challenge when introducing a mining proposal to an indigenous community is that often the level of technical and scientific expertise required for informed assessment by the community is either non-existent or inadequate. This makes it impossible for the community to understand the project and its full implications and then make informed decisions. This situation places a high level of obligation on mining companies and regulators to implement education and information programmes that will raise the level of community understanding of the issues involved. The goal of these education programmes should be to give community members the required skills to enable them to make informed decisions and ultimately participate in the project if they wish to.

Typically there will be a strong desire by an indigenous population to realize benefits from a mining operation. However, community members generally do not have the necessary skills required to enable them to immediately to step into mining jobs. Solving this problem requires joint efforts by mining companies, governments and local communities to provide education and training programmes. Good results have been achieved where joint industry–government–community training programmes have been developed and implemented and when hiring has been based on training success.

3.4. EDUCATION AND TRAINING

Mining projects can contribute to sustainable development by building human capital through workforce training and education. Skills acquired during employment in a mining operation can be carried over and have direct application within the local community. By developing these skills, a mining operation can leave a valuable legacy in a community even after the mine has shut down. Maintaining a stable work force is an important component of managing an efficient mining operation. Maximizing local employment will assist in reducing employee turnover and in retention of corporate knowledge. In addition, employing the workforce locally will maximize direct benefits to the community.

3.5. RADIATION HEALTH EFFECTS

The major difference between uranium mining and other mineral production is the radioactivity associated with uranium. The effects of radiation exposure and handling and storage of radioactive materials are of major concern to most communities. It is important that mining companies and regulators allocate sufficient resources to ensure that the public is fully and accurately informed regarding radiation issues applicable to their situation.

3.5.1. International agencies

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is a UN agency created in 1955 out of concern over radioactivity in the environment arising from the atmospheric testing of nuclear weapons. Since its initial work in the 1950s, UNSCEAR has broadened its scope to cover all sources of radiation exposure and resultant effects. UNSCEAR reports form the basis of radiation risk estimates that are used by the International Commission on Radiological Protection (ICRP) in developing recommendations for protection of humans from radiation exposure in various activities.

The ICRP has developed a system of radiation protection with three principles:

— ***Justification*** requires that any practice involving radiation exposure shall produce a net benefit;
— ***Optimization*** requires that radiation doses be kept as low as reasonably achievable, taking economic and social factors into account, and;
— ***Dose limits*** are recommended to maintain individual risk within acceptable limits, based on levels of risk in other human activities.

The ICRP makes recommendations to control all types of radiation exposure, including industrial and medical practices. It also recommends intervention in situations where human exposure may be high due to natural background or past industrial activity that was not previously recognized as being a source of radiation exposure.

In recommending dose limits, the ICRP uses the results of both experimental studies with laboratory animals and the study (epidemiology) of human populations which have been exposed to radiation.

The IAEA is a UN system organization created in 1957. The IAEA's mandate is to share knowledge on the peaceful uses of nuclear energy in areas such as:

— Generation of electricity;
— Desalination of seawater;
— Transportation;
— Production of radioisotopes for research and medical use;
— Agriculture (food irradiation and preservation, sterilization of pests);
— Other industrial applications.

The IAEA publishes international safety standards and other materials which provide practical guidance for mining and processing of radioactive ores and the transportation of radioactive materials.

3.5.2. National regulations

ICRP and IAEA publications generally form the basis of radiation protection regulations in most industrialized countries. Although most countries have some general regulations controlling radiation exposure, some may not have regulations specific to uranium mining and processing, especially if there has been no previous uranium mining in a particular country. In such cases, a company proposing to develop a mine is well advised to start early negotiations with the regulatory agency, bringing in experts from organizations such as the IAEA to assist in the development of viable national regulations. The question of legacy issues is dealt with in greater detail in chapter 7.

3.6. CONCLUSIONS

Experience demonstrates that there are often substantial social and economic benefits to local communities from mining operations, but they do not come automatically. The key issue is sustainability of the benefits. It is particularly important that there are policies in place and training available with respect to mine and non-mine employment and provision of goods and services. The most successful cases are those in which local communities (often gradually) provide many of the goods and services needed by the mining companies. In some cases mining companies have played an active role in quality enhancement of their suppliers. The skills developed were often transferable to other industries. Companies and communities that took a long term view, stretching to post closure, were also more likely to have a clearer vision of what types of training and programmes were more likely to provide sustainable benefits.

Past experience confirms that sustainability is closely related to participation of neighbouring communities in decisions affecting them. The need to ensure sustainability through increased participation of local communities is apparent in the Australian and Canadian cases and quite consistent in some African cases. The Canadian cases point out the importance of government participation in the process and the establishment of a trilateral dialogue, in which the three main stakeholders — the community, the company and the government — have direct communication with each other. Studies show that a legal licence is no longer sufficient. Companies must obtain a 'social licence', and this depends on consultation, participation, and, increasingly, strong trilateral dialogue.

In summary, the goal is not to provide a community with a given package of benefits, but to strive to provide lasting benefits. It is important that the policies and strategies adopted are adapted to the realities of a given operation, including its size, geographic location and climate, as well as socioeconomic and cultural conditions.

4. ECONOMIC ISSUES

Many of the economic issues surrounding the uranium mining and processing industry are unique to this particular sector. As uranium is considered a strategic resource by many countries, it is subject to different market forces in comparison to fossil fuels and other mineral products. An additional unique feature of the industry is that only approximately half of the uranium used in electric power generation is from newly mined sources.

4.1. INTRODUCTION

Sustainable development of uranium mining and processing operations requires identification and response to the economic constraints of the industry. In many market based economies, uranium mining and processing operations are corporate profit centres, whereas in some developing countries these operations are viewed as a source of economic exchange. Because uranium is considered a strategic resource by many countries, it is subject to somewhat different market forces in comparison to fossil fuels and other mineral products. Further complicating the dynamics of the industry, only about half of the uranium used in electrical power generation is from newly mined sources, the remainder being provided largely from material originally intended for weapons and related uses.

As with all industries, the nuclear industry should be profitable in order to survive in a free market system. In sustainable development, profits are not solely for shareholders; profit should be shared with all stakeholders. The concept of stakeholder profits requires careful consideration, as it extends beyond the classical concept of corporate profits. Currently, a relatively small number of companies produce a majority of the world's primary uranium. These companies do not all measure profit the same way. Some measure profit at the mining level, others measure profit at the fuel processing level, or elsewhere. Thus, different companies have differing measures of profitability and, therefore, sustainability.

Free market companies require a distribution of profits including a return on investment to shareholders which is competitive in the realm of investment opportunities. To develop in a sustainable manner, mining and processing operations require sufficient profits to provide return to investors and to provide continued investment in operations, such as exploration, capital improvements, and technology development. A portion of profits will likely be distributed to local governments and national governments in the form of taxes and related payments. Other fractions of profits will be used to address local, regional, and perhaps national, social and environmental considerations. It is generally recognized that social and environmental considerations have been inadequately addressed in the past.

The increased emphasis on sustainable development in the uranium mining and processing industry is likely to impact the profitability and economics of various sectors of the industry. It may be necessary to reassess operations previously considered profitable after a more formal accounting of social and environmental costs is taken into consideration. Funding for social and environmental costs may come from a mining and processing company's profits, from a redistribution of taxes, or from a combination of these. It may be determined that some operations previously considered profitable are no longer financially feasible.

This section focuses on the economics of uranium mining and processing in a free market system, recognizing that external factors can have a significant impact on the sustainability of any particular operation.

Uranium mineralization occurs in a wide range of geological environments. A number of factors must be assessed to determine which deposits can be developed in an economically sustainable manner. Decades of mining and processing experience have resulted in a relatively mature industry in which the key components of economic development are relatively well recognized. These components range from technical details associated with mining and processing, through to business models applied by specific companies, to national development policies. All must be carefully integrated, for the uranium mining and processing industry is highly competitive on an international basis, as is the case for many industries.

This discussion of sustainable development incorporates guiding principles established for mining by the Mining, Minerals and Sustainable Development (MMSD) Project, a cooperative effort by the International Institute for Environment and Development (IIED) and the World Business Council for Sustainable Development [24]. The key economic principles of sustainable development postulated by MMSD are that mining operations should:

— Maximize human well-being;
— Ensure efficient use of all resources by maximising returns;
— Seek to identify and internalise environmental and social costs;
— Maintain and enhance conditions for viable enterprise.

Sustainable development must reflect the increasing globalization of world trade and the increasing expansion of free market principles to ever more national economies. Decades of experience have demonstrated the non-sustainability of mining and processing operations of centrally planned economies. A central premise of this work is that mining and processing operations should be inherently profitable on a project basis. Individual companies and countries can approach this profitability concept in various manners. However, it is postulated that improperly considering global markets, as occurs for example through provision of state subsidies, will ultimately jeopardize the sustainability of any particular operation. Government intervention can lead to the development of business practices that are not globally competitive, with the potential that a change in government policy will render a mining operation obsolete and lead to serious social and environmental disruption.

Specific elements of major importance to the sustainability of uranium mining and processing include the open nuclear fuel market, industry profitability measures, ore deposit characteristics, the regulatory environment, and availability of resources, as well as investment and taxation. These should all be integrated with social, environmental, and governance factors, which are discussed in other sections of this document.

4.2. OPEN NUCLEAR FUEL MARKET

The bulk of uranium mined and processed worldwide from natural ores will be used in fuel for the nuclear power industry. That produced for other purposes is considered minor, beyond the scope of this work, and difficult to estimate from available literature. Mining and processing operations generally produce a commodity product, such as yellowcake, that is sold under both long term contracts and on the spot market contracts. The bulk of production has for many years been sold under long term contracts. Although subject to various national import and export requirements, uranium products are traded globally. Spot market prices are quoted daily and generally reflect long term market prices and trends.

In 2001, IAEA projections indicated a continued demand for uranium as reactor fuel for the next 20 to 50 years [25]. Approximately 56% of current fuel requirements will be met by newly mined uranium (primary uranium supplies) and approximately 44% will come from existing materials, such as converted weapons related materials (secondary uranium supplies). It is projected that newly mined material will provide an increasing percentage of fuel as pre-existing national inventories are consumed. In addition, it is projected that total fuel consumption is likely to increase, requiring increased amounts of newly mined uranium in the future. Consequently, an increased market for newly mined uranium is projected for several decades into the future.

Projecting future demand for uranium to be used in nuclear power generation is complicated by uncertainty in evolving global electrical power generation preferences. Greenhouse gases, climate change awareness, and waste disposal issues are generating much discussion about fuel sources. A historical perspective provides insight into how quickly the nuclear power industry can evolve [26]. From the late 1950s into the early 1970s, nuclear energy was considered a highly attractive source of electricity and the industry grew rapidly. This began to change in the early 1970s. Figure 2 of Ref. [26] indicates the rapid decrease in construction of new power plants as environmental and safety considerations grew internationally. These concerns grew out of an evolving regulatory environment and the Chernobyl and Three Mile Island incidents, leading to construction delays, increased costs, and in some countries outright rejection of nuclear power.

Uranium resources and prices reflect this changing environment. Figure 3 of Ref. [26] indicates the relatively low prices of uranium in the late 1960s followed by a rapid rise in the early 1970s, reflecting the rapid increase in orders for nuclear power plants and a perceived shortage of potential uranium resources. The price began an abrupt decline in the late 1970s in response to the precipitous drop in orders for new plants, cancellation of orders for planned plants, and discovery of immense new resources. Responding to these constraints, the industry has improved the overall efficiency of nuclear power plants, as shown in Fig. 4 of Ref. [26]. Significant nuclear power growth is anticipated in Asia and developing countries. Several reasons for this include the attractiveness of nuclear power plants where energy demand growth is rapid and alternative resources are scarce, where energy supply security is considered a priority, and where nuclear power is seen as an energy alternative which reduces air pollution and greenhouse gas emissions. India and China are examples of two countries that have growing energy needs, currently have relatively low nuclear power production, and which have accepted nuclear power as an important component of their power supply systems. These and other developing countries have the potential to lead the growth of nuclear power in coming years.

A basic description of the nuclear energy industry is provided by Ref. [26]. The international market for uranium is demonstrated by the nature of the producers and consumers of nuclear fuel. In 2006, 20 countries reported production of uranium from mining operations, at least several dozen deposits representing a number of geological environments were being exploited, and 30 countries reported installations of nuclear generating capacity, represented by a total of 435 commercial nuclear power plants. Estimated global uranium consumption by the nuclear energy industry was approximately 66 500 t U [1].

Primary, newly mined uranium sources can be divided into four categories: CIS production, national programmes, Chinese production, and market based production [1]. CIS production exceeds CIS demand, thus uranium is available for sale and is in fact a source of hard currency for the CIS. National programmes exist in several small countries whose programmes are designed specifically to meet domestic reactor requirements. Chinese production is difficult to estimate, as China publishes such information in a limited manner. It is believed that most Chinese production will be required for domestic use and that China will begin to rely on market based international supplies. The IAEA assumes that in the future primary production will increasingly rely on market based economic principles.

IAEA forecasts indicate that market based production from existing and planned uranium mining and milling facilities is inadequate to meet nuclear power plant requirements up to the year 2020 under a mid-range demand forecast. The shortfall in recent years has been provided by secondary supplies. Secondary supply is difficult to estimate, but it is expected to decrease to 4-6% of annual reactor requirements by 2020. Uranium resources, however, are adequate to meet demand during this time period, but significant shortfall exists when the forecast is extended to 2050 [19]. Consequently, the mid-range forecasts suggests a continuing need for exploration, mining, and processing of uranium for many years to come and that sustainability of the industry is an appropriate consideration.

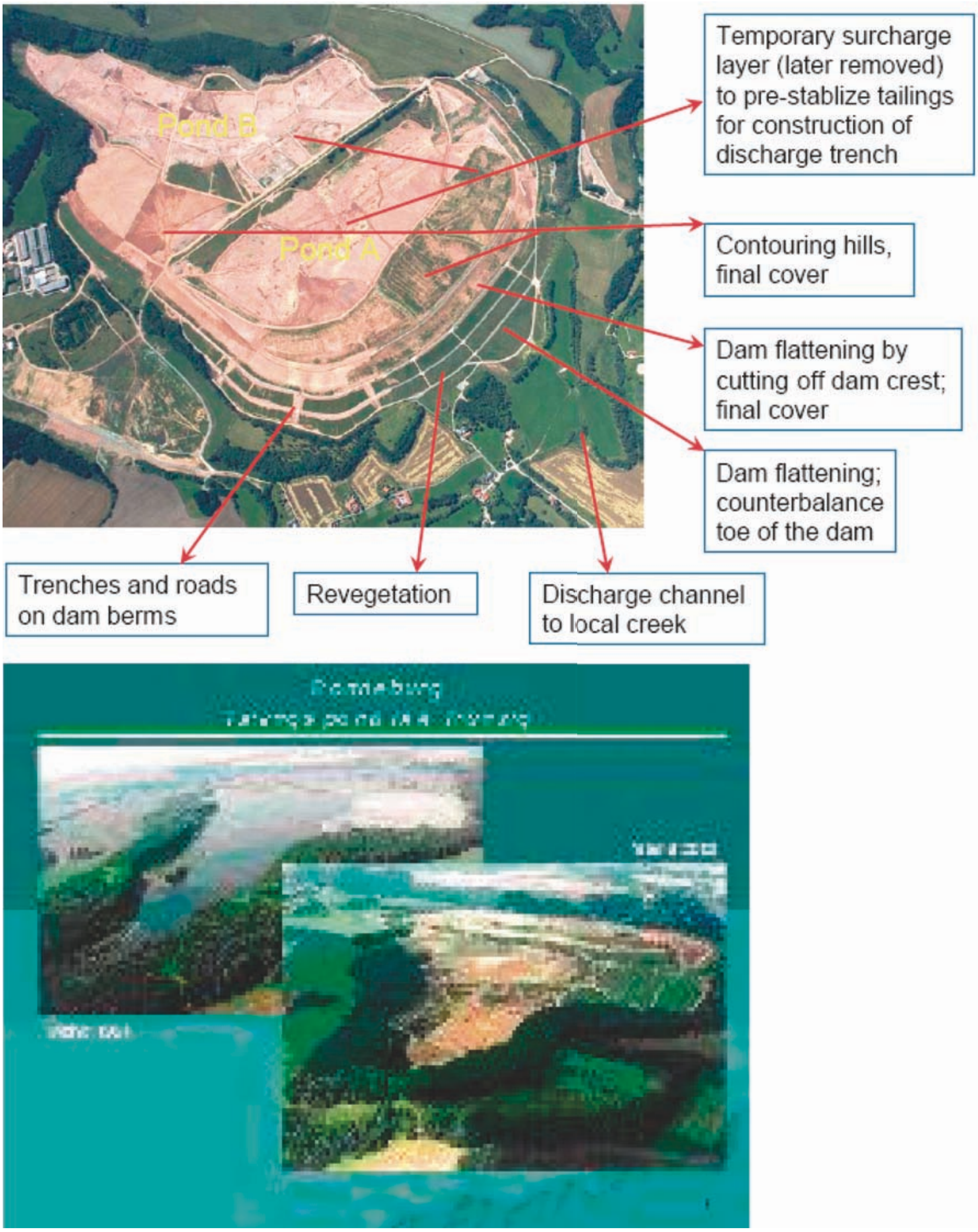

FIG. 2. Progress of the revegetation stage of refilling in 2002 of the Trünzig tailings pond.

In summary, various indicators project a competitive, sustainable, international free market in uranium for use in nuclear reactor fuel for at least the next 20 years. The demand is expected to be increasingly responsive to free market forces. For mining and processing operations to be sustainable, they must be developed and operated in the context of this global marketplace.

FIG. 3. Ronneburg open pit early stage of filling

4.3. PROFITABILITY MEASURES

An IAEA review of the industry identifies four categories of uranium producers: domestic mining companies and foreign mining companies; within each of these are government-owned companies and foreign owned companies [1]. Government mining companies represent 49% of production, while private mining companies represent the remaining 51% of production. Thus, a significant fraction of uranium production is controlled or influenced by governments.

(a) (b)

FIG. 4. Mecsek Mining District, Hungary.(a) Head frame No. 5 (b) Demolition of head frame No. 5

Generally, government agencies are not entirely motivated by profit considerations. In the long term it is projected that production will be dominated by free market factors, suggesting a greater proportion of production by non-government mining companies. This will place pressure on government production sources to be accountable to stakeholders. In the interim, a number of government operations and companies that have government support may produce in a manner that is not profitable by open market standards. Government supported production reflects national policies in maintaining stable supplies and may lead to social and environmental policies that are not sustainable from the perspective of profits at the mine and mill level, but the costs of which are considered acceptable for the entire nuclear fuel and power generation cycle for a particular country. These are considerations that individual countries should assess on a continuing basis as the industry evolves. Private companies should be acutely aware of such policies, whether they are supported by such policies or are operating entirely according to free market principles.

Examples of diversity in industry structure are provided by China, France and the USA. China is an example of a country where the uranium industry is owned by the state and the goal of the country is to be self sufficient in producing uranium for nuclear power. France has a significant nuclear industry, but ceased domestic primary production in 2001. It relies largely on foreign production involving French companies in which the French government has an ownership position. The benefit for France is a stable and secure energy resource abroad, a relatively low price for electricity, and low releases of greenhouse gases. Viewed in a complete cycle, France believes that investment in social and environmental performance at Areva's mining and milling operations abroad is beneficial and cost effective for both consumers in France and local communities where the mining takes place. The USA increasingly relies on the open market purchase of uranium by privately held utilities from international suppliers.

Alternatively, some countries, such as Germany, have discontinued subsidies that previously supported their domestic uranium industry and have furthermore announced a desire to phase out nuclear power.

It is within this framework of mixed government and private ownership, along with the uncertain amount of existing secondary material, that sustainable development should be considered. Sufficient operational experience exists to allow accurate estimates of most of the engineering parameters associated with mining and processing. Assessment of environmental and social factors will largely be site specific, and requires early and continued engagement of appropriate stakeholders.

Increasingly, sustainable development is also recognized to be a financially sound investment [23]. Fund managers and investors are showing increased interest in long term investment in companies that are well managed and socially and environmentally acceptable. Many banks and insurance companies see commitment to sustainable development as a proxy for good management, suggesting lower risk and better returns. Well managed, profitable companies generally qualify for lower cost financing compared to their peers; thus, a demonstrated commitment to sustainable development should lead to positive direct bottom line financial results.

The business case for sustainable development can be discussed in terms of explicit profitability measures [20]. Specific values believed to result from sustainable development practices include:

— Lower labour costs and more innovative solutions due to a more satisfied and committed work force;
— Lower health costs due to a healthier environment in work areas and in the surrounding community;
— Cost saving due to cleaner production methods, resulting in less waste, decreased raw materials usage, and implementation of innovative technology;
— Easier access to lenders and insurers, with lower loan and insurance rates, due to reduced project risk;
— Lower transaction costs, due to transparency and community acceptance;
— Lower closure and post closure costs, as appropriate considerations are in place from the outset and issues are often resolved on an ongoing basis during production;
— Improved reputation enhances market value by improving a company's image among investors and by allowing the company to attract the most qualified work force, leading to greater and continued profitability;
— Best practices influence regulation, resulting in the ability to participate in the development of the regulatory environment;
— Market advances, as the market will recognize that a producer is less likely to default on production commitments, and;
— Ethical investors, as part of the socially responsible investor movement, prefer to invest in companies with a progressive record, providing wider access to financing.

In summary, profitability in the uranium mining and processing industry is measured by returns to stakeholders. For non-government owned mining companies, this return is readily calculated and companies are responsive to investor demands. For companies constrained or motivated by government policies, a greater range of stakeholders should be considered. With a growing trend towards a global, free market economy, production will increasingly be required to be profitable on a mining and processing unit production basis. The increased costs associated with consideration of all social and environmental factors will undoubtedly impact a number of operations. However, companies adopting sustainable development principles will likely be rewarded by a lower overall cost structure and greater market acceptance, similar to a well known brand.

4.4. ORE DEPOSIT CHARACTERISTICS

The characteristics of individual ore deposits have a major influence on the approach to sustainable mineral deposit development. A broad range of ore deposit types are currently recognized and mined. These exhibit a wide range of mine life, use different mining technologies, and various processing approaches. A brief summary of these characteristics and their relationship to sustainable development is provided below.

Currently, four deposit types, shown on Table XXIII of Ref. [19], provide nearly all the primary uranium used by the nuclear power industry. The total amount of uranium contained in any one of these deposits can vary by several orders of magnitude. Individual deposits may have life spans ranging from a few years to several decades. It is realistic to expect that larger tonnage, higher grade, long life deposits will have a greater propensity to generate and address the social and environmental considerations associated with sustainable development. Long years of experience with major deposits types described in Ref. [19] already exists, thus providing a substantial base of information for use in planning new developments.

The wide range in deposit types and characteristics provides for a wider range of sustainable development considerations. Some relatively small deposits can be mined and reclaimed in a period of several years, and consequently may have minimal social or environmental impact. Other large deposits may have substantial impacts that require extensive coordination among stakeholders. Stakeholders in new project developments should review case histories to prepare for the conditions likely to exist in their specific situation.

4.5. REGULATORY ENVIRONMENT

Increasing globalization of the mining industry is leading to greater uniformity of a range of regulatory controls. This is especially true for environmental standards and regulations. Adoption of similar environmental standards reflects policies based on science as well as recognition that in a competitive world economy, objective, uniform standards promote development and international competitiveness. Some companies now routinely anticipate and plan for the most stringent environmental controls and apply them uniformly around the world.

The increased emphasis on sustainability is also leading to more formal consideration of social impacts. Currently this is most visible through provisions for stakeholder input and the public review process.

Different mining and milling situations, as represented by different deposit types and mining methods, will be capable of supporting different levels of regulatory controls. Regulatory officials will need to understand where flexibility is permissible in order to provide the optimum in economic development, environmental protection, and social benefits. Forums are required in which stakeholders can participate in objective reviews of site specific parameters.

4.6. AVAILABILITY OF RESOURCES

Mining and processing of uranium requires a broad range of resources, including human, power, transportation, and water resources. These are similar to the requirements of other mining operations. Because of the varied characteristics of each ore deposit and its unique location, many sustainable development criteria will be site specific. The availability of resources for remote operations will likely be constrained, leading to higher operating costs and leaving a smaller margin for profit and sustainable development considerations. Consequently, each project needs careful planning within the frame of its specific environment to determine the appropriate level of investment in social and environmental factors. Careful assessment of the entire mine life cycle at the outset can lead to social and environmental investments that ultimately provide a more sustainable operation. Sufficient industry experience exists to identify critical factors in most new operations. The case histories of Cameco in Canada and Areva in Niger provide useful examples for future developments.

Cooperation among the stakeholders from an early stage can identify key social and environmental concerns of local importance as well as provide the opportunity for the mining company to describe genuine constraints. For remote projects, fly-in/fly-out camps and construction of new, mine supported communities are common options. For projects in urbanized areas, such as some ISL deposits, the impact may be more on local traffic and services. In all cases the mining and processing operation should pay its fair share of the development costs. In some cases the development may become uneconomic if all the impact is borne by the project. Then government authorities may need to consider whether the long term impact in terms of jobs, new infrastructure, or other factors merits tax breaks or other benefits. While this may appear to violate free market principles, ample examples can be cited where non-mining industries have been provided temporary incentives to locate in a specific area, for example as part of a regional development plan. In some cases, as with the Fort Knox gold mine near Fairbanks, Alaska, a new mine required enhancement of the local electrical power system to meet increased demands created by the mine, which in the end lead to lower power costs for local residents.

4.7. INVESTMENT AND TAXATION

Profits from mining operations have traditionally been divided among taxing authorities, investment in operations, and returns to shareholders. The increasing concern for sustainable development is leading to additional costs for existing operations and generally higher initial costs for new operations. These additional costs, in actual cash or as a result of project delays, should be borne by the project stakeholders. If these costs become too large, investors will not support the project and the attendant benefits to stakeholders will be lost or diminished. It is important that stakeholders assess each situation in an objective forum. Government may want to consider tax incentives or other mechanisms in order to maximize available opportunities from a project. In the past it has been relatively common for tax revenue to pass directly to a government body distant from the project site, without providing local benefits commensurate with the impacts. Increasing emphasis on sustainability may require a review of this approach. In sustainable development, taxation by government and long term investment by mining and milling operations have similar goals: minimize adverse social and environmental consequences and prepare for the eventual termination of mining. Tax structure and tax revenue distribution should be adjusted to recognize local sustainability issues and related corporate investment.

4.8. REPORTING METRICS

Sustainability requires generating sufficient financial returns to satisfy stakeholder requirements, including generating a profit for those who have provided investment. Not all stakeholders require a direct financial return. For example, income from a mining operation may be used for social and environmental purposes, such as local educational and health care commitments made by the mine developer. Providing stakeholders access to such information is a vital part of sustainable development. A number of companies are currently producing annual 'sustainability reports' so that stakeholders and investors have greater and easier access to information relevant to the sustainability of the company and individual operations. These reports, used in conjunction with traditional financial reports, should allow stakeholders the opportunity to understand how a specific company or mining operation is addressing its commitments to stakeholders and whether sustainability is possible. These reports should contain information relevant to the economic, social, environmental, and governance aspects of sustainable development and promote increased transparency.

4.9. SUMMARY

Projections indicate that there will continue to be a need for primary uranium production for at least the next several decades to provide fuel for nuclear power plants. The economics of uranium mining and processing operations need to be reconsidered in the light of sustainable development principles. The mining industry has sufficient experience with a diverse range of ore deposits in a range of geographical and cultural environments that most engineering parameters can be established relatively well. Major uncertainties in project economics, and thus sustainability, can develop where uncertainty and ambiguity are present with respect to environmental and social considerations. It is imperative that project stakeholders share early and continuing dialogue to develop an operational framework, thus allowing maximum benefit from each specific mining and processing operation.

It is important to establish at an early stage what environmental and social regulatory parameters or procedures are essential and where flexibility is permissible. Uranium for nuclear fuel is a commodity and, as such, subject to international competition. Projects, no matter how attractive, can only withstand a limited financial burden. Stakeholders will need to establish an appropriate framework for distribution of benefits from each operation.

Currently, about half of primary uranium production is provided by government influenced mining operations. The profitability of non-government mining companies is potentially impacted by these operations. Careful consideration should be given to this evolving structure as sustainable practices are applied to the industry. The limited profits available from any operation may require a reassessment of returns distribution, such as an adjustment of tax policies, to allow for the adoption of sustainable social and environmental policies, while still providing corporate profit. It is anticipated that operating in a sustainable manner will lead to greater profitability for companies, a better environment associated with mining operations, and improved social conditions for those associated with mining and processing operations. It is also likely that some deposits will not be economic to develop if sustainable development practices are utilized. The earlier this is recognized, the more likely it is that resources will be redeployed in a more productive manner.

5. GOVERNANCE

The role of governance in resolving the often conflicting demands of the environment, social and economic factors is analysed in the following chapter.

5.1. INTRODUCTION

The continued development of new uranium mines will become increasingly important as current stockpiles are consumed and as more emphasis is placed on the reduction of carbon dioxide emissions. This development has the potential to impact the physical and social environment and, as noted in preceding chapters, a host of environmental and social factors should be taken into account to maintain a sustainable uranium production industry. Equally important is the economic side. Investors are required to finance developments, thus operations should be profitable in order to survive, customers should be assured of receiving the fuel they require and both employees and the local community have expectations from the operation. A system of governance is required to define the roles, rights and responsibilities of governments, companies, investors, labour unions, communities, international institutions and non-governmental organizations. This will allow costs and benefits to be weighed and compromises to be reached on the development and operation of uranium mines to best meet these competing demands.

5.2. NATIONAL POLICY

The first requirement for sustainable development of mining and processing activities in a country is a stable national government. Stability is obviously important because a mining company, as well as its shareholders and lenders, will not invest in an operation in a country where they cannot be assured of continued beneficial ownership and operation of that asset. Mining laws should provide clear enabling legislation. Mining companies and their investors require fair and transparent mine licensing processes, leading to predictable outcomes.

A reasonable royalty scheme should be in place to allow the government to receive payments for the depletion of mineral resources. However, royalties should not be punitive, because this would discourage investment in the project.

5.3. LOCAL POLICY

Land use is frequently a local issue, at least in populated areas. Land use planning and legislation should complement mining laws, permitting the rent or lease of the mine site and associated lands.

5.4. INTERNATIONAL SAFEGUARDS

Due to the potential use of uranium in nuclear weapons programmes, uranium production is subject to an additional set of constraints not applied to other mineral developments. The IAEA was created to allow countries with nuclear technology to share it with other countries in return for an agreement not to use that technology for weapons development. As a result, international trade in uranium requires that parties agree to IAEA safeguards. Some countries also require bilateral agreements between the producing country and the customer country. The safeguards system requires accounting for all the uranium transferred between countries and between facilities within countries, with periodic physical inspections to verify accountability records.

5.5. LEGISLATION

Legislation must provide protection to the environment and to local communities, considering both current operations and the longer term, including post mine closure. Environmental assessment legislation is necessary and must be framed in a manner to allow all interested parties, in particular people and communities close to a proposed mine site, an opportunity to comment on and influence the direction of the proposed development. A proper assessment must consider not just the physical environment, but social impacts on local communities and economic aspects of a project, in order to weigh the costs and benefits. Not proceeding with a project should be one of the options considered. However, environmental law should focus on impact reduction and management, rather than simply being an instrument for stopping development entirely. Laws that are so stringent that they are impossible to comply with must be avoided, because they will likely be ignored entirely, potentially resulting in worse situations than if no laws were applied at all.

5.6. SOCIAL ISSUES

Employees and their families require a safe workplace, which means application of appropriate occupational health and safety legislation. Because of the radioactivity associated with uranium ores, requirements are more complex than for other mineral extraction industries. However, it should be recognized that radiation hazards associated with uranium production are neither as severe, nor as immediate, as the hazards associated with some other parts of the nuclear industry, and health and safety legislation should recognize this by implementing appropriate requirements. It is usually the case that conventional mining hazards, such as rock falls and the use of strong chemicals, result in greater health risks for workers in uranium production than radiation hazards.

5.7. GOVERNMENT AGENCIES

It is not sufficient to have policy and legal structures in place. Governments should also staff necessary agencies (particularly environmental and occupational health and safety agencies) with competent, properly trained personnel and ensure that they have sufficient resources to carry out necessary inspections and enforcement. In developing countries, the recruitment of staff with adequate training and experience can be a significant problem, and governments should be prepared to consider contracting out these services until sufficient local staff can be trained and a robust institutional capability developed.

Because sustainable development encompasses many subject areas that are frequently found in different governmental departments, it is essential that mechanisms are put in place to facilitate cooperation across departmental boundaries. Poor cooperation among government departments can result in multiple, and often overlapping, demands on a mining company, which reduce efficiency and work against sustainability.

5.8. REMEDIATION

The issue of remediation requires careful consideration. The mining industry has many examples of abandoned sites that continue to have adverse environmental impacts many years after shutdown. Appropriate planning from the outset can avoid these problems by creating long term plans for final disposal of wastes and return of the site to a safe condition that minimizes restrictions on future use. In some countries closure plans are required as part of the initial licensing process. Plans for long term containment of radioactive wastes are essential. Legislation should ensure that sites are properly remediated and can be handed back to the government. Today, in most jurisdictions, best practice requires a company to provide from the outset of a project a financial instrument of some type (bank guarantee, bond, trust fund etc.). This is to ensure that costs for remediation and subsequent ongoing monitoring and potential remedial and maintenance work can be met without additional costs to the state, especially if a mining company should cease operations unexpectedly or suffer financial failure.

5.9. INVESTORS, LENDERS AND INSURERS

Financial institutions and insurers have a role in governance. They are both exposed to risk by virtue of doing business with a mining company and both wish to minimize that risk. It has become common practice for these organizations to carefully examine a company's proposed operating and environmental policies before investing money. A system that could help promote sustainability is one in which companies with good programmes and demonstrated commitment to sustainable development — evidenced by good track records — get access to lower interest rates and lower insurance premiums. Investors can also pressure companies to promote sustainable development through election of their representatives to boards of directors.

5.10. CORPORATE STRUCTURE AND RESPONSIBILITIES

Voluntary initiatives by a mining company can be an important means of promoting sustainability. Many industry associations have developed codes of practice on environmental protection and these could be broadened to promote sustainable development. Many individual companies have developed their own environmental policies and some have gone a step further by developing and adopting sustainable development policies. Although these voluntary initiatives do not carry the weight of law, companies prepared to publicly commit to these policies and codes of practice will ensure that they are seen to be following them.

Two series of ISO standards are particularly relevant in the area of management systems for performance improvement. The ISO 9000 series focuses on quality control and assurance while the ISO 14000 series defines an environmental management system based on a commitment to continuous improvement. Companies can achieve certification of these standards by meeting the various requirements defined in the standards and then being audited by third party auditors for compliance with the requirements. Certification demands commitment of personnel at all levels of a company and may require the adoption of new technologies and additional employee training. These standards require continuing quality assurance systems, continuing efforts at performance improvement and regular reporting and recertification.

5.11. TRANSPARENCY

An important part of the governance system is transparency. This requirement for transparency applies equally to both government and industry. For regulators transparency is important as it gives other stakeholders (communities, landholders, NGO's, etc) confidence that all aspects of sustainability are being considered during approval and subsequent regulation of an operation. Where regulators do not allow for transparency in their actions, there is a risk that stakeholders will perceive they are working in collusion with industry.

Companies are now finding they are expected to report on environmental and social issues in their annual reports to shareholders; some companies have begun producing separate reports that specifically address these issues. Although there are recognized measures of performance in the environmental field, currently performance measures are less well defined in the social arena. To be meaningful, social reporting must have a defined system of measurements and associated standards to be met.

Increasing requirements for transparency in corporate governance include provision by companies to stakeholders of more information on decisions made and the criteria guiding those decisions. A sustainable development report is a good tool for communicating with investors and authorities at a corporate level. However, closer to facilities, direct dialogue and meetings with local stakeholders are viewed as more appropriate methods for achieving transparency.

6. CHALLENGES TO SUSTAINABLE URANIUM PRODUCTION – LEGACIES RESULTING FROM STATE SUBSIDIZED OPERATIONS

6.1. INTRODUCTION

In the 1950s and 1960s, uranium production served almost exclusively military purposes. State aid for the uranium mining industry led to rapid expansion in main production countries. Countries that historically maintained national uranium production programmes include Argentina, Australia, Brazil, Canada, France, India, Pakistan, the Russian Federation, South Africa, Spain and the USA.

Numerous production sites were closed after termination of defense supply contracts. At that time, legal provisions setting the terms for proper decommissioning and rehabilitation were usually missing. Many sites were abandoned by their operators without necessary security or remediation measures being put in place. Some of these sites were remediated later under governmental programmes. One example is the Uranium Mill Tailings Remedial Action (UMTRA) Program of the Department of Energy in the USA.

In the former Soviet Union and COMECON countries, the production of uranium had always been treated strategically and was carried out under conditions of secrecy. Economic, environmental and social aspects were usually of minor importance in comparison with the need to maintain production. As a result, in Eastern Europe lower grade deposits were exploited and high production capacities were established in densely populated regions. The need for environmental regulations and protection was only acknowledged in the 1970s. Financial reserves for decommissioning and remediation measures had not been put into place, and government worker pension schemes were stopped immediately after closure.

Today a few countries, such as India and China, have small uranium production programmes dedicated to meeting domestic reactor and military requirements. These programmes typically have higher production costs than the world market price. China has emphasized a policy of self-sufficiency in its uranium industry, but it is increasingly faced with high production costs and a lack of known resources as it struggles to satisfy the increasing demand of a growing civilian nuclear power industry.

Special regulations now cover all activities of mining and processing in these countries. For example, in India all uranium activities are under the control of the federal Department of Atomic Energy. Environmental impact assessment and monitoring are undertaken by a well equipped survey laboratory. There are many independent central and state regulatory bodies, which regulate operations. In most western countries, mine and processing plant closure is regulated by laws covering all financial, environmental and social aspects.

In Eastern Europe and the Commonwealth of Independent States, previous uranium production activities have left a large number of legacy sites that are continuing to have serious adverse long term economic, environmental, and social impacts; some of these are discussed in this section.

6.2. PAST STATE OPERATED URANIUM OPERATIONS AND THEIR RESIDUES

A significant issue for the credibility of a sustainable uranium mining and processing industry is the legacies arising from past operations which were carried out without planning for remediation and closure.

Between 1945 and 1990 centrally planned economies (the countries in Eastern Europe, including the Soviet Union) produced around 670 000 t of uranium for military and nuclear electricity generation purposes. Germany produced 213 380 t U, the Czech Republic 105 351 t U, the Ukraine 50 000 t U and Kazakhstan 72 000 t U. This production came from specific mining and processing centres, known as 'combinates'. A total of about 50 combinates existed. Typically a single combinate managed several mines that provided ore feed to a single processing centre. Workforces at these combinates could number up to 100 000 employees. Combinates were self supporting, supplying their own electricity, chemicals, social infrastructure, water supply, and so on.

A worldwide investigation into the closure of uranium mining and processing operations still active in 1990, demonstrated that decommissioning and remediation of abandoned production centres in Eastern Europe and Central Asia is technically challenging, as well as extremely complicated and expensive. These challenges exist due to lack of funds, breakdown of management and degraded infrastructure.

In the later years of production, mining and processing of low grade ores resulted in large mines and mills that generated significant volumes of contaminated waste (waste rock and tailings). The main contaminants of these waste products are radium-226 and its progeny, uranium, thorium, arsenic, cadmium, nickel and thallium, as well as residual chemicals from the leaching process. In most cases, the high concentration of contaminants was the result of poor recovery (45% to 60%) in the early years of production.

Remediation of these legacy sites to current internationally acceptable standards is proving to be both expensive and technically challenging. Studies have revealed that total remediation costs for small production centres (total production around 10 000 t U) are around US $40 million, and for large centres (production > 50 000 t U) around US $200 million. For the small economies of CIS states in particular, it is extremely difficult to raise these funds.

Remediation of former state operated uranium operations requires international attention if a public perception of commitment to sustainability is to be established. The impacts of these operations in the context of key sustainability criteria are described below to highlight the consequences and lessons learned from unsustainable practices.

6.3. ECONOMIC ISSUES

The main issues to be considered following the unplanned shutdowns of these operations are:

6.3.1. Activities before closure

- Economic study of an operation;
- Development of agreed closure objectives in consultation with stakeholders;
- Assessment of all liabilities, including responsibilities for remediation;
- Evaluation of possibilities for further economic operations (by-product recovery, reworking of residues, outsourcing, restructuring, etc.);
- Evaluation of remediation costs in order to comply with stakeholder requirements/expectations as well as current national and international regulations;
- Evaluation of national and international governmental support, World Bank credits, and;
- Development of a remediation budget, considering all potential sources of revenue and the costs of meeting environmental and social requirements.

6.3.2. After decision for closure

- Evaluation of cost effective remediation strategies;
- Outsourcing of cost effective operations;
- Economic evaluation of potential by-product recovery;
- Calculation of income generated by the sale of fixed assets and remaining inventory;
- Estimation of costs for licensing procedures and approval, and;
- Returns from revitalisation of remediated areas.

Any major remediation measure requires that ecological, economic and social interests be weighed and balanced according to importance in a way that ensures optimum remediation quality within funding limits.

The by-product recovery of saleable commodities during the remediation process may reduce total expenditure. By-products recovered may include uranium or other metals (silver, cobalt, copper, etc.), construction material or scrap metal. An example of the generation of saleable by-products during remediation is the recovery of uranium by water treatment during tailings remediation and mine closure at the Königstein mine in Saxony.

6.4. ENVIRONMENTAL ISSUES

Setting objectives for any remediation activities is a critical task in ensuring acceptable and enduring outcomes are achieved during a remediation process. Failure of remediation programmes can often be traced back to a failure to undertake a rigorous programme to develop and define appropriate remediation objectives.

Sustainable remediation objectives reflect overall values that the operator, stakeholders, regulators and community place on a physical and social environment in which the operation is located. Remediation objectives will typically have a location or regional specific basis.

Overall values generally address the following points;

— Sustainability;
— Final or sequential land use;
— Safety;
— Human health;
— Social impacts;
— Ecosystem impacts;
— Regulatory requirements;
— Cost optimization.

Examples of how each of the overall values listed above may be represented as a closure objective are presented below; note these are only examples for the purposes of illustrating how an overall value may be interpreted as a remediation objective.

Sustainability

Remediation activities will, to the maximum extent practicable, not impact on or limit the potential for development of a site by either the permanent alienation of land from future beneficial land uses or sterilization of resources which are currently subeconomic.

Remediation strategies will not cause accrual of an ongoing liability or risk to landowners and/or stakeholders. Remediation strategies must, to the maximum extent practicable, be maintenance free and minimize requirements for ongoing management or intervention.

Final or sequential land use

Recreation of a habitat and ecosystem similar to that which pre-existed development of the site and which incorporates traditional human activities.

Safety

Human safety considerations shall be paramount above all other considerations.

Human health

Remediation activities will take into account human health considerations in all aspects of planning and execution and will ensure that where the potential for adverse impacts on human health have been identified, plans are developed to ensure they do not occur.

Social impacts

Stakeholders are identified and fully integrated into the remediation planning process.

Ecosystem impacts

Where an ecosystem impact is identified it can either be demonstrated that it will diminish over an acceptable period of time or the extent of the impact will be minimised using best practice technologies and appropriate resources are provided for ongoing management of identified impacts.

Regulatory requirements

Compliant with current legislation and anticipates changes in international legislative and community expectations over the life of the project.

Cost optimization:

Where impacts requiring remediation are identified and appropriate agreed closure criteria have been developed then the most cost and resource efficient method of remediation will be developed, taking into account site specific social conditions.

Objectives are the overall guiding principals that every activity (including operations and remediation) must be checked against to ensure activity is compliant; possible adverse impacts are recognised, and the activity is either modified or control mechanisms are implemented to manage the impacts, keeping them at levels compliant with objectives.

Without clearly defined overarching remediation objectives, none of the subsequent stages of the remediation process can be developed with accuracy or certainty. Only once the required outcomes are known can processes be developed to meet these objectives.

Implementation of remediation activities typically includes:

— Treatment of mine waters and tailings waters;
— Remediation of aquifers, particularly those affected by ISL operations;
— Mine site remediation;
— Relocation and/or covering of waste rock;
— Dewatering and covering of tailings (with planting of vegetation);
— Decontamination of equipment and contaminated areas;
— Revegetation;
— Transfer of remediated areas to local communities for reuse.

Environmental monitoring (water, radon, dust, etc.) is required during and after remediation. Monitoring is essential to assess the performance of remediation measures and to predict current and future risks.

6.5. SOCIAL ISSUES

One of the biggest challenges is the socially acceptable reduction of the workforce. In the human resources area, job creation schemes (job conversion training programmes) are an important element. These require forward planning, communication with the workforce and cooperation with regional employment authorities. Other important activities are:

— Assessment of health impacts from former operations;
— Epidemiological studies;
— Assessment of social impacts (infrastructure, pension plans);
— Social plan for closure (pension plan, new jobs, etc.);
— Replacement by other industrial operations;

— Revitalization of old mining land for subsequent beneficial land use through evaluation of possible options (use as recreation areas, golf courses, industrial parks, etc.);
— Public relations activities (information centres, posters, presentations);
— Education and training (e.g. training courses by the IAEA).

7. RECOMMENDATIONS

Following discussions contained within this document, the following recommendations have been drawn up with regard to sustainable development for uranium mining and processing operations. It is hoped these recommendations will be adopted by relevant stakeholders, if they have not already done so.

Member States/governments

Governments need to:

— Develop consistent energy policies;
— Develop mining and mineral processing regulations that are not so stringent that they set up the energy policy for failure;
— Establish radiation and environmental protection regulations to protect all stakeholders, but at the same time which are not so restrictive that they prevent the operation of a mine or mill;
— Adopt international standards for a consistent approach to environmental, health and safety issues in all aspects of operations and between national regulatory authorities;
— Develop decommissioning rules and regulations which, while protecting the environment do not to effectively prohibit mining and mineral processing;
— Ensure that levels of royalties are fair and that funds obtained are distributed to stakeholders to allow for sustainability of mining and processing operations.

Companies

Mining and mineral processing companies need to undertake the following activities:

— Complete (1) a stakeholder identification and needs analysis study, and (2) an environmental, social and economic impact and risk analysis;
— Where aboriginal or other groups of native people and local populations may be involved in a development, companies must consult with these groups to determine their expectations and negotiate agreements to optimize benefits to all parties;
— Demonstrate that they have sufficient technical and financial resources to ensure the sustainable development of an operation;
— Consult and communicate with stakeholders at the local community level in an open and transparent manner, provide information to these stakeholders and provide education and training where necessary to assist them in better understanding mining and mineral processing operations, thus enabling them to make informed decisions;
— Define sustainable development policy and develop actions that improve environmental, social, and economic performance of a company;
— Develop standards for collecting, measuring and analysing data, and communicating results to stakeholders;
— Adopt programmes (eg. ISO 14000) that can be used to demonstrate compliance with environmental requirements and commitment to continual improvement in environmental performance.

Communities

The local communities and stakeholders around a mine development need to:

- Recognize that companies need to be profitable for both the community and company to benefit from the mining and processing operations;
- Develop their own plans for sustainable development and negotiate with mining companies to develop joint plans for mutual benefit;
- Recognize that mining operations have a limited life expectancy. Benefits from the mine should be applied to the long term benefit of the community.

8. CASE STUDIES

While tailings deposition strategies are continuing to evolve, two examples of successful decommissioning and closure, undertaken immediately following the cessation of mining and mill operations, took place in Australia. In these examples, a decommissioning plan was developed prior to or during operation. The two mines (Mary Kathleen Uranium and Nabarlek) are also of interest as they offer examples of remediation in dry and wet tropical environments, respectively. Further case studies are also discussed where 'hindsight' decommissioning has been successful.

8.1. THE AUSTRALIAN EXPERIENCE

8.1.1. Remediation in a dry climate — Mary Kathleen Uranium

Operation

Mary Kathleen uranium mine (MKU) is located near Mount Isa in northwest Queensland. The climate is dry with average annual rainfall and evaporation of 450 mm and 2 700 mm, respectively. Rainfall is highly variable, falling mostly in summer as localized storms or under monsoonal influence. Artesian bores provide the major source of water in the region but it is generally suitable only for stock watering purposes.

A total of 31 million tonnes of material was recovered from the open pit, including 7 million tonnes of ore at an average grade of 0.2% U_3O_8. This left an open cut roughly circular in shape with an area of about 25 ha and a depth of 230 m. After radiometric sorting, the ore was processed by conventional acid leaching. Tailings were pumped, as acidic slurry, to the tailings dam about 1.5 km from the mill. Tailings were deposited using the beaching method.

The tailings dam was constructed across a narrow section of valley and had a retention area of about 30 ha. Two intermediate embankments were constructed, effectively dividing the dam into three sections at different levels. This enabled the final slope of the tailings surface to be kept to about 1 in 200 to minimize erosion. Water from the lower dam was decanted into evaporation ponds with a total area of 60 ha and a capacity of 2.5×10^6 m^3. Seepage control was an important aspect of both operational and rehabilitation phases. The principal seepage path under the evaporation pond wall was along the original streambed. This was impounded in a collection pond and pumped back to the evaporation pond or to the treatment plant for reuse.

Decommissioning of mine and mill

Uncontaminated, discarded equipment was disposed of at the bottom of the mine. Access roads to the pit were blocked off and the pit was filled with water to a depth of 50 m. Useful structures and equipment in the mill were decontaminated and sold. The remaining contaminated equipment was buried in the tailings dam.

Tailings and water management

The tailings dam and evaporation pond were covered with a 0.5 m layer of compacted soil/clay mixture, followed by a 1 m layer of waste rock. The rock layers were leveled, contoured and seeded. Radon flux data for the design of the cover system and leaching rates of tailings were provided by the Australian Nuclear Science and Technology Organisation (ANSTO) [27, 28].

To accelerate the decommissioning process, several steps were employed to reduce the volume of water in the evaporation ponds. Infiltration trenches were dug in alkaline clays where neutralization and cation exchange rapidly improved the water quality of any seepage. Seepage from the trenches was collected using a borehole system and pumped back into the mine pit.

Seven hectares of additional evaporation area were built around the perimeters of the original evaporation ponds to compensate for a lower than expected infiltration rate into the trenches. The remaining liquid in the temporary evaporation area was then treated with finely crushed limestone to precipitate dissolved salts and radionuclides. Following a drying period, soil and waste rock were added to the resulting precipitate to assist solidification and provide a suitable base for cover material. This material was placed in the tailings area and covered with soil and waste rock. The infiltration trenches were cleaned up and revegetated.

Waste rock piles

Waste rock piles and ore sorter rejects totaled about 24×10^6 t and occupied an area of about 64 ha. The surfaces of the piles were leveled and covered with a layer of rock containing sufficient fine material to promote growth and attenuate radiation levels.

Monitoring

Detailed monitoring was undertaken throughout the rehabilitation work, which took place over three years. Following a year of post rehabilitation monitoring, the programme was revised to a surveillance level. For example, monitoring of surface and groundwater near the tailings and evaporation ponds was undertaken for two years following cleanup. This involved monitoring levels of seepage from the tailings storage area into the groundwater and levels of surface seepage flow to establish long term stability of the dam embankment, chemical analysis of sediment deposited along the initial section of the drainage line and water quality studies.

Radon concentrations in air were measured by Tracketch® continuous sampling units at stations located around the perimeter of the area. Radon levels were found to be significantly below the required limits. Gamma radiation measurements taken in the year following rehabilitation showed the levels to be below the allowable limit for the general public.

Cost of rehabilitation

The total cost of the entire rehabilitation project was in excess of $A18 million. The project was successfully completed in 1984 without any subsequent requirements for institutional control, and received an environmental award for excellence.

8.1.2. Remediation in a humid tropical climate — Nabarlek

Operation

The Nabarlek mine and mill in Australia is probably the first example of successful closure of an in-pit disposal facility for uranium tailings. Queensland Mines Limited (QML) commenced mining at Nabarlek in 1979 and the facility can be considered to be of the same generation as the initial Cluff Lake, Rabbit Lake and Key Lake operations.

The Nabarlek ore body was located in Arnhem Land, an Aboriginal Reserve about 60 km NE of the Ranger mine and 300 km east of Darwin. The climate at Nabarlek is similar to that at Ranger. Because of the high grade and relatively small size of the Nabarlek deposit, a rapid mining technique was used to recover all the ore in four months of one dry season. This ore was stockpiled for subsequent treatment. Open cut mining was completed in October 1979. The milling operation began in March 1980 and was completed in June of 1988, with a small heap leach operation continuing for another 12 months.

The mining operation produced 2.3 million t of waste rock and 600 000 t of ore at an average grade of 2.9%. During the mining operation, ore and below ore grade material was placed on temporary stockpiles, while waste rock was used to construct the permanent stockpile pad and water retention ponds. Top soil and remaining waste rock were stockpiled separately for use in remediation at project completion. Local clays were used to provide an impervious liner over the stockpile pad. When all the ore was placed on the stockpile, the top was sealed with compacted impervious clay and the whole stockpile was covered with shotcrete (a spray-on cement based cover material) to reduce wet season water ingress, erosion, dust losses, and gamma and radon emanations.

As for Ranger, water management was a major issue at Nabarlek. The plant, stockpile, open pit, two runoff and two evaporation ponds were all located within a restricted release zone (RRZ) and no water was allowed to leave this area, except by evaporation and unavoidable seepage. The runoff ponds were meant to retain rain that fell within the plant and stockpile areas; this water was used for plant makeup.

Decommissioning and remediation

When the ore stockpile was exhausted in 1988, the plant was placed in a care and maintenance state while further exploration was undertaken. No suitable ore body was found, and in 1994 the company was instructed to commence work to ensure decommissioning would be complete by the end of 1995. Decommissioning and remediation of some areas of the site had already begun in 1989.

The overall remediation objective was that the landform should be stable, safe and blend into the surrounding countryside. There was also to be no limitation on the site for traditional hunting and food gathering activities, which would include occasional overnight camping. An occupancy factor of 10% was agreed upon for dose rate calculations.

When the plant was dismantled, it was thoroughly cleaned and motors and instruments removed. Each major item was inspected to estimate the amount of decontamination work required and to assess whether sale or disposal was the more economic alternative. All pipe works, overhead gantries and similar structures were deposited in the pit.

Once the mechanical plant had been removed from the site, the foundations were removed. All surplus concrete was removed to the pit, with anything deeper than 1 metre left in place and covered with a layer of either clean waste rock or laterite. The area was then leveled to an approximation of the original surface contours, covered with top soil and revegetated.

Standards for radiological decontamination were set down by the Northern Territory Department of Mines and Energy. Items were decontaminated by sand blasting, scraping, washing and high pressure hosing. All cleaning residues were also placed in the pit.

Disposal in the pit of material from the plant was conducted on the basis that at the end of decommissioning the upper level of waste would be below the base of the weathered profile and, therefore, unlikely to have a significant influence on the water quality of the near surface aquifer. Again, as these materials were placed in the pit, water flowed from the wicks that had been placed in the tailings in 1989 and assisted further settlement of the tailings within the pit.

Tailings management

Uranium was extracted by acid leaching at pH1.5. The acidic tailings slurry was neutralized with lime to ~ pH8 and discharged in the mined out pit via the sub-aqueous technique used from the commencement of milling. The pit required very little work in preparation to receive the tailings.

Like Ranger, operating authorization required a 2 m cover of water. Under these conditions the expected consolidation of tailings within the pit was not being obtained. In 1985, QML sought and received permission for the use of the sub-aerial method of deposition. Because of constraints posed by the shape of the pit, the end result was a combination of beach discharge and sub-aerial techniques. To improve the efficiency of tailings deposition, and reduce the volume of water entering the pit, a thickener was installed adjacent to the pit to increase the density of slurry discharge. This was to counter the effect of the additional water added to the slurry to facilitate pumping to the pit.

When ore processing was completed in 1988, the overall density of the 60 m deep tailings in the pit was 0.90 to 0.95 $t{\cdot}m^{-3}$. The predicted settled density after final compaction and settlement was 1.1 to 1.2 $t{\cdot}m^{-3}$. The estimated time for natural drainage to achieve the desired removal of water from the interstices exceeded 10 years. The method chosen to accelerate drainage and consequent settlement of the tailings was the installation of vertical strip drains, known as wicks.

Differential settlement was also a potential problem, exacerbated by the change in tailings deposition method, which had led to lenses of less dense material spread randomly throughout the tailings mass.

The installation of wicks required access by heavy machinery (up to 60 t) onto the tailings surface. The change to semi-dry discharge of tailings in 1985 was partially successful in that when the tailings were allowed to dry at the surface and consolidate under their own weight for about the first eight months, access by light vehicle was possible.

The procedure used for installation of the wicks was as follows. After allowing the surface of the tailings to dry for two to three weeks, a layer of geo-textile was placed on the surface. This was covered by a layer of free draining, graded rock. The best substance for this cover was bogum material (below ore trade unraniferous material), mined rock from which the fine material had been removed for treatment by heap leaching. As this material was in short supply, it was supplemented by finer, but still free draining material from the waste rock stockpile. The average depth of fill material on the tailings was 2 m, compared to the design thickness of 1.5 m. The wicks were then driven to depths of up to 30 m with about 3 m centres in a rectangular grid pattern.

During installation, almost every wick immediately ran with water. The expelled water collected in the pit and was pumped away for radium removal and then passed to an evaporation pond. The wicks continued to run for some months before settlement of the tailings slowed.

After receiving the waste arising from decommissioning, the pit was finally remediated through application of a covering with more than 13 m of waste rock,, which was then planted with locally collected seeds. The cover design and revegetation strategy are described in detail elsewhere.

Modeling has shown that the pit cover should remain viable for at least 10 000 years, and erosion studies of surrounding landforms suggest that the tailings will stay contained for at least 100 000 years. Infiltration of groundwater is a potential problem for sub-grade disposal of tailings. At Nabarlek, the pit was relatively impermeable, confirmed by monitoring during the operational phase, and major water movement from the tailings was not expected, except over a very long term.

Water management

During operations decant waters from tailings in the pit were recycled to the mill via a storage pond. Excess pit water was treated with barium chloride to remove radium and passed through a clarifier to remove the radium/barium sulfate precipitate. The treated water was pumped to an evaporation pond and the precipitate was returned to the pit.

The water management system was designed for no release of process/tailings water, but as the system failed to stay in balance through evaporation alone, a programme of irrigating the least contaminated waters onto bush land was attempted. However, the water contained relatively high levels of ammonium sulfate, which led to adverse impacts on the ground water and vegetation in the irrigation areas. Irrigation was then restricted to specially planted grass paddocks at the side of the airstrip. Subsequently, the original irrigation area was cleared and reseeded with local species, and was in the process of returning to its original state. After some setbacks due to bush fires, additional tree planting was undertaken in the wet seasons of 2001/2 and 2002/3 to try to speed up establishment of a vegetation cover that would be acceptable to the native people and to regulating authorities. Tree planting continued as an annual activity but Cyclone Monica leveled all vegetation in the area in March 2006 and subsequent regrowth has been slow. To speed up regeneration of the tree cover enrichment, planting of suitable tree seedlings is being undertaken by the mining company for the next few years.

About 10^6 m^3 of water was in the system at the end of the ore processing operation, after disposal of some 400 000 m^3 by irrigation, as mentioned above. Mine water management ponds were allowed to evaporate to dryness in 1992, allowing the bottom of the ponds to be scraped to remove sediments and salt residues (mainly ammonium sulfate), which were deposited in the pit. The increased load on the tailings surface caused the drains to start running again. Water in the pit was recirculated through an irrigation system on the inner faces of the pit walls as a means of enhancing evaporation.

Revegetation

Earthwork to shape the final landform commenced in mid-1995. This included collapsing the dried out water management ponds, filling the pit with waste rock, redistribution of soil and seeding. More detailed descriptions of the various works are given in Refs [29–31].

Starting in 1996, the site was allowed to revegetate with a minimum amount of management. The only active elements were the annual weed control programme, an annual campaign to repair erosion damage and the maintenance of fire breaks.

Closure

The decommissioning and final landform earthwork have been successfully completed at Nabarlek. Revegetation is proceeding slowly and unevenly across the site. The long term prognosis for the site is good, but it may require enhancement through a period of active management concentrating on erosion control, fire management, and weed and feral animal control.

A final issue requiring resolution is the long term stewardship at Nabarlek. This is being actively debated by the stakeholders, including the regulating authority, the Commonwealth Government and the Aboriginal Traditional Owners.

8.2. FURTHER CASE STUDIES

The situation in France is also worthy of mention. Cogema had been mining and extracting uranium since 1946 and has decommissioned all its sites. With the decision to discontinue uranium mining in France, the remaining major milling sites and impoundments were decommissioned. These sites had operated for many years, and at the time of their construction pre-planning for decommissioning was not as rigorous as current requirements. Nonetheless, detailed studies were undertaken to develop generic and site specific remediation techniques, which have already been successfully applied to many of the sites [23, 32, 33].

The ability to resolve legacy issues is important for public and stakeholder confidence in environmental sustainability. While proper planning and management should eliminate such problems, if it can be demonstrated that technology is available to reverse the effects of minimal environmental management and even abandonment, the credibility and commitment of the industry will be enhanced. Projects in progress in Eastern Europe and Central Asia illustrate solutions to a range of such problems.

One example of remediation of an abandoned site is Rum Jungle in Australia. The processing operation ceased in 1971. An initial cleanup of the site was carried out in 1977, but major pollution issues were not addressed until a government funded remediation project commenced in 1983. Acid mine drainage arising from pyritic minerals in the waste rock dumps was the main source of pollution. In the early years after completion of the cleanup, the remediation was regarded as a great success. The effectiveness of the remediation was monitored for a number of years and then the level of scrutiny was allowed to fall. However, observations in more recent times have indicated that the remediation is failing [34]. Further studies were undertaken by federal government experts between 2003 and 2006 to assess the situation and a plan of action is being prepared.

8.3. CASE HISTORIES — SOCIAL ISSUES

This section uses detailed examples of mining operations from four different areas which illustrate both the successes and failures of various approaches of introducing uranium mining and milling operations into communities. Also included are a range of examples from Alaska of sustainable mineral development involving First Nations people.

8.3.1. Northern Saskatchewan, Canada

Northern Saskatchewan comprises an area of about 350 000 km^2. In 1951 the population was 11 000 people but by 2003 it was approaching 40 000, of whom about 87% are aboriginal, consisting of either First Nations or Métis people. The first uranium mining area developed in northern Saskatchewan was Uranium City, north of Lake Athabasca, at about 59º 30' north latitude. It is on the Canadian Shield and characterized by large rock outcrops and small pockets of soil, together with many small rocky lakes. These first mines started production in the early 1950s. Of the 10 producing mines, only Eldorado Nuclear remained in operation after 1965. The development of Uranium City, including better services such as a hospital, drew some aboriginals into the area. There was some aboriginal employment in the early mines but, with few exceptions, these employees only stayed a short time.

All of the more recent uranium developments have been in the Athabasca Sandstone Basin, south of Lake Athabasca. The sandy soil, low in nutrients, the cold climate, and the lack of precipitation result in an area of very slow growing vegetation and relatively low numbers of game animals. The one exception is caribou, which have an annual migration involving the passage of thousands of animals through the northern part of the basin. Even today there are few communities permanently settled within the Athabasca Sandstone Basin.

The native people here tended to be semi-nomadic, fishing in summer and following the caribou in winter. After the treaties were signed (1899, 1906–1907), the government encouraged the development of permanent communities to more efficiently deliver the services required under the treaties. It was only in about 1960 that the last of these small nomadic bands settled in a permanent community. The result of this settlement and the improved delivery of services such as health care led to a drastic reduction in infant mortality. However, with little reduction in birth rate there has been a significant increase in population growth. One consequence of this population growth is that the traditional lifestyle of the past is no longer sustainable.

The second generation of mines in the Athabasca Sandstone started with Rabbit Lake (Gulf Minerals, now Cameco Corporation) in 1974, to be followed by Cluff Lake (Amok, now Areva) in 1980 and Key Lake (Key Lake Mining Corporation, now Cameco) in 1983. The more recent projects are McClean Lake (Areva) in 1999, McArthur River (Cameco) in 1999, and Cigar Lake (Cameco), still under development. The Cluff Lake project was subjected to an extensive provincial Board of Inquiry in 1978 that examined all elements of the development, including safety, environmental, social and ethical aspects. A similar inquiry was held for the Key Lake project in 1981.

In order to ensure that local aboriginal people would benefit properly from these mine developments, the government made a specific level of aboriginal employment a condition of the mining licences. An issue arose because many local people had no technical background and had never been employed in a wage earning environment.

The mining companies developed training programmes to prepare aboriginals for regular, wage earning jobs. This included lifestyle training such as how to manage personal finances. Further extensive training programmes were required on the job to help these employees become fully contributing members of the workforce, who could advance in their jobs, expand their job opportunities and earnings, and in order to reduce turnover. In return, the companies received agreement from the government to eliminate hard quotas; instead they were asked to exert their best effort to increase RSN employment. Apprenticeship programmes were developed to train more tradesmen and special agreements were made with labour unions to allow more RSN participation in the apprenticeship programmes with less emphasis on union seniority. A joint Federal–Provincial industrial training programme was developed to train people specifically for jobs in the uranium industry. A community college in northern Saskatchewan was created with assistance of the mining companies; courses were specifically designed to produce graduates with technical skills needed by the mining operations. The mining companies have several programmes designed to encourage northern students to remain in school, including university scholarships. The objective is to produce more scientifically trained aboriginals to take professional jobs at the mines.

At the same time the companies set their own objectives for increasing RSN employment. They also applied these objectives to their suppliers and contractors. These programmes have slowly yielded positive results. By 2000, RSN participation in the workforce at the uranium mines was about 50%, with increased numbers in the trades and technical areas and even a few supervisory staff. The turnover in RSN employees is equal to or less than that among employees coming from the southern part of the country, resulting in reduced personnel costs and more efficient operations.

A second area of development has been the service industries. A remote mine requires numerous services that are not readily available, such as transportation, supplies, catering, laundry, etc. The mine can develop all these services itself, which requires greater capital investment and a larger number of employees, or it can look at other ways of achieving desired services. The approach taken in this case was to encourage partnerships between experienced service suppliers in southern Saskatchewan and more entrepreneurial aboriginal bands to develop service industries that were not solely dependent upon the mines for their business. The first major success was Northern Resource Trucking, which partnered a major trucking company with an aboriginal band. That trucking company has evolved over the past 20 years and is now 71% owned by aboriginals and employs over 120 people. It is now a multimillion dollar per year business, supplying services to all northern mines. Business partnerships have further developed, and today northern companies are involved in 15 different supply sectors, including catering, construction, contract underground mining, aviation, environmental management, maintenance contracting and exploration. About 70% of all services required to support the mining operations are now provided by companies that have majority ownership in northern Saskatchewan.

The effort to train aboriginal tradesmen has benefits beyond the workplace. Electricians, pipe fitters, mechanics and welders have a vital part to play in their own communities as these northern areas become more modern and demand more amenities.

One major hurdle in the development of Saskatchewan uranium mines in particular has been the lack of technical understanding of the product and its use. Although education levels among the northern population are improving, technical/scientific training is lagging far behind the southern, urban school system. The use of uranium in the fission process to generate electricity and the management of radioactive wastes are difficult concepts for well educated people to deal with. The environmental assessment process in Canada requires public hearings. These hearings have become major educational undertakings in order to allow the people closest to the new uranium operations to glean some understanding of what is being done and how the product is being used. This has necessitated major outreach programmes on the part of the mining companies to maintain contact with aboriginal communities and continue raising awareness of the mining business.

The question of accommodating mine staff is a complex one, including several options. The first option, a company town, can be developed adjacent to the mine site. It is owned by the company and accommodates everyone who works at the mine and in its service industries. This can result in lower cost accommodation for mine staff with the benefit of no personal capital investment that cannot be recouped after mine closure. The capital cost to the mining company is higher; there is an administrative cost to managing and maintaining many houses, apartments and bunkhouses, and the decommissioning problem at the end of mine life is bigger. Initial developments in northern Saskatchewan were based on the company town concept. At the time there were 25 or more advanced exploration projects in the Uranium City area, 10 of which developed into producing mines.

The provincial government believed that development of company towns exacerbated the boom-bust cycle associated with mining, and developed the second option, incorporating Uranium City as a regional municipality, and forbidding further development of company towns in the area. While this spurred commercial growth in the area and likely expanded amenities beyond what would have been expected of the mining companies, it created serious problems when the last mine closed. Businesses that had flourished when the mines were in full production were suddenly valueless. People who had built their own houses suddenly found there was no market for them when they wanted to leave the area. Hence, although there were advantages to developing a regional municipality rather than a company town, the financial impact of mine closure was shifted from the mining company to the people living in the municipality.

The third option, which is now used at all Saskatchewan uranium mines, is a fly-in camp with workers spending one week on-site and one week off-site The capital cost of accommodation is shifted back to the mining company and is clearly lower than building houses or apartments, but the cost of transport to and from the mine site is increased.

8.3.2. Alligator Rivers Area — ERA experience

The Kakadu Region Social Impact Study (KRSIS) was commissioned in 1996 as an outcome of the environmental impact assessment process associated with the proposed Jabiluka uranium mine. The objective of

KRSIS was to provide "a clear statement of aboriginal experiences, values and aspirations regarding development of the region; and a proposed community development programme to enhance and/or mitigate impacts associated with development of the region".

Key stakeholders represented in overseeing the study included the Northern Land Council, the aboriginal community, Energy Resources of Australia (ERA) and the Northern Territory (NT) and Commonwealth governments. The study was jointly funded by the Australian government and Energy Resources of Australia, the mining company owning the Ranger and Jabiluka uranium interests.

KRSIS reported on 18 issues of major significance in November 2000 and, while progress has been made in responding to these recommendations, a number have been incorporated into continuing programmes by both the Commonwealth (Federal) and Northern Territory governments.

It has been accepted that the township of Jabiru could not remain a closed mining town (the original concept), and the town's future as a regional centre was discussed at a series of community forums. A major issue has been to increase the level of involvement in town development by aboriginal people, especially the traditional landowners. This is also being addressed through specific actions of the Jabiru Sustainability Working Group (JSWG).

JSWG was first mooted in October, 2002 by the native people and came into being in January, 2003. The group employs a professional researcher/project officer. The terms of reference of the group include: having the town slated as aboriginal land, establishing new governance rules about who can 'speak for country' among the population, establishment of non-mining activities to provide an economic future, security of tenure for businesses, and sustainability of the town in its post-mining phase.

Issues of governance and service provision were a significant part of the KRSIS report. Many of these are being addressed through a recently established agency in the NT government called the Department of Community Development, Sport and Cultural Affairs, which is responsible for provision of essential aboriginal community services. All earlier agencies have effectively been streamlined into one for funding purposes through this action, which has also been seen as a way to maximize aboriginal employment opportunities. Regional development has been identified as a priority policy area by the NT government.

In the area of education, new special funding was announced for an Aboriginal Education Unit, which commenced with a planning and consultation phase in mid-2001. The programme has since been renamed the Indigenous Heritage Education Project. New elements of the programme implemented to date have included outstation and home liaison visits for children speaking the local language, assistance with transport, school uniforms, a homework centre and school meals. All of these are considered to be successful so far. There has also been emphasis on use of appropriate teaching methods and introduction of inclusive curriculum practices. It was anticipated that when the Commonwealth funding programme ended with the 2004 academic year, the NT government would assume responsibility for all aspects of this initiative.

There have been efforts made by all local employers, both in the public and private sectors, to increase levels of employment and training for local aboriginal people. The federal government has been active in this area. For example, in Kakadu National Park, 44% of Parks Australia employees are aboriginal. In addition, the Supervising Scientist Division is operating an aboriginal employment and training programme, which emphasizes skills that are of use in a wide range of employment areas, e.g. four wheel driving, fork lift truck operation, etc. The local hotel runs very successful training courses in hospitality skills. Aboriginal graduates have a completion rate of 75% or more. Work placements are being found, but retention rates are less than hoped for. Reasons for this have been identified and are being addressed where possible. There are training programmes for tour guides to service the growing ecotourism market and ERA has a very active aboriginal employment strategy.

There is also a Community Development and Employment Programme, which provides short-term employment opportunities and training in a number of areas. The structured Training and Employment Programme offers training in car mechanics, tourism and child care employment as well as drug and alcohol counselling services. There are also language and literacy programmes in place, which are considered to have had successful outcomes. With respect to housing and infrastructure problems, there has been a considerable volume of upgrading, repair and maintenance work carried out, mostly coordinated by the Kakadu Housing and Infrastructure Group. The Indigenous Housing Authority of the NT and the National Aboriginal Housing Strategy programmes have taken over much of the work on outstation properties as well as providing building trades training for a number of local aboriginal people.

Health services are now organized by a local aboriginal association on behalf of the NT government as a combined service, including primary health and aged care programmes. There has been an extensive programme for health education as well as provision of specialist support in the form of alcohol and drug counselling, a culturally competent health service programme, health workshops and information sessions, and a patient transport service. There are plans to establish a women's refuge when funding can be secured. An overnight shelter for alcohol affected people and a night patrol service have also been established, although staffing has been a problem at times.

For younger people, an enhanced programme of sport and recreation activities has been created. This included employment of a full time officer to manage the programme. Unfortunately, funding for this programme has lapsed and so effort is maintained at a much lower level than previously.

Cultural issues are of great concern to aboriginal people and it has been agreed that a culturally appropriate Women's Resource Centre will be established in Jabiru. A site was identified and building works were scheduled to be completed in 2003/2004. In the same category, it has been agreed that the Commonwealth will examine the concept of 'cultural leave' provisions being added to the working conditions of aboriginal employees in the region.

A major issue for KRSIS has been communication. A great deal of effort has been going into providing more appropriate communication with, and specifically targeted at, aboriginal people in the region. The ERA, the Commonwealth government's Environmental Research Institute of the Supervising Scientist (ERISS) and the Kakadu National Park Board of Management are all applying resources to this matter. Special open days at offices and facilities and displays at community open days as well as community consultation visits and newsletters are all being employed in this arena.

A key element of the overall plan is to establish an aboriginal economic development plan, known as the Kakadu Regional Economic Development Strategy (KREDS). An early version of KREDS identified tourism as an area providing opportunities for sustainable indigenous social and economic development, although within the region this industry has not developed at the same pace as the rest of the NT. Also, potential benefits to traditional aboriginal owners have generally been rather limited for a variety of reasons. The plan is to pursue this development option more vigorously in the future. Some business opportunities have been identified, including a minibus and taxi service around the park.

It was agreed in KRSIS that social impact monitoring should be considered essential in the future. To date, it has proven very difficult to obtain adequate funding for this work, and to determine who or what sort of organization should be in charge of progress in this area. To date, negotiations continue between representatives of the native people and Parks Australia as to what suitable performance indicators there are for social impact monitoring. It is likely that external consultants will be required to resolve this matter.

8.3.3. Alaska — Doyon, Limited and the Red Dog experience

Alaska, the northernmost state of the USA, provides a range of examples of sustainable mineral resource development involving aboriginal people. For several decades the aboriginal people of Alaska have been active participants in efforts to integrate mineral development with traditional lifestyles. This opportunity is the result of an innovative agreement between Alaska's native people and the US Government designed to integrate native interests into the economic development of the state while preserving traditional native culture.

Alaska was purchased from Russia in 1867, but it was not until 1971 that the US government reached a settlement with Alaska's native people. This was formalized as the Alaska Native Claims Settlement Act (ANCSA), an act of the US Congress that provided land, cash, and other rights and obligations to Alaska natives. As part of ANCSA, the state was divided into 12 separate geographical regions representative of the ethnic variety of Alaska's native population (Alaska Miners Association, 2003 Handbook and Service Directory; www.alaskaminers.org). Within each region a privately held corporation was established; these were owned and managed principally by natives who could demonstrate a relationship to the respective ethnic group. These corporations are known as 'regional corporations' and their native American owners are 'shareholders'. Each regional corporation was given land, mineral rights, and cash. Each regional corporation received a different amount of each, largely determined by the number of shareholders and the extent of the region. The regional corporations have both social and economic obligations to their shareholders. Within each region approximately 10 to 15% of the land was provided to the natives in a number of distinct parcels distributed across the region.

Some land was provided in areas of traditional native habitation, such as near native villages, allowing a continuation of traditional lifestyles. For various reasons, some corporations were allowed to select some of their land from the public domain for other purposes. A number of corporations selected land for resource development, recognizing the value this could bring to the economic well-being of their shareholders. In total, approximately 44 million acres (17.8 Mha) of land was provided to the regional corporations, equaling about 12.5% of the area of the state. This land provides an opportunity to pursue a traditional subsistence lifestyle for those who desire such activity, while at the same time providing a base for contemporary economic development.

Three regional corporations provide examples of evolving approaches to sustainable development. Two corporations, Doyon, Limited and Calista Corporation, are discussed briefly, as mineral development is in the exploration and development stage for these companies. The third corporation, NANA Development Corporation, is discussed in greater detail, as its land contains the largest zinc mine and deposit in the world and it demonstrates a commitment to sustainable mineral development dating back to 1982.

8.3.3.1. Doyon, Limited (Doyon)

Doyon is the regional corporation representing a large area in interior Alaska (www.Doyon.com). Doyon has approximately 11 000 shareholders. The company has rights to approximately 12.5 million acres (5 Mha) of land distributed in about 50 parcels across about 300 000 square miles (777 300 square km). The region has an abundance of mineral occurrences and a rich history of mining. Doyon selected a significant fraction of its land for its mineral potential. Many of the mineral occurrences are located near traditional native villages. Recognizing this, Doyon has developed, with the mineral industry, a systematic, village sensitive process of encouraging responsible mineral development. It structures exploration and development agreements to allow balancing local village interests with those of all shareholders. Agreements generally contain provisions for native training and hire, scholarships for shareholders, and preferential contracting opportunities for native owned service companies. Doyon recognizes that many of its rural shareholders prefer to live in their traditional villages and that nearby resource development provides one of the few opportunities for employment that will allow continuation of lifestyles emphasizing a close association with the land, its fish, and its wildlife.

8.3.3.2. Calista Corporation (Calista)

Calista is a regional corporation that owns approximately 6.5 million acres (2.63 Mha) of land, distributed across a region of approximately 56 000 square miles (145 000 square km) in southwestern Alaska (www.Calistacorp.com). Calista has over 13 000 shareholders, many living in 56 villages distributed across a region having a population of about 20 000. The Calista region has a history of placer gold and platinum mining, as well as lode mining for gold, mercury, and other metals. Currently, Calista — in partnership with Barrick Gold (a large international gold mining company) and Nova Gold (an exploration company; www.novagold.net) — is evaluating development of one of the largest gold deposits discovered in North America, the Donlin Creek deposit. Development of this deposit has the potential to dramatically transform the economy of this remote, isolated, economically distressed region. Estimates suggest the mine would have a life of 18 years or more and employ a workforce of several hundred. The deposit is in a sparsely populated area, inaccessible by road, and there is no nearby power source. To provide optimum regional benefit from the development of this resource, the federal government, state government, regional corporations, and other stakeholders have been evaluating various development scenarios. Power and access are two paramount issues. Development scenarios include using the mine's power requirements as a key reason to expand the regional electrical network, and new supply infrastructure, such as roads and ports, as elements in an improved regional transportation infrastructure. Mine employees will likely be housed at a fly-in/fly-out camp at the mine. Major considerations in the development include minimizing disruptions to the traditional lifestyle of the local, largely native population while simultaneously providing economic opportunities.

8.3.3.3. NANA Regional Corporation (NANA)–Teck Cominco Red Dog Mine

NANA and Cominco (now Teck Cominco) have been partners in the sustainable development of the Red Dog zinc-lead deposit in northwest Alaska for over 20 years. NANA is the owner of the ore deposit while Teck Cominco is the operator.

NANA is a native regional corporation with approximately 2.3 million acres (931 200 ha) of land distributed across a region of approximately 38 000 square miles (98 461 square km) (www.NANA.com). There are 11 predominantly native villages in the region, with populations ranging from 100 to 3700. NANA has approximately 7500 shareholders, with about 6600 living a subsistence oriented lifestyle within the region. The NANA region is bisected by the Arctic Circle. There are no roads into the region from outside commercial centres. Access is by air, water, or snow machine. This isolation has assisted in allowing continuation of a traditional lifestyle to the present day. The terrain ranges from rugged mountains to vast expanses of tundra, with extensive Arctic Ocean seacoast and rivers. Villages tend to be along the rivers and the coast and inhabitants depend on fish and other wildlife for maintaining subsistence lifestyle activities. Summers are short and winters are up to nine months long and severely cold; up to –40°F. The ancestors of NANA shareholders have occupied the region for over 10 000 years. Even today, those living in the region strive to maintain key elements of their culture, including a subsistence lifestyle. A desire to continue this relationship with the land provides NANA shareholders an incentive to protect the natural resources of the region.

The Red Dog operations include a mine, a mill, a fly-in/fly-out camp for workers to stay on site, a port on the Arctic Ocean, and an 86 km stretch of road connecting the port and the mine-mill site. The operations produce concentrates, which are hauled to the coast and stored, then shipped from the port during the brief summer season when the port is free of ice.

Mineralization at what became the Red Dog deposit was recognized as early as the 1960s. Cominco began exploration of the area in the 1970s. In 1980, NANA selected a 12 square mile parcel of land containing the deposit as part of its ANCSA entitlement. In 1982 NANA and Cominco entered into a joint development agreement for the deposit. The underlying development consideration for NANA was to have the mine contribute to the development of sustainable communities within the NANA region. This included creating job opportunities in a modern economy and simultaneously preserving culture, language, and subsistence lifestyle traditions.

The development agreement requires Cominco to finance, construct, and operate the mine and mill, market the concentrates, and provide a range of benefits to NANA. These benefits include training and employment of NANA shareholders, payment of royalties and other fees, and participation in decision making with respect to operational activities impacting the NANA region.

Teck Cominco follows a strategy with five elements to sustainable development: empowering people; respecting community values, culture, and traditional economics; developing and internalizing capabilities; equity in benefit sharing, and; protecting the environment. Key applications of these concepts at Red Dog are discussed briefly below.

— **Empowering people:** Teck Cominco and NANA established at an early stage, and continues to maintain, a number of committees and other opportunities to allow input from all appropriate stakeholders, providing an opportunity to develop shared goals.

— **Respecting community values, culture, and traditional economics:** the NANA-Teck Cominco agreement contains provisions to protect the natural resources important to the subsistence lifestyle of the region's residents and also provides for flexible work schedules to allow pursuit of this lifestyle.

— **Developing and internalising capabilities:** NANA and Teck Cominco have established training programmes to provide NANA shareholders the opportunity to acquire the skills necessary to work in most positions at the mine and mill complex. Off-site educational programmes are also supported for university and high school education, including educational leave, tuition support, and other benefits.

— **Equity in benefit sharing:** examples of benefit sharing include payments by Teck Cominco to various local and regional government agencies and organisations to support activities important to the region. NANA has also established mine related service and support businesses. These NANA related businesses in turn provide training and jobs for NANA shareholders, developing skills that can be transferred to other employment opportunities.

— **Environmental protection:** while a variety of state and federal regulations direct environmental protection at the mine, NANA and Teck Cominco augment these with additional protections. Chief among these is the Subsistence Committee, which coordinates mine related activity with subsistence considerations. For example, the road route to the port facilities was designed with input from the Subsistence Committee to minimise disruption of caribou migration pathways. Caribou are important to the subsistence lifestyle of NANA shareholders, and the Subsistence Committee continues to provide guidance and will at times recommend temporary suspension of truck traffic to avoid disruption of the caribou migration. The goal of Teck Cominco is to be the environmental model for the mining industry.

The Red Dog mine is expected to operate for at least 40 years. The complex currently employs about 360 people, about 59% of which are NANA shareholders. NANA has developed eight joint ventures to provide support and services to the mine. These include business ventures in housekeeping and food services for the camp, exploration drilling services, explosive supply services, sea barge transportation from Seattle to Alaska, materials testing, and electrical and mechanical services.

Red Dog's benefits to the region are widely recognized. The mine provides employment, educational opportunities, business development opportunities, and support to shareholders and government while maintaining programmes that respect traditional culture.

8.3.4. Niger — Cogema experience

In 1950, a Hungarian geologist prospecting for copper discovered yellow minerals southeast of Arlit, in Niger. Many French prospectors proceeded there, and teams from the French Atomic Energy Commission (CEA) identified the presence of uranium in the 1960s. In 1965, the existence of a deposit on the Arlit site was conclusively established, and SOMAIR, an operating company, decided to build a township, designed for 5 000 inhabitants.

Today, Areva is the principal shareholder of the two companies, SOMAIR and COMINAK, which mine a series of uranium deposits located on the western margin of the Aïr range, in northern Niger. The Arlit region deposits have been mined on a concession of 360 km^2 granted to Areva. The towns of Arlit and Akokan, 8 km apart, have a population of more than 60 000 each. By late 2000, SOMAIR had mined about 40 000 t U from an open pit mine, and COMINAK nearly 45 000 t U from underground deposits.

Areva has a policy of sustainable development which it implements for all its activities, including mining activities in Niger. Many projects aimed at preserving natural resources, protecting local populations and contributing to long term economic development have been initiated and conducted by Areva in partnership with Niger authorities [35], and are discussed below.

Priority is assigned to the employment of local manpower. In Niger, 99% of the jobs are held by natives of Niger, and the maintenance of a minimal expatriate staff helps guarantee the transfer of knowledge and experience. Natives of Niger are also employed elsewhere in the Areva group to promote exchanges of skills.

Like any deposits, those currently mined by SOMAIR and COMINAK will ultimately be depleted. It is therefore necessary to plan now to seek new deposits and participate in the development of new activities. To do this, on 20 March 2003 a rider to the COMINAK mining agreement concerning an extension to the AFASTO west zone was signed by the Minister of Mines and Energy of Niger and the Chief Executive Officer of COMINAK. This rider sets the stage for the forthcoming granting of a prospecting and exploration permit on this zone. In addition to its mining operations, Areva is examining any project likely to upgrade local natural resources and durably maintain economic development in the region.

The mine sites in Niger are located in a desert zone. The two operating companies presently employ 1 650 personnel, representing, with their families, a population of 21 000, distributed in two towns. The two mining companies, which provide free medical care for employees and their families, have built and continue to manage hospitals that are largely open to the rest of the population in the sector. In 2000, the mining companies spent about 2.6 million euros for the two Arlit hospitals to cover personnel costs, and provide medicines and medical services. Support for the employees of the two companies and their families represent two-thirds of the medical services and the operating costs of the two hospitals. The care provided to the rest of the population represents one-third of the services.

In the towns of Arlit and Akouta, COMINAK and SOMAIR also produce and supply drinking water. Consumption of drinking water, pumped from groundwater tables untouched by mining activities, is the focus of optimization programmes. Optimal management of the network and familiarization of consumers with rational use have reduced consumption.

Between 1978 and 1980, with an investment of around 260 million euros, a 685 km sealed road between Tahoua and Arlit was built by the two mining companies to serve the region of Agadez and Arlit from the south of the country.

Finally, to alleviate the serious food crisis affecting Niger in 2000 and 2001, Areva participated in a joint fund of donors, which helped to complete a number of projects, such as the installation of 12 new cereal banks and the revamping of five pastoral wells.

The environmental impacts of mining operations are well known. In a desert zone, there are specific problems which need to be anticipated. Water is the main natural resource impacted by mining activities. The excavation of an open pit or underground mine is always accompanied by perforation of the groundwater table, hence the need to permanently pump accumulated water. This so-called pumping water, unfit for human consumption, is partly used to extract uranium from the ore.

As for drinking water, both mining companies have launched programmes to reduce the amounts of water dumped into the mines. Good practice in this area consists of channelling aquifers during excavation. The techniques employed have been the subject of technology transfer and, thanks to better water management, the quantities extracted from aquifers are steadily decreasing. In a region where there is very low rainfall, and thus no replenishment of natural reservoirs, these actions help to ensure the essential needs of future generations will also be met. During mining operations, everything has been done to improve environmental performance by managing mining reserves as well as possible, by promoting the fight against waste and by systematically recycling reagents and rare resources, thereby helping to decrease releases and wastes generated by mining activities. To do this, SOMAIR and COMINAK have set up environmental management systems meeting the international standard ISO 14001 [35].

COMINAK and SOMAIR are committed to the continuous improvement of their environmental performance and the reduction of negative impacts of their operations. The improvement programmes are specifically concerned with:

— Tailings and their containment;
— Monitoring of radiological exposure of the employees and neighbouring populations;
— Atmospheric releases of fines from uranium ore and radon associated with the uranium mines;
— Management of water resources and treatment of aqueous effluents;
— Recycling or elimination of industrial wastes.

8.3.5. Former centrally planned economies, including the Russian Federation

The current conditions at former uranium mining sites in the Russian Federation are a direct consequence of the Soviet era operation of uranium mines without effective management of the environmental and social aspects of production and without remediation of contaminated areas, much less planning and design for remediation and long term containment of wastes. Mining operations without environmental protection or closure plans were the normal operating approach in the USA and other western countries but the resulting problems were being recognized in the 1960s and most of the legacy sites have since been cleaned up. Similar operating conditions without effective pollution control and closure concepts prevailed at uranium sites in other centrally planned economies such as the Central Asian Republics, East Germany, Czechoslovakia and Hungary prior to 1990.

Currently, many mining areas in eastern and western European countries, including Spain, Hungary and the Czech Republic, have instituted effective remediation standards at major mining sites, including programmes applicable to existing as well as new uranium and other metal mines. These programmes are in areas in which long and active mining traditions provide a set of strong working models for effective environmental controls for current and proposed mines in the Russian Federation and other countries in transition from centrally planned economies.

Several community surveys document hundreds of homes with radiation levels as much as 10 to 20 times the level requiring remedial action under international standards acknowledged by Russian investigators. Radon concentrations were reported to reach from 2800 to 3000 Bq/m^3, compared to a Russian standard of 200 Bq/m^3. The comparable USA standard, the USEPA action level for indoor radon is 4 pCi/l, or approximately 150 Bq/m^3 and the European action level is 200 Bq/m^3. Local plans calling for action resources have not been able to provide a prompt response nor protect and compensate affected families. This large scale problem reflects a pattern in major uranium districts worldwide. Significant examples of some of the most extensive uranium areas in the world where residential radiation exposure problems are as poorly addressed include:

— Southeastern Germany, where tailings and waste rock were used in construction in densely populated areas and in dozens of communities in mining districts, and;
— South Africa, where new housing areas, primarily black townships, were constructed near tailings facilities and in wetlands and floodplains contaminated by tailings seepage.

The mining districts of southeastern Chita, (the Russian Federation) including Baley (thorium contamination) and others, reported high indoor radiation areas such as Krasnokamensk and Nerchinsk, which are among the first population exposures to these worldwide problems identified in the Russian Federation. Effective national and international attention to the severity of local population exposure can help accelerate a response, set a positive standard for the elimination of radiation exposure, and compensate people when appropriate. Local and regional administrative authorities are seeking to ensure that future operations meet the best available international standards (or norms) in terms of environmental technology, prevention of environmental impacts and distribution of economic benefits.

8.3.5.1. Initial assessment and opportunities for future action

The Chita region as a whole is on the front lines of two economic and environmental struggles in post-Soviet Russia, including: (1) the need to assure high standards of performance for Western investments in resource development, and (2) the need to address the environmental legacy of past regimes. New projects provide opportunities to address the legacy and damage from past practices within the framework of an environmental policy for future mineral developments. This framework could include the integration of remediation of environmental damage and long term containment of existing hazards into the design, review and approval process for future resource development.

8.3.5.2. Closing of former uranium production combinates in the Russian Federation and the CIS

The key to increasing the responses of the Russian Federation and the international community to community radiation problems is a demonstration of the severity of conditions in comparison with other affected communities worldwide. While progress in solving social problems in industrialized Western economies with efficient regulations is very impressive, additional work is necessary to assess the problems of poorly managed combinates in the former Soviet Union and develop practical recommendations. A review of this data and its conclusions could both:

— Focus on future public health and community based solutions;
— Provide data to explain the severity of the problem to national and international institutions which may have resources to respond to the problem, including both remedial work and compensation.

The development of a database and analysis detailing the conditions in all affected regional sites has been started for European (Technical Assistance to the Commonwealth of Independent States, (TACIS)) and World Bank financed projects. Models from other countries can also be considered to provide protective measures and compensation for damages as a basis for specific solutions to regional problems.

Sources for comparison of radiation levels, health effects and pension systems are available for affected communities in the USA and Eastern Germany, among others. In some of these locations, government agencies and non-governmental organizations have been active for many years. Available models for community and governmental actions include:

— A federal indoor radiation awareness and action campaign;
— Radioactive contamination repair and replacement programmes (US efforts with the Uranium Mill Tailings Radiation Control Act of 1978, EU national radiation protection regulations of 1996, the EU-TACIS programme);
— Radiation victim compensation programmes (US Radiation Victims Compensation Act of 1990, Germany WISMUT compensation programme, etc).

The following three case histories study lessons learned from past decommissioning and remediation experience of state subsidized operations.

8.3.6. Decommissioning and rehabilitation of old production centers of the former USSR (1945–1990)

In 1990, , the extent and the conditions under which uranium had been produced since 1945 became visible. Up to the end of 1992, centrally planned economies (the former USSR and its neighbouring countries) produced over 671 000 t U for military purposes and for nuclear electricity generation (East Germany 213 380 t U, Czech Republic 105 351 t U, Russia 93 980 t U, Kazakhstan 72 000 t U, Uzbekistan 82 763 t U, Ukraine over 50 000 t U, etc.) [36]. Within the former USSR, approximately 50 combinates existed, some of which continued production until 1995; others stopped production immediately after the former USSR ceased to exist.

Uranium production in the former USSR can be divided into five periods, described in Table 1.

Generally, each combinate included several mines, which supplied one processing centre. Mining and processing operations were often placed near the deposit, even when the areas were densely populated. Between 1945 and 1980 two types of production centre were developed by the Russians. The first type of centre was a facility in which underground ores were crushed, gravimetrically and radiometrically classified, and the physical concentrates produced for transport. Commonly, first classification of ores took place directly at installations near underground mines. There the mine ore was sorted into ore concentrates and waste rock, which was transported to waste piles near the plant. Examples are the radiometric automatic sorting plant (RAS) at the Pribram mining centre in the former CSSR and RAS Aue near the Aue-Alberoda underground mines.

In the early phases, physical concentrates were transported over 1000 kilometres to hydrometallurgical plants, the second type of production centre, in Central Russia. There the ores were chemically leached and a chemical concentrate (yellowcake) was produced.

After 1960, when the vein deposits became exhausted, more and more low grade ores such as black shale, phosphates or radioactive coal were mined and processed. Due to the huge amounts of ore involved, concentration and transport became very complicated and new mills with high capacities were built near the mines. Also, more sophisticated techniques in hydrometallurgical processing, especially alkaline leaching, were

TABLE 2. HISTORY OF URANIUM PRODUCTION IN THE USSR

Period	Time frame	Scope of production
I	pre 1945	radium period
II	1945–1950	single production centre; production for first nuclear bomb
III	1951–1980	main period, > 20 production centres; production for military purposes and nuclear reactors
IV	1981–1990	concentration on big production centres with low grade ores and high output
V	1990–2000	most centres closed because of uneconomic production and uncontrolled environmental pollution; production mainly for nuclear energy

developed. The hydrometallurgical plants became gradually bigger, resulting in capacities of over 1 million t ore/year with a uranium output of 4000 to 5000 t/year. Consequently the residues, consisting mainly of tailings from hydrometallurgical processing, grew to over 1 million t/a. Today, tailing ponds with contents of 10 to 70 million t have been inherited from this production phase.

The production facilities were co-located in so-called industrial combinates, because housing for workers, medical complexes, power generation, water supply and administrative facilities as well as all industrial installations were centralized in one place. The manpower of a combinate ranged from 1000 up to more than 100 000, including workers and their families. Environmental measures and social efforts were organized by governmental institutions, however no special funds were raised to support these activities and no provisions were made to cover costs of remediation.

After 1990, most of the Russian technical staff left the combinates and the new governments in Eastern Europe and Central Asia became their owners. The first economic studies carried out by governmental organizations or consultants concluded that production under Western market conditions was uneconomic, due to the poor condition of the huge infrastructure of the old combinates and the high cost of exploiting low grade, high tonnage ores such as black shales. Consequently, the governments decided to close the centres and carry out remediation at public expense. Germany suspended production in 1992, Bulgaria in 1994, Hungary in 1997 and the Czech Republic in 2003. The Ukraine and Central Asian republics reduced production sharply. This led to significant reductions in uranium production, which occurred much later than in the West.

Today, remediating the legacies left by former Soviet uranium production is one of the largest ecological and economic challenges facing Eastern European and Central Asian countries and it is very important this remediation take place in order for the public to accept nuclear energy. Remediation is directed at reducing current environmental impacts as quickly as possible. To attain this goal, discussions and professional debate between proponents, licensing authorities and experienced consultants on complicated technical and legal issues are necessary. Funding of the proposed activities is a heavy burden. In some cases international support by the European Union or the World Bank is necessary.

8.3.7. Wismut experience, eastern Germany (1946–2002)

In 1946, uranium production started under control of the Soviet army in Saxony, East Germany. The mining and milling area is located in a densely populated area of Saxony and Thuringia, which has been known since the Middle Ages for production of silver, cobalt and bismuth by vein mining. In 1947, the Sowjetische Aktiengesellschaft (SAG) Wismut was founded. In 1954, the Sowjetisch-Deutschen Aktiengesellschaft (SDAG) was formed under joint control of the Soviet Union and German Democratic Republic governments. Between 1954 and 1990, uranium ore was mined and processed by the SDAG Wismut. Total production was 216 000 t U, which was exported to Russia as both chemical concentrate (yellowcake) and ore concentrate. Mining and milling resulted in 56 shafts in three mining districts — a total mining area of 111 km^2, 48 mine dumps with 311 million m^3 of mine waste, one open pit (160 ha, 84 million m^3), two mills (alkaline and acid leaching) and 14 tailings ponds (723.8 ha, 160 million m^3).

In 1990, after German reunification, uranium mining was terminated under terms of a transition agreement with the Soviet Union and decommissioning of the site commenced. In 1991 under a new German-Soviet agreement, Soviet shares were transferred to the Federal Republic of Germany, which is now the full owner of Wismut, and the Soviet Union was exempted from contributing to remediation of Wismut wastes.

In 1990, the Government asked German industry and Federal Institute for Geosciences and Natural Resources (BGR) for advice on how to proceed with the operating combinate. At that time, Wismut employed 34 500 workers, with 18 650 employed in the mining and processing facilities, compared with a maximum of 120 000 workers in 1954. It is estimated that more than 500 000 workers were employed in uranium mining activities in East Germany at some time between 1945 and 1990. In 1990, reported reserves were about 66 300 t uranium with an ore grade of 700 to 800 ppm U, and annual production was 3080 t U. Production costs were estimated at three to four times the world market price. A decision was made to close all production facilities, to transform the combinate into separate technical and consulting companies and to start a federal remediation programme. According to the legal conditions and ownership structures, a distinction was made between the two groups of mining residues:

— Wismut rehabilitation sites, which belonged to Wismut in 1990 and later to the federal government, and;
— Uranium mining and processing sites that did not belong to Wismut, and older mining sites with enhanced natural radioactivity, many dating back to the Middle Ages, mainly from silver-cobalt-bismuth-uranium ores mined for silver and cobalt production.

The first step was to create a database of all residues with their radiological relevance. Therefore, the objective of the first federal programme was the registration, investigation and evaluation of all mining sites. Based on the results, decisions on the justification of a remediation programme were made. In 1991, the German Federal Ministry of Economy approved a remediation plan with total costs amounting to about ?6.6 billion (US $7.6 billion) over a period of 15 years. The remediation programme was based on both radiological and socioeconomic concerns. The legal background consisted of the West Germany mining and environmental protection laws existing in 1990 and also one part of the East German radiation protection law (VOAS).

According to the existing German mining law, closure of mining activities requires fulfillment of two main tasks (key objectives of the mine closure plan):

— Protection of life and health against dangers caused by the mining activities;
— Revegetation and rehabilitation of areas occupied by the mining activities.

At the end of 2002, after ten years of remediation work, the greatest progress had been made in the following areas:

(1) Significant reduction of environmental pollution through:

— Introduction of water treatment plants and biological barriers to manage mine waters, process waters and surface waters;
— Reduction of air pollution due to radon and radioactive dust, through closure of ventilation shafts and covering of radioactive waste dumps and tailings;
— Minimization of mine damage through seismic control.

(2) Decommissioning of 93% of the total of 1 300 km of underground mine openings.
(3) Sealing off of surface openings and backfilling of 97% of shafts, large diameter boreholes, ventilation raises and underground excavations.
(4) Flooding of underground mines.
(5) Completion of 92% of surface environmental restoration activities (dismantling and demolition of equipment and buildings).
(6) Remediation of 51% of waste rock piles (through covering with multilayer systems, revegetation of piles, collection and treatment of contaminated seepage and runoff waters).
(7) Rehabilitation of the Lichtenberg open pit was over 90% complete by 2007 (see Fig. 1).
(8) Safe encapsulation of 70% of tailing ponds (160 million m^3, dewatering, water treatment, (see Fig. 2)).
(9) Landscape modelling for revegetation, (see Fig. 3).

At the end of 2002 the work force was reduced to 1177. After spending 60% of the allotted federal budget (€3.9 billion), it can be concluded that most environmental impacts have been reduced to an acceptable level. The local community accepts that progress has resulted from the project and is slowly leading to revitalization of the region. At the same time Wismut GmbH has become an important economic player. The project is resulting in the establishment of new industries, construction of living and recreation areas, parks and rural areas and the recovery of natural biological systems. The significant steps taken have been the subject of documentation on a decommissioning project at World Exhibition 2000 and have led to the reopening of a radon spa at Aue in 2001.

8.3.8. Mining, decommissioning and rehabilitation of the Mecsek mining centre in Hungary (1956–2004)

The Mecsek Mine, an underground facility, was the only uranium producer in Hungary. It was operated as the state owned Mecsek Ore Mining Company. The mining complex began operation in 1956 and was producing ore from a depth of 600 to 800 m in 1997 when it was permanently shutdown. The uranium ore bodies were 0 to 200 m deep in the southern part of the mountain ridge and up to 1 200 m deep in the northern area. From 1965 to 1989 the company mined 0.1 to 0.3% uranium from Upper Permian (270 Ma) sandstone 'roll-front' ore deposits; additionally, low grade (100–300 ppm) uranium ores were processed for heap leaching. During this period, 7.2 million tonnes of low grade ore were crushed with an average mining recovery of 50–60%. Total uranium production was 21 050 tonnes of uranium, including 525 tonnes of uranium recovered by heap leaching.

The uranium facilities were located in the Western flank of the Mecsek mountains, in the South Transdanubian region of Hungary, known as Baranya county (see Fig. 4(a)). Its county seat is Pecs, the third largest town in Hungary, with about 190 000 residents. The uranium facilities were located 6 to 18 km from Pecs. There were five mines in the area; Nos. 1 to 3 were on the southern side of the mountain, and Nos. 4 and 5 were on the northern side. The main gallery in mine No. 3 was a focal point for the ore from the other four mines, which was brought through underground tunnels to the gallery. The ore travelled by trucks to the mill, which was located about 2 km from Mine No. 3. The ore processing plant became operational in 1963; until that time, raw ore was exported to the USSR. A total of 1.2 million tonnes of ore was shipped to the Sillimäe metallurgy plant in Estonia. After 1963, uranium concentrates were shipped to the Soviet Union. In December 1994, the Hungarian government decided uranium mining would stop as of 31 December 1997.

During the operation, the town of Pecs and the surrounding countryside, including its hillside vineyards and groundwater, were given high priority regarding environmental protection. During mining, several local projects were completed to assist with environmental protection, including:

(1) Installation of water supply pipes for neighbouring villages.
(2) Planting of a forest belt around the mill and tailings ponds where trees had been removed.
(3) In 1964, a well monitoring network was set up around the mill and tailings ponds; similar monitoring was carried out on local drinking water.
(4) Special private roads for ore transporting trucks were built to avoid pollution of public roads.
(5) During mine operation (1956–1997), contaminated mining and processing equipment did not leave restricted areas of the facilities without decontamination.

The local population adequately supported the mining operation throughout its tenure. The uranium industry employed on average 6 500 to 7 000 workers at the mines and mill, in the service sector, and for geological exploration and drilling, laboratories, and administrative offices. Additionally, family members found jobs in related services that would not have existed without the mining operation, such as transportation, food service, janitorial, clothing industry workers, etc. Altogether, the mining venture employed 12 000 to 15 000 people. The uranium company built a new district in the town of Pecs with free flats, a community centre, movies, and a clinic with medical specialists. The company contributed the money and work force that established the schools, nursery schools, playgrounds, a zoo, etc. In the medical clinic, it was mandatory for all employees to receive an annual examination; this service was continuously available for all employees, workers, and their relatives.

The most important activities since mine closure in 1997 were the experimental covering of tailings ponds and vertical drainage with waste rock. Figure 5 illustrates one of the tailings ponds during the remediation work; the forest belt planted around the tailings during mining to minimize impact on the local population can clearly be seen. The decommissioning and remediation efforts gave jobs to hundreds of workers (see Fig. 4(b) — demolition of head frame No. 5). Figure 6 shows the sequence of events in remediation of the heap leach operation.

The programme for total remediation was expected to continue until the end of 2004, but budget constraints resulted in delays and in 2007 final completion of some aspects had yet to be achieved .

The Hungarian government assumed full financial responsibility for decommissioning and remediation because the uranium industry was directed and operated by a state owned company. The total cost of the decommissioning and remediation, including radiation protection and human health issues, was about US $105–115 million or US $5 per kilogram of uranium produced.

Such a mining venture would probably not be sustainable in today's free enterprise economy. However, at the time of its production, it served the purpose of developing infrastructure for the town of Pecs and

FIG. 5. Mecsek uranium mine tailings pond No. 1 during remediation work.

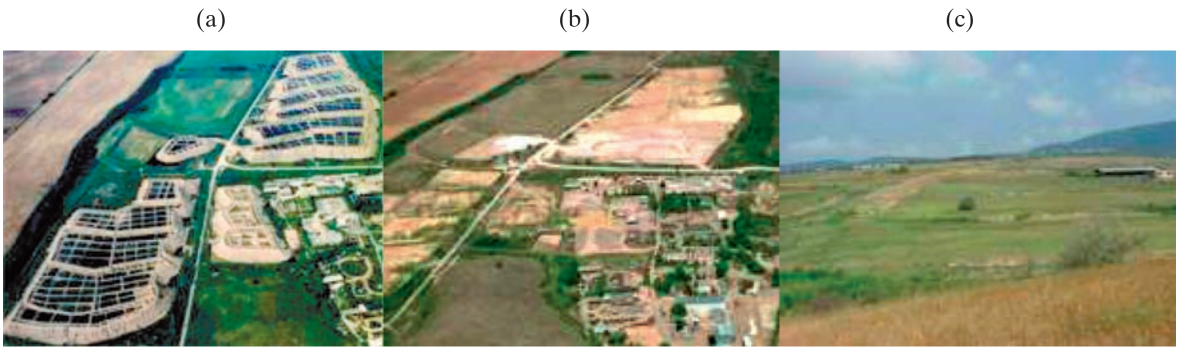

FIG. 6. (a) Mecsek heap leach operation; (b) the same view of the heap leach area during remediation; (c) heap leach area after remediation.

surrounding villages, employing a significant proportion of the local population, and supplying the country and its allies with the uranium that they deemed necessary for their purposes.

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GLOSSARY

g CO_2– eq/kW·h	grams carbon equivalent per kilowatt hour. A measure of greenhouse gas released per unit of electricity generated.
GW(e)	gigawatts electrical. A measure (1 billion watts) of electrical generating capacity.
kW·h	kilowatt-hours. A measure of electricity generation.
L	litre
ppm	parts per million
$t \cdot m^{-3}$	metric tonnes per cubic metre. A measure of density.
t U	metric tonnes of uranium
wt%	weight per cent
μm	micrometre. One-millionth of a metre.

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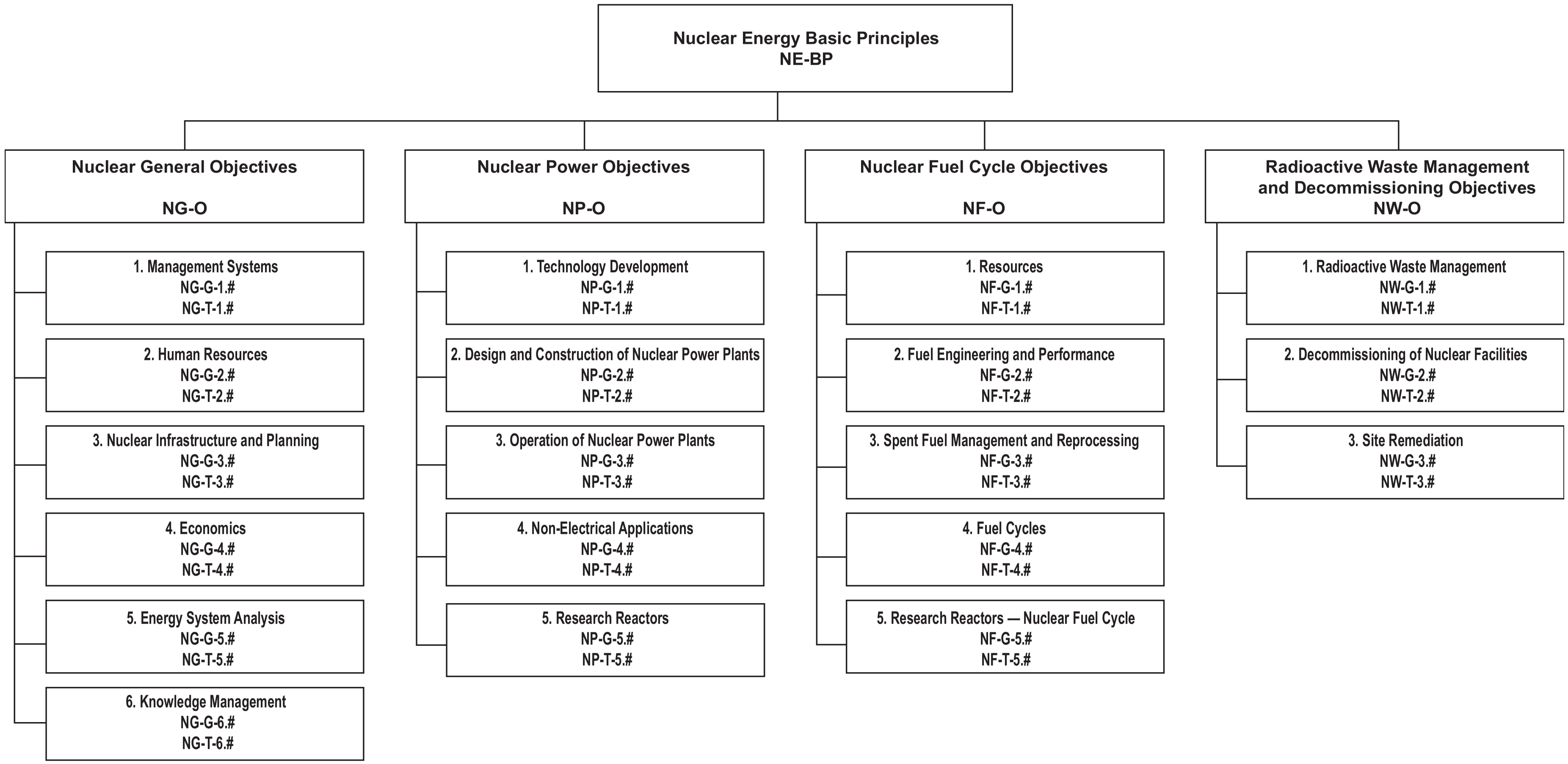

Key

BP: Basic Principles
O: Objectives
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Nos. 1-6: Topic designations
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