

Perceptions and Realities in Modern Uranium Mining

Extended Summary

Nuclear Development

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Introduction

Producing uranium in a safe and environmentally responsible manner is not only important to the producers and consumers of the product, but also to society at large. Given expectations of growth in nuclear generating capacity and associated uranium demand in the coming decades – particularly in the developing world – enhancing awareness of leading practice in uranium mining is important. This extended summary of the report *Managing Environmental and Health Impacts of Uranium Mining* provides a brief outline of the driving forces behind the significant evolution of uranium mining practices from the time that uranium was first mined for military purposes until today.

Uranium mining remains controversial principally because of legacy environmental and health issues created during the early phase of the industry. Today, uranium mining is conducted under significantly different circumstances and is now the most regulated and one of the safest forms of mining in the world. The report compares historic uranium mining practices with leading practices in the modern era, and provides an overview of the considerable evolution of regulations and mining practices that have occurred in the last few decades. Case studies of past and current practices are included to highlight these developments and to contrast the outcomes of historic and modern practices.

With over 430 reactors operational worldwide at the end of 2013, more than 70 under construction and many more under consideration, providing fuel for these long-lived facilities will be essential for the uninterrupted generation of significant amounts of baseload electricity for decades to come. While phase-out plans have been announced by a few countries following the 2011 accident at the Fukushima Daiichi nuclear power plant (NPP) in Japan, the long lifetimes of existing and future NPPs will prompt an increase in uranium mine production. The issue of sourcing uranium from producing countries with an acceptable regulatory framework and from mining companies applying leading mining practices is therefore becoming increasingly important considering that a number of countries with NPPs or plans to construct them have no domestic uranium mining.

However, public perception of uranium mining is largely based on the adverse health and environmental impacts resulting from past practices that took place during an essentially unregulated early phase of the industry. During this early phase, uranium mining was conducted principally for strategic military purposes. As with all forms of mining, the driving force of the era was maximising production, with little regard for environmental consequences. This was also true for other heavy industries in that period, where the priority was production and economic benefits. Because of the radioactive properties of uranium, the health and environmental impacts of these early operations and practices were more pronounced than for other commodities. Legacy mining facilities in countries that produced uranium in this early era now need government funding to finance the remediation required to render the sites safe and stable. Worker health and safety awareness and associated regulations were in their infancy at the time. As a result, workers were being exposed to levels of radiation considered hazardous today and an increased incidence of lung cancer and other diseases was documented. The health of residents in the vicinity of early uranium mining facilities was also negatively affected at times since uncontained tailings and untreated discharges contaminated local drinking water supplies.

Historic mine development and operating practices, combined with a general lack of effective remediation, has contributed to a negative public view of uranium mining. The contaminated legacy sites resulting from these poor past practices present an additional challenge to proponents of new uranium mine development.

Why uranium?

Uranium was first encountered in the mineral pitchblende when mining for silver in the Czech Republic in 1789. Miners soon became aware of its unique properties, with some coming down with a mysterious illness after working with this black mineral. By the mid-1800s, pitchblende was increasingly valued for the brilliant yellow colour and green fluorescence it gave to glass. In 1895, the radioactive properties of uranium were confirmed, stimulating further research, particularly in the medical field. Interest in uranium intensified during World War II as the discovery of the power of its fission properties became of interest to the military and later, with the development of civil nuclear power, to utilities supplying electricity.

The move to regulation and best practice

From its discovery to World War II, uranium was often mined in what can be broadly termed as a “free mining” system. The impacts of this free mining approach are evident in the gold rushes of the 1840s to 1890s across North America and Australia, where staking and mining took place in an uncontrolled fashion leaving a legacy of mine sites in need of remediation.

By the 1970s, the impacts from the early military era uranium mining operations on the health of workers, the environment and the communities located nearby the mines became increasingly evident. Societal pressure, typically driven by unions representing miners, led to a number of investigation boards, commissions of inquiry and numerous health studies that clearly identified the extent and far-reaching impact of historic mining operations, which lacked proper operational and waste management practices. It is out of these investigations and associated research that modern mining and milling practices were born.

Moving from virtually no waste management planning to multistage effluent treatment processes with the engineered, purpose-built waste management systems of today was an arduous process that built on lessons learnt and spanned more than three decades. In terms of worker protection, the mining industry was transformed from one where miners were working in poorly ventilated underground mines with minimal training and ground support, to one with a geotechnical and structurally designed, well-ventilated and monitored mine working environment with well-trained staff, qualified mine engineers and dedicated safety supervisors to monitor and oversee the operations. It was equally as challenging to make improvements in these areas, which ultimately led to the emergence of stronger regulatory/government oversight and inspections, including increasing consequences via the force of law for poor performance or non-compliance.

Today’s leading practice uranium mine and mill sites, and other types of nuclear facilities, are regulated by an independent agency that reports to the head of state or parliament and its elected officials. This greatly reduces the possibility that political or economic goals could influence regulatory decisions. A nuclear regulatory agency ideally operates under a judicial or quasi-judicial process, making decisions in an open and transparent manner, maintaining a clear record of decisions and allowing everyone the right to be heard.

Experiences from modern uranium mines show that successful companies have developed strategies to handle both the positive and negative impacts of mining and processing on communities and the environment. This has occurred with the close cooperation, communication and participation of local communities. A dialogue must take place among the community, the company and the government, with the end goal of ensuring that no additional legacy mining and milling sites, health or environmental issues are created.

Countries beginning uranium mining for the first time have the opportunity to benefit from past experience in other countries, but it will take time to develop the capacity required to promote the development of leading practice mining. Developing, staffing and maintaining a leading practice mine regulator requires both time and resources.

Extraction methods

The main types of mining examined in *Managing Environmental and Health Impacts of Uranium Mining* are *in situ* leach (ISL – sometimes referred to as *in situ* recovery, or ISR), open-pit and underground mining. Although there are other ways to produce uranium, including recovery as a by-product, water or effluent treatment and retreatment of mine tailings or other waste streams, in these cases the ore has already been mined and the management of impacts will be addressed under the main mining types.

ISL operations extract uranium from the host rock without the need to excavate and mill the ore, thereby avoiding the production of tailings. Generally, ISL consists of introducing a leaching solution via injection wells into the mineralised aquifer and recovering the mobilised uranium from solutions pumped to the surface. ISL operations have very low surface impact and disturbance. The critical environmental consideration is almost exclusively the potential impact on groundwater resources.

Open-pit mining (sometimes referred to as open-cast or open-cut) involves extracting the ore directly after first removing overburden to access the deposit. This is most commonly used to extract orebodies which are either on surface or relatively near surface. As depth to the deposit increases, the size and cost of the operation will increase, as will the amount of waste rock generated. Open-pit operations are characterised by a high ratio of waste rock to ore and hence have the largest surface impact.

Underground mining is generally used for more deeply buried deposits or where the ore is distributed in such a way that high-grade zones can be mined preferentially (i.e. vein-type deposits). Underground mining is typically the most expensive form of mining per tonne of rock and has historically been regarded as having the highest risk due to potential rock falls and underground collapses. It has a low ratio of waste rock to ore and in some underground mines there is no significant generation of waste rock. Therefore, the surface signature from an underground mine is relatively small.

Phases of uranium mining

The report outlines the five life cycle operational phases that begin once exploration has been successful in defining an orebody of commercial interest.

- **Design** covers all aspects of developing an orebody from discovery to mine production and is critical for documenting all potentially significant impacts, obtaining regulatory approvals and developing corresponding corrective actions.
- **Construction** includes all physical activities on the site to prepare the area, to mobilise workers and materials to the site and to carry out the physical construction work determined by the detailed design. This phase lays the groundwork for the safe operation of the facility during the production phase.
- **Production** includes all aspects of the operation while production is the primary purpose. This phase is where most of the immediate impacts will occur and, in turn, where active controls dominate.
- **Rehabilitation** covers all activities from the end of production, including closure of the operation, physical decommissioning and remediation activities, and the monitoring and surveillance required to confirm that the rehabilitated site is performing as designed. Moving from active controls to passive controls is the dominant activity in this stage.
- **Handover** is the period when formal control is transferred from the mining company to the authorities. Acceptance of the rehabilitated facilities can be a significant risk to the authorities; so there is a need for rigorous requirements and a need to demonstrate that the facility is capable of long-term compliance (sometimes referred to as **institutional controls**). In setting handover criteria, the onus is on government authorities to ensure that measures for long-term health, safety and environmental protection are in place, are well-funded and sustainable.

For each individual operation, there are a wide range of issues that must be addressed in order to minimise health, safety and environmental impacts to acceptable standards. The report divides operational challenges into **key historical challenges** and **modern life cycle parameters**. It underlines that any approach employed must be tailored to the individual circumstances of the operation; generic approaches are not universally appropriate.

Contrasting key global aspects of past and leading practice uranium mining

The key challenges of uranium mining are:

1. Worker health and safety;
2. Radiation protection (worker and public);
3. Water (surface and groundwater);
4. Tailings;
5. Waste rock management.

1. The **health and safety of workers and the public** is critical to societal acceptance of uranium mining since past practices led to serious impacts that remain a fundamental part of the arguments against uranium mining today. Workers were not properly trained or supervised and they often worked in dangerous conditions.
 - **Historically**, the health and safety of workers in the early phase of mining was neither well-understood nor the high priority issue that it is today. Injury and fatality rates were high.



Hand loading ore onto a wheelbarrow in a small mine on the Colorado Plateau in the mid-1950s. In early operations, miners were not properly trained and hazards were not well-understood. As a result, injury and fatality rates were high.

Source: US Department of the Interior, Bureau of Mines.



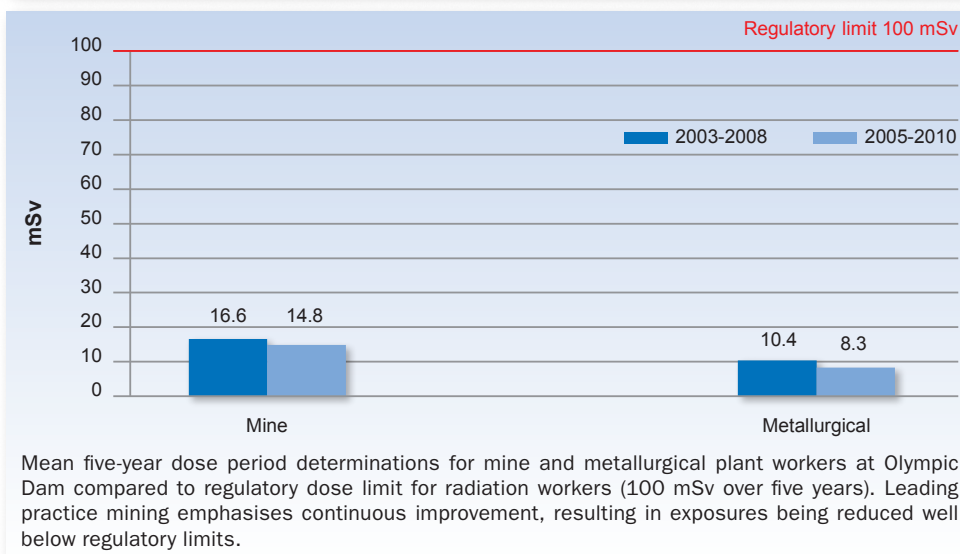
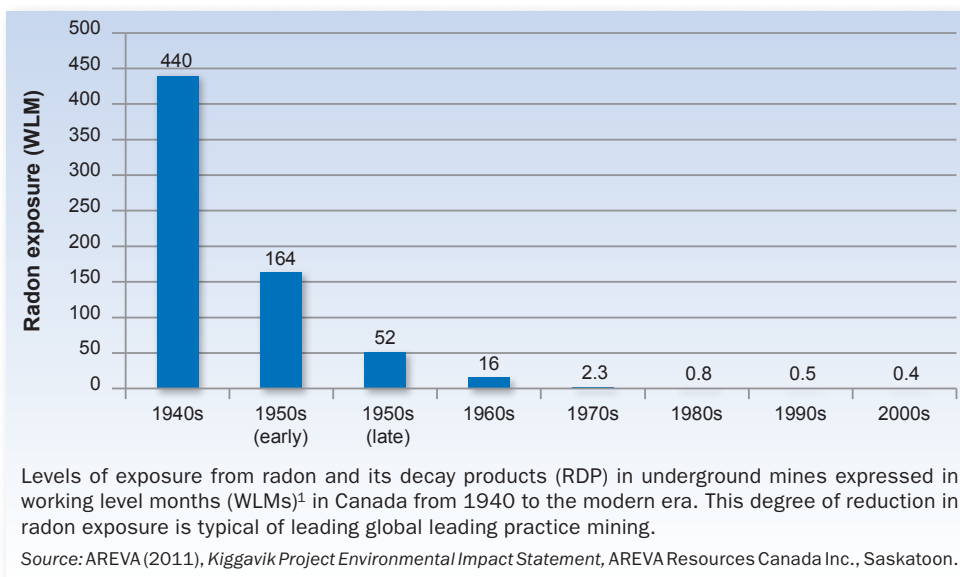
Cameco mine safety briefing. In leading practice uranium mining, worker safety is a high priority. Training prior to beginning employment is supplemented on a regular basis with briefings and updates, sometimes on a daily basis.

Source: Cameco Corporation, Canada.

- **In modern, leading practice mining**, the responsibility for identifying and correcting health and safety hazards in the workplace is shared among all parties involved: employers, contractors, owners, supervisors and workers. Laws are enforced by a workplace regulator that independently inspects, reviews, records and promotes workplace safety. As a result of these modern approaches, a marked improvement in **conventional worker health and safety** performance has been demonstrated. These advances have resulted from the development of legislation to establish standards, the creation of regulatory agencies with inspection and enforcement powers and the implementation of training programmes by mining companies. Leading practice uranium mining has better safety performance than occupations generally considered much safer, such as retail and office work. The critical role of workers is to effectively implement their training on a daily basis to create a safe workplace, take reasonable precautions to protect their own health and safety as well as that of their colleagues, make effective use of the safety equipment provided and co-operate with their site occupational committees. Workers are also responsible for reporting safety concerns internally and to regulatory authorities. Uranium mining companies in Canada, for example, have received national recognition for award-winning safety performance in recent years.

2. **Radiation protection of workers and the public** is a core requirement for successful uranium mining operations, and occupational doses are dependent on the characteristics of the operation as well as site-specific factors.

 - **Historically**, during the military production boom in the mid-20th century, little was known about radiation health risks, and virtually no radiation protection measures were in place in uranium mines and mills. Combined with a strong motivation to maximise production at all costs, this resulted in exposure situations that were much higher than today due to the lack of proper dust controls and adequate ventilation. These circumstances led to the build-up of high levels of the radioactive gas radon. Historical operations have subsequently been the focus of epidemiological and other studies that have led to a better understanding of the risks and have strengthened the radiation protection system.



1. Cumulative radon exposure in mining is specified in WLMs. If 2 000 working hours are assumed per year, then 1 WLM = 5 mSv. A working level (WL) is equivalent to any combination of short-lived RDPs in 1 L of air that generates an emission of 1.3×10^5 MeV of potential alpha particle energy. A WLM equals the exposure to 1 WL for 170 hours (working hours per month). $1 \text{ Bq m}^{-3} = 0.00445 \text{ mJ h m}^{-3}$ and $1 \text{ mJ h m}^{-3} = 1.4 \text{ mSv}$ (ICRP, 1993).

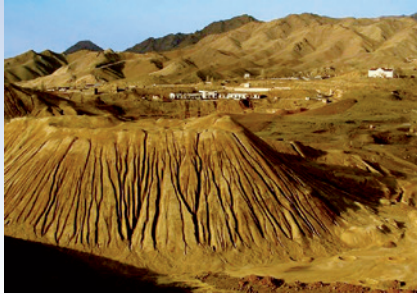
- **In modern, leading practice uranium mining**, levels of occupational exposure today are far below established regulatory limits. Dose limits have been adjusted accordingly and modern occupational exposure is significantly lower than historic levels of exposure. Corrective measures to successfully reduce doses include using mining methods that limit the time that personnel work in high-grade ore areas, providing cleaning areas to prevent the build-up of active material, monitoring to keep personnel informed of higher dose areas and using shielding to reduce dose rates. Controlling worker exposure to radon in uranium mines and mills also requires engineering designs and processes to remove radon from the workplace. Radon gas produced during mining and milling is continuously monitored, controlled and ventilated away from workers to avoid hazardous exposure. Presently, worker exposure to radon and its decay products in the uranium mining and processing industry are as low as, or only slightly higher than, public exposure to natural radon.

Public health and safety – members of the public have expressed concerns about the potential for being exposed to higher than regulated limits of radon, uranium and other potential hazards, particularly when residing in proximity to an active uranium mine. Radon releases into the atmosphere from a very small portion of total human exposure (<1%), and releases beyond the licensed boundaries of the mine and mill have been shown to be insignificant. Releases of uranium and other heavy metals into the receiving environment can be effectively managed so as to limit them to acceptable levels.

Radon is a colourless, odourless gas and exposure in excess of regulated limits can increase the incidence of cancer. However, off-site doses during operations, even historically, are generally relatively low (typically a small fraction of the natural background dose). Studies show that within a very short distance from uranium mining and milling facilities (usually around the site's licensed boundaries), radon concentrations are close to background levels measured at reference sites far from the facility.

- **Historically**, the most significant public radiation doses were associated with the post-closure phase of the operation when restrictions on site access can be either lifted or ignored, allowing direct exposure pathways to dominate in cases where sites have not been properly decommissioned and remediated. During rehabilitation, radon emissions can be substantially reduced by installing a soil or water cover on radon-emitting facilities. In cases where remediation has not been properly completed, the continued exclusion of the public from higher risk areas through zoning and land use controls or warning signs reduces the potential for increased public exposure.
 - **With modern radiation protection** and controls at the uranium mine facility, off-site members of the public, even those living nearby the operations, are well-protected. Separation of the public from the immediate direct sources of exposure is generally sufficient to ensure that doses remain low. In addition, practices that reduce dust emissions, such as restricting emanating areas to a minimum size and number and keeping tailings moist, reduce total emissions.
3. Ensuring that overall **water quality** is protected is of paramount importance to the success of the facility. High performance standards implemented by the operator, effective regulatory oversight, comprehensive monitoring programmes and public engagement are all key factors in dealing with water quality issues. Water may be encountered in or near mine workings or used in extraction processes. Mining activities can be undertaken in the proximity of water sources important to both human and non-human biota. Uranium mining and milling can also be undertaken in dry regions, where water is not readily available for make-up or process water and must be pumped into the site from a considerable distance. Alternatively, mining can be undertaken in environments characterised by large amounts of seasonal rainfall, where management of excess water may periodically require significant planning and effort.
- **Historically**, early mine practices did not employ adequate control and treatment techniques, resulting in the contamination of local watersheds, nearby low-lying areas and, in some cases, areas further downstream. Drawdown of groundwater resources and groundwater quality impacts have also been documented. Over time, however, and especially since the 1970s, standards for water releases have been strengthened. Initially these improving standards were designed to protect subsequent human use of water resources, but more recently they have been further developed to protect non-human

biota (fish, flora and fauna) and groundwater resources. Previously, ISL operations at times resulted in unacceptable groundwater impacts because the potential environmental impacts were not taken into account prior to mining and the technology was in its infancy. This led to the injection of more acid or alkaline fluid (lixiviant) than was withdrawn to increase production, resulting in an outward flow of lixiviant from the mining area. The latter was compounded by improperly installed wells that leaked into the surrounding aquifers, some of which were high-quality sources of drinking water.



Taboshar “Yellow Hill” of ground ore prepared for heap leaching. Lack of planning and regulatory control combined with outdated mining and milling practices led to significant environmental impacts, including the spread of contaminants from uncontained wastes via streams draining from the mountainous site to agricultural plains.

Source: A. Jakubic, UMREG.

Key Lake uranium mill: water management has been and remains a key issue for the operator and regulators since the beginning of mine development. The collection and treatment of water are major activities at the site. Baseline environmental data collected prior to site development, along with an extensive monitoring programme throughout the life of the facility and consideration of the predicted impacts during the environmental assessment phase, have been used to objectively determine the operation’s potential impact on the local environment and to successfully adjust water treatment programmes as concerns or improvements are identified.



Source: Cameco Corporation, Canada.

- **In modern, leading practice mining**, water management and the control of water that is either flowing to the site or discharged/diverted from the site are a costly and challenging focus of activities. The operator must collect and treat all contaminated water to meet acceptable standards prior to release.

In situ leach (ISL) mining, the fastest growing method of uranium mining in the world, needs to be planned and conducted in a way that protects surface and groundwater resources. In 2010, approximately 40% of world uranium production was mined by ISL and the share of ISL production is increasing. ISL has become the dominant method of uranium production because capital expenditures for mine development are relatively low and mining of extensive, low-grade sandstone deposits is considered economically feasible. Kazakhstan became the world leader in uranium production in 2009 with over 95% of its production by ISL. Unlike conventional mining, no large volumes of waste rock or mill tailings are generated in the process.

- For effective control over the ISL operation, water balance modelling of the well field and plant must be undertaken during operations. Extraction must be designed to minimise the risk of breaching impermeable strata and excursions of mining solutions from the area being mined. For example, the volume of the extracted solutions in flowing aquifers should be slightly higher than the volume injected to ensure a net inflow from the neighbouring aquifers, as opposed to an outward flow, as was the case in past operations. A mining proposal must be based on a full understanding of the hydrological, hydrogeological and hydrogeochemical features of the area, including those that would justify the use of ISL extraction. The nature of the mining solution and the well field design needs to match the site characteristics, particularly the minerals and groundwaters in the mineralised aquifer. Mining should not compromise groundwater in the mineralised aquifer to the extent that it cannot be remediated to meet the agreed post-mining use. At no stage should mining

compromise groundwater use in the mineralised aquifer outside an agreed distance (not exceeding a few kilometres). Other aquifers present in or around the mine lease should not be affected by uranium extraction.



Wellhead with drip tray and online detector (left); evaporation pond with leak monitoring (right) at the Beverley ISL mine. A comprehensive environmental impact assessment (EIA) process based on a thorough understanding of local site conditions, field trials and baseline environmental data that demonstrated well field containment was required before approval to begin operations. Ongoing environmental monitoring provides assurance that the facility is operating as planned.

Source: Heathgate Resources Pty Ltd, Australia.

4. **Tailings** are the waste product remaining after the extraction of a valuable element from the mined ore in open-pit and underground mining operations. In extractive industries, tailings often represent the primary hazardous waste which must be managed in the very long term. Tailings management broadly encompasses the chemical and physical processes involved in the production and placement of tailings, as well as the development, operation and closure of the facility where the tailings are impounded. Uranium extraction is generally accomplished either by acidic (e.g. sulphuric acid) or alkali (e.g. bicarbonate) leaching, the choice depending on the mineral composition of the ore. The treatment process also liberates other constituents of environmental concern, such as heavy metals. Consequently, water (liquid effluent) discharged with the solids to the tailings impoundment must be removed by evaporation or treated prior to release.

After extraction of uranium, tailings still contain some uranium (extraction never reaches 100%), as well as other radioactive elements of the uranium decay chain, including radium. The decay of radium is responsible for radon exhalation from the tailings surface. The amount of radioactivity remaining in the tailings is to a large degree controlled by the grade of the ore brought to the mill for processing. Generally, about 85% of the total activity contained in the uranium ore is deposited in the tailings. After decay of thorium-234 and protactinium-234 radioisotopes within a few months, the activity diminishes to approximately 75% of the ore and remains stable at this level of activity for more than 10 000 years.

The arsenic, nickel and other heavy metals in the ore, as well as chemicals from the extraction process, are typically found in the tailings. The risk presented by the tailings containment relates to the probability of a containment failure and/or seepage from the tailings impoundment impacting the surrounding environment, particularly surface and groundwater. For uranium tailings, the perceived risk is heightened by the presence of radioactive elements, despite the fact that the most significant risk arises from concentrations of heavy metals. However, if tailings are managed properly, the impact on the environment and human health is considerably lower than societal perceptions would have some believe.

- **Historically**, when environmental impacts were neither understood nor an issue of concern to the public, few governments regulated the environmental aspects of mining and tailings management.



Helmsdorf tailings disposal area during operations: tailings were deposited in a shallow valley adjacent to the processing plant, contained by two dams constructed of waste rock. No bottom liner for groundwater protection was installed prior to operation and little consideration was given to the potential impacts from leakage or a dam failure on communities located downstream of the impoundment.

Source: A. Jakubik/Wismut, Germany.

This meant that the physical and chemical compositions of the tailings were not adequately managed or controlled. Tailings were simply placed in low-lying areas, such as streams or lakes convenient to the processing facility. Such practices would not be approved by regulatory agencies today unless the appropriate lack of adverse impacts could be clearly demonstrated.

- **In modern, leading practice mining**, contaminant transport modelling tools are used to support the design and validation of tailings management facilities and the long-term predictions of the effects of contaminant transport on the receiving environment. Calibration of the models using environmental monitoring data collected during the operating period adds validity to projections of long-term performance. Beyond improving the design of the facilities in which tailings are stored, advancements in tailings management have focused on controlling the chemical and physical properties of tailings. Today, even tailings from the most challenging high grade ores can be managed and safely disposed.

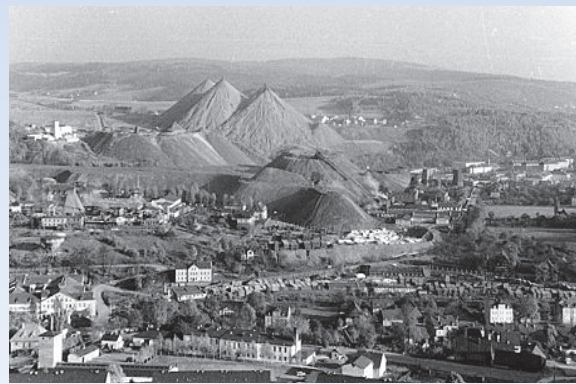
Leading practice is to either dispose of tailings in a purpose-designed management facility or in a mined-out open pit that has been engineered to contain and consolidate tailings in a way that isolates the material from the receiving environment long after the facility is closed, remediation is completed and the land and monitoring responsibilities are transferred from the mining company to the government. Mined-out open pits have physical stability advantages over man-made structures, require less maintenance and are not prone to physical failure.



Cluff Lake tailings management area (TMA) prior to decommissioning (left) and after decommissioning and re-vegetation (right). During the operational life of the Cluff Lake mill, all tailings and contaminated water generated at the site were transferred to the TMA for disposal and treatment. Decommissioning in 2001 and 2003 included placement of a 1 m till levelling course over the tailings storage areas to minimise radiological hazards and dust emissions, as well as to promote tailings consolidation.

Source: AREVA Resources Canada.

5. **Waste rock** is material excavated during the open-pit and underground mining of any mineral, including uranium, which is of no commercial value. It can be either clean (of no environmental concern) or problematic.
 - **Historically**, limited consideration of the chemical composition of waste rock was given prior to its placement in waste piles or its use as mine backfill or construction material. As a consequence, a legacy of acid drainage and heavy metal leaching from mine sites around the world was created. In some cases, problematic waste rock has been removed from mine sites and inappropriately used elsewhere.



Waste rock piles, Schlema, 1960: the Schlema area was mined from 1946 through 1990, producing about 80 000 tU. During the course of mining operations, an extended waste pile landscape was created at and around the site of the historic Oberschlema spa (one of Germany's most renowned radium spas, first developed in 1918). During mining, the spa and town were obliterated as waste rock was dumped in the town's centre and at other locations nearby. Favourable urban development following comprehensive rehabilitation of the historic era mining legacies is exemplified in Bad Schlema, where tourists have returned and the title of "spa town" has been regained.

Source: Wismut GmbH, Germany.



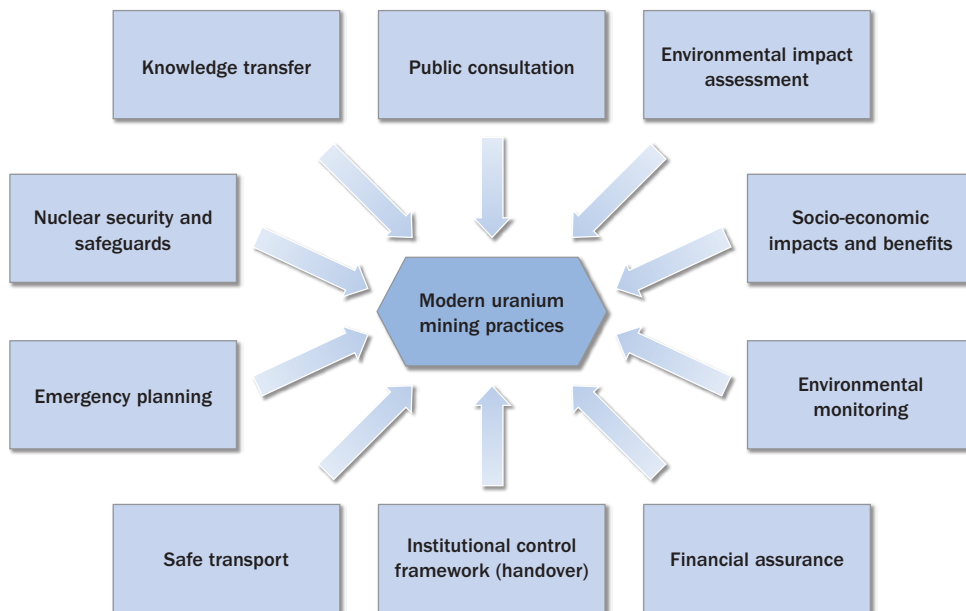
Overhead scanning of mined rock to classify ore and segregate potentially problematic waste rock for appropriate disposal, McClean Lake.

Source: AREVA Resources Canada.

- **In modern, leading practice mining**, good characterisation and controls allow a significant portion of the clean waste rock to be stockpiled and readily used for construction purposes, such as in roadways or for erosion protection around stream crossings. Problematic waste rock with trace quantities of the target mineral or other minerals that have the potential to adversely impact the environment must be separated and treated appropriately. The presence of sulphate or carbonate minerals is of particular concern. The weathering (exposure to air and water) of waste rock containing such minerals has the potential to alter the chemical properties of water, which can have a direct and detrimental effect on the environment through acidification or through the mobilisation of other heavy metals in the waste rock or the environment. The flow of acidified water from mine sites, generally referred to as acid rock drainage (or acid mine drainage), is a common issue for all mining activities. Uranium mining, however, has the additional concern of the presence of radioactive elements, and thus the mobility and effects of radionuclides in the environment must also be considered in the management of mine rock. The properties of open-pit and underground mine waste rock are an important planning consideration in modern mines. Waste rock is characterised through sampling and laboratory testing to understand the potential for acid generation and leaching of trace elements. Mine rock management plans are developed and the potential effects on the environment are considered early in the mine development process. Such plans include strategies to segregate benign (clean) rock from potentially problematic mine rock.

Modern parameters of uranium mine management

As the regulatory regime evolved and the industry adapted and developed innovations to meet emerging requirements and issues, a number of parameters have been introduced into leading practice operations that were seldom, if ever, used or even considered during the mine life cycle in the early stages of the industry. These additional aspects of mine development, operation and closure are today considered crucial to effectively managing the health, safety and environmental impacts of the operations. With the implementation of these mine life cycle parameters and regulatory requirements, leading practice uranium mining has become a leader in safety and environmental management.



Public consultation

Uranium was first mined in large quantities in order to meet strategic military requirements following World War II. Mining in these early days was conducted with a degree of secrecy, and stakeholders were seldom if ever informed of mining plans, developments and related issues. In leading practice uranium mining today, public consultation is an important feature during the entire life cycle of the mine to keep all stakeholders, in particular local residents, informed of plans for development, operations, environmental performance, decommissioning and rehabilitation. Interested stakeholders are provided with numerous opportunities for information and dialogue with producers and regulators. Included in public consultation is an assessment of both the positive and negative social and economic impacts of mining and planning for the important end point of mining when the mine will be shut down and the economic stimulus of the mining activity will come to an end.

1. An effective **public consultation** process facilitates a dialogue with the public and other stakeholders to take into account questions and concerns. This is not just an outward-flowing information programme. Rather, it is a two-way process that actively encourages and documents questions and answers that arise throughout the stakeholder involvement process. Improving public information efforts and consultation with stakeholders allows the industry to better counter any unfounded concerns or fears about the regulation and management of radiation and its impact on workers, the public and the environment. The public is a valuable resource to proponents of uranium mining and regulatory agencies, and should be treated accordingly. A knowledgeable and supportive public will facilitate the timely review and licensing of new mines. Public fear and resistance will do just the opposite.

In countries with leading practice uranium mines, public consultation is a requirement in mine development from the early stages of a proposal through all licensing steps, including the operational stage when monitoring data is made publicly available and the mining companies and regulators discuss results with the public and other interested stakeholders. Public consultation and stakeholder involvement are crucial components to obtaining and maintaining a social licence to conduct mining.

2. An **environmental impact assessment (EIA)** is needed to plan projects carefully with opportunities for stakeholder participation, including the interested public and special interest groups, such as indigenous populations.

An EIA is a process used to predict and minimise the environmental effects of proposed initiatives before they are fully planned or undertaken. It is a planning, decision-making and public consultation tool that is used to inform and engage members of the public and other interested parties. Overall, the objectives of an EIA are to incorporate environmental factors into decision making, identify potential environmental impacts of a proposed project and to outline ways of minimising or avoiding adverse environmental effects before a project is licensed and initiated. It provides stakeholders with an overview of the project and details specific measures proposed to mitigate or minimise potential environmental effects that could arise if the project is to proceed.

3. An analysis of **socio-economic impacts and benefits**, in order to evaluate local community impacts, is undertaken in leading practice jurisdictions prior to decisions to begin mining – often as part of an EIA. Mining is a temporary use of the land and all mines eventually close. Although the industry can generate significant economic opportunities during mine development and production, it will ultimately leave a gap in the regional economic infrastructure when the operation is closed. Mining can also bring a transient workforce to a region, sometimes in remote areas. If mining is approved, arrangements with governments are typically established to ensure that local inhabitants benefit from the extraction of the resource, even after the mine closes, since businesses and skills developed during operations are transferable to regional mining and other activities. It is after all at the local level that the impacts of mining will be the greatest.

The mining industry is a major force in the world economy, occupying a primary position at the start of the resource supply chain. The benefits of mining include direct foreign investment, national investment in the local economy and the creation of exports that can be significant economic drivers. Uranium mining can provide increased employment, training and salaries. It can also be an economic stimulus to the local and broader economy, allowing for the development of secondary industries such as retail and service sectors that supply the mine and the mine's employees. Mining requirements for infrastructure such as roads, airports, electricity and water can lead to longer-term regional development.

Mine lifetimes vary considerably and although some can continue operating for decades, eventually either local resources will be depleted or the economics of the operation will change, leading to mine closure and decommissioning. The direct economic benefits from the activity come to an end and trained and experienced workers may have to seek employment elsewhere. During the operating lifetime of a mine, negative influences can also take place, particularly at the local level, such as a disruption of traditional lifestyles, potential social pressures created by the influx of workers and, at times, increased wealth in small communities that could lead to dependencies and other social pressures. As a result, all socio-economic aspects of mining should be carefully evaluated by stakeholders prior to the development of a mine. While uranium mining can provide important socio-economic benefits to local populations, the industry alone cannot be expected to resolve all regional socio-economic and development issues.

4. **Environmental monitoring** programmes are required to demonstrate that facilities are performing as designed. This is done through the collection of environmental data that objectively assess ecosystem impacts throughout the life of the mine and provide assurance of performance. In its early history, all types of mining and milling facilities had little or no environmental monitoring and the result was often widespread contamination that required challenging and costly remediation efforts. Had the degree of contamination been better understood with environmental monitoring programmes in place when mining began, contamination could have been detected early and corrective measures undertaken. With heightened awareness and the development of regulatory oversight in the 1970s, more and more effort has been made to establish adequate environmental monitoring programmes. Monitoring allows for the comparison of facility performance against targets and requirements set out within the EIA and licence conditions of the operation. Its general purpose is to check whether operations are impacting the environment beyond limits established by the regulator and, after decommissioning, to verify that rehabilitation works are performing as planned.

Environmental performance

Uranium was first mined in an era when maximising production was the principle objective of mining, with little consideration given to managing environmental impacts. Today, environmental impacts are a focus of leading practice uranium mining throughout the entire life cycle of the mine, beginning with the collection of baseline environmental data during advanced exploration and continuing through the operational phase and on to mine closure, decommissioning and rehabilitation. Developing strategies to minimise environmental impacts is an integral part of the EIA and licensing. Measurements of critical environmental parameters are regularly conducted throughout the operating and decommissioning phases of the mine to ensure that environmental performance is being achieved as planned.

Since environmental monitoring is an essential safety and environmental protection function of any uranium mining facility, the collection of sufficient **baseline environmental data** is a vital first step in designing and carrying out a proper environmental monitoring programme. It is only when monitoring data can be compared to pre-mining (baseline) data that the impact of the operation can be objectively assessed. It is therefore important to begin collecting baseline information in the exploration phase, before the site undergoes any significant physical disturbance. Monitoring programmes should be reviewed regularly to ensure that they remain relevant in terms of the parameters being monitored, the location of monitoring stations and the frequency of the monitoring activities. Reports must be submitted to regulators and preferably made available to the public, typically on a semi-annual or annual basis. Upstream and downstream water quality monitoring around the site must include all adjacent streams (even if intermittent), as well as rivers and lakes, and must be performed seasonally during dry periods, winter conditions, spring runoff or during the rainy season in tropical climates. A periodic full sweep of parameters in the receiving environment is typically required, interspersed with more routine reviews focused on a smaller number of aspects of concern. This can be an effective, efficient and cost-effective method of monitoring some of the key aspects.

5. **Financial assurance**, to cover the costs of closure and remediation activities in the case that the company cannot meet its commitments, is part of leading practice mining. Past uranium mining legacies from the early strategic era have been left to governments to remediate, often at a high cost. To provide assurance that mining companies, and not governments, are fully responsible for funding decommissioning and remediation activities, leading practice jurisdictions require uranium mining companies to post such financial assurance. This means that mining companies must produce an approved remediation plan prior to beginning production and must post appropriate financial guarantees for the expected cost of closure and remediation that could arise at any stage of the mining life cycle.

To determine the value of the financial assurance required, mine reclamation and potential long-term care costs must be forecast. In many mining jurisdictions, requirements have evolved to call for the development of mine reclamation plans at the time of initial permitting, with forecasted costs of future remedial work and corresponding financial assurances required. As mine activities develop, reforecasting is periodically required (e.g. every one to five years). To account for limitations encountered when forecasting costs of activities far into the future, including reasonably foreseeable uncertainties, the value of financial assurances can be substantial. Future rehabilitation costs, as well as the cost of the financial assurances needed to address them, have proven to be effective motivators to minimise environmental liabilities during the operating period. Periodic review and adjustment of the financial guarantee for a particular site would include reductions associated with approved decommissioning of facility components during the operational phase (where possible) that reduce overall decommissioning costs. This has the added benefit of encouraging producers to conduct remediation activities during operations.

Planning for closure

Like all mines at the time, uranium mines closed during the early phase of mining were rarely decommissioned properly, since legislation that set out responsibilities for companies to properly close mine facilities did not exist. This situation often resulted in significant environmental impacts that governments were left to address. Today, in leading practice uranium mining, planning for mine closure is conducted before the mine is licensed to begin production. Companies are required to post financial assurance with regulatory authorities to cover the cost of an approved plan of mine decommissioning. Governments must also establish a framework to take responsibility for the mine after the mining company has completed decommissioning and the site has been stabilised as planned. Finally, records of closure activities need to be archived in case intervention is required at the decommissioned mine site at any time in the future.

6. **Planning for the institutional control framework** or the “**handover**” phase is an important final step in the mine life cycle. In order for uranium mining companies to understand operational and financial requirements in the long term, the requirements that must be met in order for properly decommissioned mining properties to be returned to the land owner – typically the government – must be clearly established.

After the operator has completed the approved decommissioning and reclamation activities, the site enters a period of transition-phase monitoring, during which the operator is required to continue monitoring and maintaining the site. During the transition-phase monitoring period, regulators continue to conduct periodic inspections and review monitoring results; and the operator continues to remain fully liable for any impacts the site may have on the environment, surrounding communities and public safety.

If the site performs in accordance with the decommissioning and reclamation plan and achieves the predicted stability during transition-phase monitoring, the operator may make an application to obtain a release from further monitoring and maintenance responsibilities, as well as the obligation to maintain financial assurance.

Two types of funding for the handover phase may be required, one for monitoring and maintenance and a second for unforeseen events. In addition, a formal record of the closed site is required along with management of the funding and performance of any required monitoring and maintenance work. The monitoring and maintenance fund is designed to pay for these long-term activities, while the unforeseen events fund will pay for damages resulting from severe natural events, such as floods or tornadoes.

Security and safeguards

Members of society want assurance that uranium produced at mines is used exclusively for its intended purpose; that is, primarily as the raw material for nuclear fuel in nuclear power plants, but also some small amounts for research reactors and for the production of medical radioisotopes. Since mines are typically located some distance from facilities in the production chain of nuclear fuel (conversion, enrichment and fuel fabrication plants), safe transport is an additional priority. Through a combination of leading practices implemented by mining companies and international standards and agreements, uranium is today safely transported around the world on a regular basis, with the material being tracked from the mine through fuel production to its final destination after being used in a reactor to produce electricity.

7. Safe **uranium ore concentrates (UOC) transport** is a necessary component of production. With expectations that increasing uranium demand will drive expansions and development of new mining operations in various jurisdictions, and considering that production is often located outside uranium-consuming countries, safe transport continues to be a high priority.

During operations, transport of various hazardous materials – including operating materials, such as acid, alkali, fuels and explosives, as well as the final or interim product – is required. Movements of dangerous goods by road, rail and/or sea are regulated by the national and/or regional competent authorities. Due to its low activity per unit mass, UOC is considered a low hazard and can therefore be transported as an industrial package with appropriate placarding and labels. The shipment of UOC is currently carried out in sealed, reusable steel drums that are loaded in ISO containers (i.e. containers certified by the International Organisation for Standardization). To ensure safe and efficient transport, good industry practices have been defined and implemented, including recommendations for drum design, size, materials and labelling, as well as requirements for lids and rings. Although UOC consists mainly of uranium, its radioactivity per mass is well below the activity of the ore. Therefore, the main health concern from UOC is related to its chemical toxicity as a heavy metal, rather than its radioactivity.

Early in the development of nuclear energy, it was recognised that the transport of UOC posed a potential environmental and security risk. Strict regimes were therefore instituted as early as the 1960s. In the late 1990s, the World Nuclear Transport Institute was founded by industry to represent the collective interests of the radioactive materials transport sector. International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material have become an internationally accepted standard for governments and the industry. It is incumbent upon governments to adopt these regulations, which have now been adopted in about 60 countries. The transport of nuclear materials has a very good safety record, which is especially noteworthy due to the great distances involved and the large number of shipments that have been successfully made. Although UOC has been transported around the world for decades to the few existing conversion and enrichment facilities, no accident resulting in serious harm to people or the environment has been recorded to date.

8. **Emergency planning** encompasses both emergency preparedness and emergency response activities. At any mining site, emergency planning is part of daily business, as hazardous operating materials are regularly used. Radiological hazards also have to be considered in uranium mining and milling. As a result, the major preparedness and preparation measures for onsite emergencies at uranium mines and mills are covered within the radiation protection programme.

Emergency preparedness is related to the type of mining undertaken (underground, open-pit or ISL), since different emergency scenarios have to be considered for each type. Nonetheless, off-site consequences, radiological or otherwise, are not expected from uranium mining operations. Off-site contamination requiring intervention could occur, however, through leakage from tailings management facilities.

The requirements for emergency preparedness are defined in national regulations and are therefore country-specific. In general, national authorities and operators are expected to regularly conduct assessments of threats posed by facilities. A very important point when dealing with incidents related to radioactive material is keeping the public informed. This helps to avoid any inappropriate public reactions on the one hand and any criticism for a lack of transparency on the other. To this end, it is recommended that protocols be established that outline means of communicating incidents to the public.

9. Nuclear **security and safeguards** have gained importance over the past years, especially after the terrorist attacks of September 2001 in the United States, and have turned out to be more complex than safety-related issues due to the external environment and varying threats. The main apprehension is that a criminal organisation will obtain nuclear materials to either create a nuclear weapon or a radiological dispersion device (“dirty bomb”), or that it will sabotage a nuclear facility or the transport of nuclear material. In the case of uranium mining, the main item of security interest is UOC, where about one shipping container (25 barrels) or 10 tUOC is considered a “significant quantity”. The term significant quantity denotes the amount of fissile material necessary to create a nuclear explosive device, although considerable expertise and access to restricted facilities for processing would be required to turn UOC into a weapon. The creation of a dirty bomb from radioactive materials located at a mine site is rather unlikely and accordingly is less of a security concern. Although there is radioactivity contained within the tailings, they have low activity per mass and are therefore not as easily distributed and would not be as effective as other sources.

The establishment and maintenance of a good physical protection regime for nuclear materials lies in the hands of the state. It is responsible for creating the legislative and regulatory framework, designating competent authorities, providing education and training, setting responsibilities and evaluating national threats. IAEA safeguards also provide a basis for nuclear security since confirming that relevant material is only used for its intended purpose contributes to the prevention of illegal acts. The IAEA monitors and verifies all source and special fissionable materials in countries under safeguards. Under an Additional Protocol, a state is required to provide the IAEA with broader information covering all aspects of its nuclear fuel cycle activities, including uranium mining.

Mine operators are required to take measures that make unauthorised access to radioactive materials as difficult as possible. These are based on feasible risk and threat scenarios and entail the establishment of limited access areas, the installation of detection systems against unauthorised intrusion, the development of contingency plans to counter malicious acts and the familiarisation of state response forces with the sites. Effective management accounting for uranium mine production is also important so as to avoid understating uranium production and to facilitate the detection of insider threats. The use of established measurement and record systems, automated data entry and clearly defined responsibilities are all part of an effective management system. Probably the most vulnerable operation in uranium mining is the transport of nuclear materials. However, due to the non-fissile nature of UOC, it is of limited safeguard concern, and as such, security requirements are generally comparatively low. Although incidents of loss or theft of uranium have been halved since the early 1990s, the occurrence of a handful of incidents each year indicates that security and safeguards at mines could be further improved.

10. **Knowledge transfer** is a key final step for the operator or the project manager who hands over the site to the long-term care and maintenance programme. The long-term objective of modern uranium mining is to ensure that the site where mining and milling activities take place, once decommissioned and remediated, will remain stable and safe over the long term. To ensure this long-term safety and stability, future generations must be fully aware of what is located where, why it is there and what must be protected or maintained, to name just a few of the important pieces of necessary information. The key documents that summarise the operation and remediation of the site, as well as the engineered close-out design and monitoring verification programme, must be readily available in a secure location. All of this detailed information must

be archived in an information management system that is likely to be government-controlled. This occurs after long-term stability has been achieved and confirmed by the post-remediation monitoring programme, and after regulatory approval has been obtained following a final phase of public consultation.

Conclusions

Experiences from modern uranium mines show that in countries with the appropriate regulatory requirements and a regulatory agency staffed with qualified personnel, successful companies develop innovative strategies to manage all potential impacts of mining and processing on workers, communities and the environment. An ongoing dialogue among the main stakeholders – the community, the mining company and the government – has proven critical in this regard.

Leading practice uranium mining is highly regulated and in several important ways distinctly unlike mining practices employed in the past. Today, mine and mill workers are trained and protected from unacceptably high exposure to radiation through a combination of implementing safe working practices and, in both underground mining operations and uranium mills, using high-capacity ventilation systems that continuously evacuate airborne radioactive particles from higher-risk working areas. Environmental planning and monitoring throughout the life cycle of the mine ensures that the planned life cycle performance is achieved through to the post-decommissioning period, minimising the environmental effects to acceptable standards and avoiding impacts on local populations. These greatly improved modern mining practices are the combined result of learning from past practices, implementing stringent regulatory requirements to achieve societal expectations and successfully applying innovative approaches developed by companies to meet, and in many cases exceed, these regulatory requirements.

In addition to providing an overview of leading practice uranium production for the interested public, recommendations on regulation and mine development policies for currently producing countries and for those countries that are considering hosting uranium production for the first time are included in the full report. For countries considering hosting uranium mining for the first time, implementation of all the aspects outlined in the report should be adopted as long-term goals since it takes time to develop the significant capacity required to create legislation and regulations, as well as to accumulate the resources and expertise needed to effectively regulate the facilities. However, the key components of life cycle mine management must be in place prior to mining.

Uranium will be an energy resource that is in demand for decades to come owing to the need to meet raw material fuel requirements for an existing and developing global fleet of nuclear power plants. New mines will be needed, in some cases in countries that have never hosted uranium mining. Key stakeholders will play an important role in facilitating the safe development, operation and closure of uranium mining operations in an environmentally responsible manner.



Perceptions and Realities in Modern Uranium Mining

Uranium mining and milling has evolved significantly over the years. By comparing currently leading approaches with outdated practices, the report demonstrates how uranium mining can be conducted in a way that protects workers, the public and the environment. Innovative, modern mining practices combined with strictly enforced regulatory standards are geared towards avoiding past mistakes made primarily during the early history of the industry when maximising uranium production was the principal operating consideration. Today's leading practices in uranium mining aim at producing uranium in an efficient and safe manner that limits environmental impacts to acceptable standards. As indicated in the report, the collection of baseline environmental data, environmental monitoring and public consultation throughout the life cycle of the mine enables verification that the facility is operating as planned, provides early warning of any potentially adverse impacts on the environment and keeps stakeholders informed of developments. Leading practice also supports planning for mine closure before mine production is licensed to ensure that the mining lease area is returned to an environmentally acceptable condition. The report highlights the importance of mine workers being properly trained and well equipped, as well as that of ensuring that their work environment is well ventilated so as to curtail exposure to radiation and hazardous materials and thereby minimise health impacts.