



Environmental Remediation of Uranium Production Facilities



Nuclear Development

Environmental Remediation of Uranium Production Facilities

**A Joint Report by the
OECD Nuclear Energy Agency
and the
International Atomic Energy Agency**

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PREFACE

Since the mid-1960s, in co-operation with their members, the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) have jointly prepared the periodic report *Uranium: Resources, Production and Demand*. The report commonly known as the “Red Book” is published by the OECD. The eighteenth edition of the “Red Book” was published in 2000.

In 1999, the Joint NEA/IAEA Uranium Group, which prepares the “Red Book”, established a Working Group on Environmental Restoration of World Uranium Production Facilities. This was done in response to the broadened mandate of the Joint NEA/IAEA Uranium Group to foster the exchange of information on environmental effects and environmental technologies associated with uranium mining and ore processing.

In order to obtain an overview of the situation, the Working Group sent a questionnaire to Member countries/states requesting information about remediation activities. The results of the survey were analysed by the Group and analytical reviews were prepared describing the most relevant issues involved in the remediation of uranium production facilities. The questionnaire results and analytical reviews form the basis of this report.

Acknowledgement

The Working Group and the Joint NEA/IAEA Uranium Group would like to acknowledge the co-operation of all the organisations (see Annex 2) that submitted information for this report.

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EXECUTIVE SUMMARY

Remediation programmes for uranium production facilities being conducted or planned in the world have a major objective of establishing long-term, stable conditions to ensure the safe use of the site by both current and future generations. Wherever possible, the remediation plan aims to achieve the return of affected areas to previously existing environmental conditions or to a land use that will be sustainable in the long term.

This report provides a summary of the most relevant issues and practices in remediation programmes of uranium production facilities and an overview of activities and plans in countries that participated in the study. Twenty-two countries (12 OECD and 10 non-OECD countries) provided information on historical, ongoing and future remediation activities and on relevant governmental policies and regulations.

Remediation of uranium production facilities encompasses activities to restore areas including mines, mills, waste management facilities, tailings containment, and land and water resources. At the outset of a remediation programme, the final land use for the site is agreed with the stakeholders. Every effort is made to ensure that the expectations and requirements of the stakeholders are fully taken into account. At the same time, care is taken to ensure that the agreed outcome is practicable within the constraints of environment, economics or finance that may apply in the specific instance at the time of planning or in the foreseeable future. The principles of environmental protection, sustainable development and intergenerational equity should be taken into consideration at all stages of the remediation process.

A remediation programme typically includes considerations such as the following:

- Remediation is carried out with appropriate plans and specifications that must comply with relevant laws, regulations, license provisions, and established criteria.
- Remediation limits the residual impact to as low as can be reasonably achieved (ALARA), economic and social factors being taken into account. Most countries have defined an acceptable level of impact to the public and the environment.
- All residual contaminants are properly contained or controlled as long as necessary. Many countries have regulations or guidelines for the design and construction of containment systems used for contaminants.
- Radon and radioactive dust emissions are properly controlled and/or contained in view of future land use scenarios or site development plans.
- All water resources, both above and below ground, are protected from contamination to appropriate levels and extents.
- For final land use, radiation doses and exposure pathways for individuals who might live at, work on or visit the site, are assessed.
- The site is remediated in such a way that future maintenance requirements are minimised to the extent practicable.
- There should be a minimum limitation to public access to remediated land and site.

In the report, relevant topics are discussed in the following areas: site characterisation; decontamination, dismantling and decommissioning; waste management; water remediation; long-term stewardship and monitoring; policies and regulations; and costs.

Clean-up criteria, policies and regulations

Given the increased awareness of environmental and health issues in general, many countries have adopted, or are in the process of adopting, policies aimed at the improving and reinforcing the: health and safety of workers and the public; protection of the environment; sustainable economic, social and environmental development; and public participation in environmental decision-making.

The policies and legislation pertinent to the uranium mining industry tend to be rather complex in most countries and they typically include sometimes competing requirements from a number of diverse fields, such as mining law, environmental law, toxic and / or radioactive waste regulations, radiation protection at the work place, etc.

Risk analysis and management

The remediation of uranium mining and milling facilities is an activity that calls for the application of proper risk analysis and management at all stages of the process. Environmental risk management in particular should be applied to ensure that optimised outcomes are achieved from the remediation work. The scope of environmental risk analysis in this context is very broad and should consider adjacent communities as part of the environment, which means that health risks become an integral part of the risk analysis.

The risk analysis and resulting management steps need also to take into account conventional as well as radiological risk emerging from the actual remediation operation, such as the operation of heavy equipment and the transport of contaminated materials between sites.

Site characterisation

Pre-operational and post-operational characterisation of the site forms the basis of any environmental remediation programme. This characterisation included the collection of data on the hydrological, climatological, geological, geotechnical and ecological properties of the site and its surroundings. The type of mining and processing methods employed over time and the types of waste generated need also to be assessed.

In many instances communities, ranging in size from small camps to large cities, have been developed in association with, or became dependent on the mining operations. The cessation of mining and milling operations may have a substantial social impact on such communities and such effects must be taken into account when planning the overall remediation process.

The collection and use of site characterisation data are indispensable and their availability is crucial to ensure the successful implementation of remediation.

Decontamination, dismantling and decommissioning

Based on the agreed land use plan, a decision on the future use of the mine-related infrastructure will have been made. All buildings, mills, laboratories, chemical and product stores, airfields, etc., which are not needed any more are often decommissioned and removed in a remediation programme. Roads may also need to be removed, although they are often left to provide access for monitoring and surveillance after the works programme has been completed and for community use. Many elements of an uranium mining and processing facility are likely to be below ground level. These may include the mine workings itself, basements, storage facilities, explosives magazines, crushers, silos, service tunnels, cable ducts etc. Such installations may be either left underground and perhaps, backfilled, or may need to be removed to clear the ground for new foundation work.

Radioactively contaminated sites will require decontamination as part of the decommissioning process. The rules and regulations relating to public and worker safety must be strictly observed in all decontamination work. Decontamination techniques include scraping or jack hammering, sand blasting, washing and high pressure hosing, chemical solvent washing, strippable paints, water treatment, etc.

Waste management

Mining operations produce waste of different types, all of which require appropriate management. These waste materials include development waste from initial excavations such as soil materials, un-mineralised rock materials, ores with sub-economic levels of mineralisation or high levels of contaminants, as well as processing wastes, the largest volume of which are mill tailings. Wastes from water treatment, and residues from cleaning and dismantling processes also need to be managed. Upon closure, mining and milling waste management facilities need to be decommissioned and sometimes remediated, in order to ensure their long-time stability.

Mill tailings are a type of processing waste associated with uranium production that pose particular problems. The final containment of tailings is usually one of the largest issues in uranium mine site remediation due to the risk to the environment and to the public in terms of the physical volume, radiological and chemical contaminants.

Water remediation

One of the principal pathways by which contamination may reach the environment from uranium mining and milling operations is by water. In mining operations, dewatering underground and open pit mines might produce water contaminated with radioactive or other materials. Contaminated water might also occur as a consequence of surface water runoff from, and seepage through, the waste rock piles and ore stockpiles, and as seepage through tailings impoundments. Therefore, the environmental restoration of any uranium production facility may need to include the restoration of surface and groundwaters and the treatment of effluents from waste management facilities, such as tailings impoundments.

Long-term stewardship and monitoring

Monitoring has become a standard principle by the uranium industry and governmental authorities in countries all over the world. This is to ensure and verify that the public and environment

are protected from the effects of radiation exposure during operation and after uranium related facilities have been closed and decommissioned. When mining facilities are closed, monitoring may be required for an extended period to verify that closed facilities are not causing adverse impacts to human health or the environment.

The use of long-term monitoring as a part of the decommissioning plan is, in effect, long-term stewardship or institutional control, which is often provided by the country. Decisions on whether controls should be “active” or “passive” are made during the planning process. The period for which monitoring is to be part of these controls is also a question that must be determined, as is the question of how frequently monitoring will take place, what will be measured, what kind of equipment will be used, what measurements will trigger a response action, and who is responsible for the monitoring and emergency actions.

Costs and funding

The statutory framework regulating modern uranium mining in many countries makes it mandatory for uranium producers to take into account the costs of decommissioning and remediation and to make appropriate funding provisions during the operating life of facilities to cover these costs.

Although cost data are provided in the report for a number of countries, it should be noted that meaningful comparison of costs could not be made between sites or countries without additional detailed data and analysis, as these costs were found to be very site specific. The cost data reported are primarily to provide a global perspective and information base for policy and decision makers so that such costs can be accounted for and allocated as with any other social costs.

1. INTRODUCTION

Increased awareness of issues related to human health and the environment represents one of the most important priorities in current public attitudes and societal values in the world. This has resulted from concern over the degradation of local environments due to problems such as traffic congestion and air pollution, and through the increasing evidence of adverse effects of industrial development on the global environment, e.g. acid rain, global warming, biodiversity. These changing societal values are reflected in a heightened political profile for such issues. Environmental and health issues must be factored into industrial development and growth. Environmental issues now form a key element of government policy in many countries. There is an increasingly broad legislative base in this field, both at the national level and at the international level, as evidenced by the growing number of international conventions on issues of global environmental concern.

These environmental concerns and priorities are also affecting the uranium mining and ore processing industry. For example, it is likely that any new mining project, no matter where it takes place, will be subject to strict assessments of the impact on the local environment and public health. In many cases, full details of mitigating measures and final remediation plans will be required before development licences are granted. Many countries have already implemented very strict criteria for uranium exploitation projects. A major concern, however, is how modern standards of environmental protection can be met in places where past mining practices were not subject to the current, more stringent levels of regulatory control and have left a legacy of abandoned sites and facilities. Many of these sites require remedial action to reduce the levels of risk to workers, the general public and the environment.

Environmental remediation of uranium sites encompass [1]:

- Decommissioning and clean-up of redundant or disused structures on a site.
- Remediation of any contaminated waters and soil.
- Remediation of the site to a level appropriate to its planned future use.
- Management of any resulting wastes.

This problem is especially challenging to countries that are currently facing economic difficulties and where the burden for remediation has fallen on the State [2-4].

A major objective of remediation programmes for uranium production facilities being conducted or planned in many countries is the establishment of long-term stable conditions that will ensure the safe use of the site by both current and future generations [5]. Wherever possible, the plan is to achieve the return of affected areas to previously existing environmental conditions, or to a land use that will be sustainable in the long-term and acceptable to all stakeholders. Alternatively, the objective is to reduce the area of restricted use to a minimum.

This report provides a summary of the most relevant issues and practices in remediation programmes of uranium production facilities and an overview of activities and plans in reporting countries. Relevant issues are discussed in the areas of: site characterisation, decommissioning,

decontamination and dismantling, waste management, water remediation, long-term stewardship and monitoring, policies and regulations, and costs. The country profiles of remediation activities and plans include information related to issues judged to be important by the country and are based on survey responses provided by 22 countries (12 OECD and 10 non-OECD countries). However, the reported information varies from country to country in scope and level of details, and no attempt has been made to standardise the submissions to follow any particular format or style.

The report is not intended to provide specific recommendations or guidelines nor is it a comprehensive review of all activities related to environmental remediation.

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2. SITE CHARACTERISATION

Objectives

Site characterisation is the first step required in the remediation and reclamation of former uranium facilities. Data on site properties and conditions form the basis for environmental impact assessments, risk analyses, decommissioning/close-out plans, remediation programmes, long-term stewardship and monitoring and ultimate release of the site. In general, data on geological, biosphere, radiological, operational, and socio-economic conditions are necessary to characterise the site. Ideally, the data gathering should have begun before exploitation activities commenced (baseline data) and continued until after operations ceased. While final land use planning may have a significant effect on remediation, environmental remediation programmes are developed based on baseline data (if available) and post operational characterisation of the site and depend significantly on the type of mining and processing methods utilised, as well as the types of waste generated. Therefore, the collection, availability, and use of site characterisation data are indispensable to ensure the successful implementation of remediation projects [1,2].

Data quality objectives and appropriate quality control and quality assurance procedures have to be put in place before data collection begins.

Key factors that can influence the design and implementation of an environmental remediation programme are: site topography; geology; hydrogeology; hydrogeochemistry and climatology; ecology; operating characteristics; radiological characteristics; socio-economic characteristics; legal requirements and risks assessment and risk management. These factors will be discussed in more detail in the remainder of this chapter.

Topography of the mine site and adjacent region

- The topographical setting, e.g. whether the site is located in a valley or on a hillside etc., can have a major bearing on potential environmental impacts. The basis for the assessment are up-to-date topographical maps and plans. Today, much of this information may be available in digital form, and indeed Geo-referenced Information Systems (GIS) are the tools of choice for managing the data discussed below.
- Identification of all plant, mine, and waste management areas, affected infrastructure and confirmed or suspected areas of on-site or off-site impact.
- Administrative delineation of protected zones, such as nature reserves, groundwater resources, etc.

Geology

The required geological characteristics of a site include:

- Data on the properties of rocks and soils, including stratigraphy, tectonics and seismicity, lithology, sedimentology and mineralogy (particularly the presence of acid-generating minerals, such as pyrite, or toxic elements, such as heavy metals and radionuclides).
- An inventory and characterisation of any materials available for remediation purposes, e.g. cappings for waste rocks or tailings impoundment.

Hydrogeology, hydrogeochemistry, and climatology

The climatological, hydrogeologic and hydrogeochemical characterisation of an area is needed for the assessment of impacts the operation may have on water bodies located in the area. In turn, the specific climatological and hydrogeological characteristics may influence decisions on strategies and techniques for remediation.

The climatological and hydrological characterisation typically includes:

- Annual/monthly precipitation (rain and snow) pattern.
- Annual/monthly temperature pattern.
- Annual/monthly wind speed pattern and storm frequencies.
- Distribution of surface water bodies, such as lakes, ponds, rivers and creeks, their catchment areas, drainage and storm runoff pattern.
- Data on evapotranspiration and the distribution of groundwater recharge/discharge areas and associated rates.
- Information on the scope and frequency of ongoing monitoring programmes.

The hydrogeological and hydrogeochemical characterisation of an area needs to include:

- Identification of aquifers, impermeable strata and depths to water table(s).
- Groundwater isohypses, hydraulic gradients, flow rates, permeabilities and transmissivities as a basis for a conceptual hydrogeological model.
- The groundwater quality (e.g. pH, Eh, major cations/anions, trace elements, organic contaminants) and related aquifer properties such as sorption characteristics, etc.
- The surface water quality and the quality of respective bottom sediments.
- Records of changes in the surface water and groundwater characteristics over time and in particular since the beginning of the operation.
- Information on the scope and frequency of ongoing monitoring programmes.

In some cases, the available information on pre-operational water conditions is limited, making it difficult to understand the changes resulting from uranium production. Knowledge of water composition, including contaminants, is necessary to determine the effect complexing agents (hydroxyl, carbonate, sulfate ions, organic compounds), might have on the fate of radionuclides, such as U, Th and Ra, in terms of migration behaviour (sorption, retention) and also their bio-availability.

Understanding hydrological balances of the site and the surrounding lands is an important input into the design of waste management facilities and remediation programmes. Knowledge of the catchment area occupied by the mine as well as the identification of surface and subsurface discharge areas is of prime importance, particularly for understanding environmental contaminant migration

dominated by water pathways. In the case of *in situ* or heap leaching mines, surface and groundwater information and monitoring data are essential. Analyses of water sampled from surface runoff, wells and piezometers at the mine site, its boundaries, and non-impacted background areas provide a direct measure of the extent of contamination, and will guide the measures necessary to remediate the site.

National laws and regulations of each country will assist in identification of contaminated water (pollutant concentrations) and extent to which the water must be cleansed. A case study of the Cunha Baixa mine in Portugal at the end of this chapter demonstrates how preliminary geohydrological and geochemical studies can promote future site characterisation efforts.

Typically this information is used to construct a computer-supported hydraulic model of the site and the adjacent area. Such models are used in the planning and operational phases to derive relevant engineering parameters and perform risk analyses, and during closure phase to assess impacts and the effect of mitigation measures.

Ecology

The remediation of an uranium mining and milling site typically requires that the local ecological system, comprising fauna and flora, be restored as closely as possible to baseline conditions or at least to a sustainable state. The newly created ecological system may also need to be compatible with the planned future use of the site, or in turn, may place restrictions on the use. Mapping of flora and fauna is a standard element in environmental impact assessments supporting the licensing procedures and will often provide the needed baseline information.

Revegetation is likely to be the major activity in ecological restoration. The factors likely to impact on revegetation success include:

- The stability and erosion resistance of slopes and berms.
- The mineralogical and granulometric properties of the substrate, e.g. waste materials, cover materials, including the availability of humus.
- The presence in the soils of conditions inhibiting growth, such as presence of heavy metals, high salt concentrations, or organic contaminants, or too high or too low soil pH values, toxic soil gases, or the supply of nutrients.
- The climatological and micro-climatic conditions at the site.

The habitat restoration will also be guided by aesthetic factors, e.g. trying to blend in the revegetated areas. Natural re-inhabitation by fauna and flora can be an important mechanism that also can be actively supported.

Operational characteristics

Baseline data

The development of a mine complex can result in major changes to local site topography, hydrology, and ecology. Remediation and reclamation activities usually attempt to restore a site as much as possible to its pre-mining conditions, so a collection of pre-operational baseline environmental data should be undertaken before commencing major site activities. These measurements can be used as references during cleanup associated with the decommissioning/close-

out phase and for post close out monitoring and surveillance activities. These data may have been collected as input for environmental impact assessments associated with the license application process in many modern mines (typically post-1970).

When pre-operational baseline data are unavailable, such as is the case for many older facilities, it may still be possible to obtain suitable data by making measurements in nearby areas unaffected by the mining operation or mineral processing facilities. However, in extrapolating such data to the site, it is important to recognise that natural baseline conditions can vary significantly over short distances.

The successful rehabilitation of a mine/mill complex can best be achieved if, from the time of the initial project planning, all mining and milling operations are planned and carried out to meet the requirements for final site remediation [3]. If not, rehabilitation will usually involve additional effort and be more expensive. It is generally known which facilities, structures, buildings, etc. would need to be decontaminated and dismantled and which waste management areas would be closed out. However, the characteristics of the mill tailings impoundments and other waste management facilities may, or may not, be well known, depending on when these facilities were built and what were the regulatory requirements at that time.

After the decommissioning/close-out requirements have been established, existing operational data and records should be evaluated in conjunction with the site characterisation data to determine which operational data will be useful.

Mining operations

The characterisation process needs to consider the type of mine, and the operational approach used. Some of the issues are:

- The mine type: whether conventional open-pit or underground operations, *in situ* leaching (ISL) or in-stope (bloc) leaching, or a mixture of two or more of the above methods have been employed. The type may have changed over time.
- The mine layout: structure of the mine, depth, type of access, number of levels, shafts, drifts, adits etc., and their lateral extension as laid down during the operational mine surveys, arrangements for dewatering the mine, the nature and method of backfill, degree of backfilling, numbers and placement of injection/extraction wells for ISL operations.
- An inventory of all surface facilities and installations at each mine and related waste and debris disposal areas and impoundments, together with relevant plans and maps.
- The extraction methods used over the lifetime of the mine(s): blasting, cutting, digging, leaching etc. Explosives used in blasting can result in enhanced concentrations of nitrates and organic compounds in mine drainage and groundwater. For ISL, the use of acid or alkali leachants may lead to metal contamination in surface and subsurface waters if not properly contained. Also, improper ISL well closures can significantly impact groundwater and foster migration of pollutants outside the ore zone.
- Geotechnical aspects: stability of underground mine workings, subsidence and settling, stability of slopes and berms in open-pits, stability of waste rock and impoundments, stability of any backfills both for open-pit and underground mines.
- The tonnages of mine outputs over its lifetime, characteristics of the ore bodies such as size, mineralogy and grade, associated potential contaminants, amounts of ores and below-grade ores remaining.

- The amounts of waste and barren rocks produced, amounts of below-grade ore stockpiled, volumes of mine drainage discharged, volumes and location for disposal of treatment residues such as evaporation pond sludges, types of liners, cappings and drainage systems, if any.
- The method of treating and discharging drainage waters and other mine effluents, disposal of solid water treatment residues.
- The type and sequence of operations involved in the closing of the mine.
- The history of the site's general industrial development.

Milling operations

Characterisation of mill facilities encompasses data on:

- Milling processes employed, e.g. crushing, grinding, vat leaching, heap leaching, resulting residues and wastes, and any materials used, such as acids, alkaline solutions, ion exchange resins and precipitating agents.
- An inventory of all systems, facilities and installations at each plant and waste management facility, together with relevant plans and maps; data on their historical development; information on the method of transport and delivery of ores.
- A description of all areas, and their location, and the respective classes of environmental concern, e.g. radioactive contamination and wastes; controlled and hazardous substances and products; hazardous and special wastes.
- Methods of treatment of residues and wastes: such as neutralisation, flocculation, dewatering, evaporation, e.g. in ponds, and any materials and agents used for these processes.
- Methods of storage and disposal of residues: such as tanks, settling ponds, tailings impoundments, injection wells.
- Amount of residue and wastes in each storage and disposal facility, and residues in facilities that have not been decommissioned, such as evaporation ponds.
- Surface and subsurface contamination resulting from these operations would have been assessed as part of the site characterisation process, while health and environmental hazards ensuing from wastes and residues would be assessed as part of the risk assessment process.

Waste

There are three main types of waste arising in mining and milling operations: mine wastes, milling wastes and wastewater. Each type of waste is subject to an appropriate management strategy. Hence data on tonnages/volumes and composition/characteristics of each are needed, together with their mineralogical and geochemical characterisation, e.g. concentrations of radionuclides and other contaminants. Residues and wastes from conventional uranium mining are similar to those from non-uranium mining. For uranium mining and milling operations, potential contamination by radionuclides of soil, rock, water, and radon emanation into the ambient air is more obvious, but not restricted to them.

Concerning *waste rocks*: storage and disposal methods of this material may directly result in impact on the environment (generation of acid drainage and its impacts on wastes), as well as on site stability. Information on waste rock composition and geochemical characteristics are needed, in particular on the content of acid-generating minerals (sulfides, such as pyrite), of heavy metal (e.g. Cu, Cd, Zn) containing minerals, and minerals containing other elements (e.g. As, Se) of potential concern. Sulfide minerals are the source of drainage water acidification, which in turn increases the mobilisation of heavy metals and other elements of concern from both, the waste rock and underlying strata.

Concerning *tailings*: surface disposal of tailings may impact the environment through discharge of porewaters and acid leachates containing heavy metals and other contaminants. In addition, records of other materials disposed of in tailings impoundment, such as debris, should be searched. It should be mentioned that, typically, milling processes do not remove most of the non-uranium radioactivity, and therefore, a radiological characterisation may be necessary.

Concerning *residues from water treatment*: Residues from the treatment of ISL mine and HL effluents may also impact the environment as evaporation ponds can contain significant levels of residual uranium, radium, and metals either dissolved or as suspended solids in the water, and as solids collecting at the bottom of the impoundment. Other waste water treatment techniques potentially resulting in surface or subsurface contamination are: the spraying of effluents on lands, or deep well injection. Evaluation of records on those processes is useful for assessing potential future environmental impacts resulting from migration of radionuclides and other pollutants.

Radiological characteristics

Health impacts may be attributable to the various emissions generated by the site in question.

- The water quality of surface and groundwaters can have a direct impact on human health via drinking waters and indirectly through irrigation of agricultural land or watering livestock.
- The quality of the air around the site (emission of contaminated dust, radon emanation, etc.) will potentially have a direct affect on human activities and health via inhalation.

Hence, gamma, alpha and beta surveys are needed to determine the nuclide-specific (background) radiological characteristics. As emphasized previously, baseline environmental data should be collected during the pre-operational stage of a mine/milling facility. In fact, relevant data are usually collected as input for environmental impact assessment that are a key element of the licensing procedure. This information is also needed to determine zones of impact. Modelling of the dispersion through waters and the air will constitute an important tool for the assessment and management of potential impacts.

A discussion of methods of site characterisation for radiation as employed in the United States of America is included later in this chapter as a case study. The method highlights sampling and characterisation methodology at the different stages of the remediation programme. This includes steps from the preliminary assessment, to the remediation support survey and final status survey.

Exposure scenarios and critical groups

While the remediation workforce certainly will be one of the most exposed groups i.e., a “critical” group, their exposures will formally be regulated and monitored. However, the adjacent population may also be at risk to be exposed to the radioactive emissions from the site itself or from

the remediation activities and thus may also need to be treated as a critical group. Examples of such groups are:

- People living closest to the site and subject to direct exposure from the site.
- People living downwind, potentially receiving (radioactively) contaminated dust and radon emanations from the site, or consuming foodstuffs contaminated by fallout of dust from the site.
- People living downstream of the site, which may drink water or consume food derived from the downstream aquatic environment, e.g. fish from lakes, or plants irrigated with contaminated water.

When considering the exposure levels of the critical group, it should be remembered that the issue is the increase in dose over the “natural background exposure” in the area concerned. This added exposure is calculated according to a realistic scenario based on measured data from where the population lives, and after deductions based on measurements made at a reference station. It will only be after a comprehensive analysis of the potential pathways and risks has been completed that the most exposed group can be identified. For this analysis, the calculation of the potential exposure will be based on a combination of measured and estimated doses, using data collected from either a regional reference station or, preferably, data collected on and around the site before the remediation work commences and possibly before the uranium operation has started. It is likely that a modelling exercise will be required to complete the dose calculations, especially for the periods before works begin.

Once this has been undertaken, appropriate management plans can be formulated with the intent of reducing the risk to the critical group, by either eliminating or minimising the different exposures. In this context, the idea of risk “treatment” is often used rather than management, as this will separate the activity from the overall environmental management processes that will be in place during the remediation works.

Throughout the remediation programme, the risk assessment should be updated after each successive stage that contributes significant data. The process of “Plan, Do, Check, Act” should be the dominant process of the environmental management system in this phase. Such an iterative process will ensure that the optimal solution is achieved in the final stage. Since the particular risks under consideration are radiological, the principles of ALARA must also be included in the evaluation process.

Additionally, at every significant stage of the programme, the works must be evaluated for compliance with the appropriate regulations and standards set by the regulatory authorities. Also, the progress must be evaluated against the targets and objectives of the overall remediation programme.

Socio-economic characteristics

In certain communities, mining activities constitute a major source of community income. Closure of a mine can socially and economically destabilise a community, resulting even in its abandonment. Therefore, assessing in advance, potential social and financial impacts, and planning to mitigate those impacts and community is extremely important.

In general, the socio-economic aspects of closing, decommissioning and remediating uranium production facilities constitute key components for the success of the project, and are as important as the scientific and technical aspects.

Socio-economic aspects include variables such as the demographic structure, business areas, employment patterns and opportunities, and levels of education and training. In addition, actual and potential land uses need to be assessed, together with restrictions or easements, such as sites of historical, archaeological, spiritual or religious value or scenic beauty. The land use options may also be predetermined by existing legislation, agreements and plans.

Ultimately, decommissioning and remediation objectives are often determined in an iterative procedure reconciling public acceptance and expectations, availability of socio-economic resources, legal requirements and technical feasibility.

Legal requirements

Appropriate international, national, regional, and local legal statutes and requirements must be assessed in regards to their relevance and potential influence on all aspects of site remediation. In instances where controlling laws, regulations, or other standards are missing or conflicting, means must be sought to determine or obtain governing requirements for each step in the remediation process. Failure to take this into account from the beginning will likely severely interrupt project activities, delay implementation and result in additional costs and impacts.

Risk assessment and risk management

There are a variety of risks which ensue from mining and milling sites and indeed, from any remediation activity. Hence, remediation of uranium mining and milling facilities is an activity that requires appropriate risk management at all stages of the process. These risks may be conventional or radiological and typically include:

- Damage to the environment.
- Environmental and occupational human health risks.
- Financial and economic risks.
- Technical risks.

Optimised risk management integrates all these aspects to ensure that the intended outcomes are achieved from the remediation work. The scope of an integrated risk analysis in this context is very broad and may include consideration of the community as part of the environment. This ensures that health risks become an integral part of the risk analysis. Risk assessment and management programmes are organised in several stages:

- **Scoping**
Qualitatively evaluate contaminant release, migration and fate. This includes identification of contaminants of human and ecological concern, receptors, exposure pathways, known and potential effects and hazards, selection of endpoints of concern, and specification of objectives and scope of the problem for assessing the uranium mining or milling site and planning its remediation.
- **Exposure assessment**
Conduct field and laboratory studies to quantify the release, migration and fate of contaminants, characterise the receptors and the site including its surroundings, and measure or estimate exposure point concentrations and doses. Quality assurance and quality control

methods applied during this stage provide a means for assuring the risk assessment is an appropriate portrayal of site conditions.

- Ecological and human effects assessment

Determine the impact of contaminants potentially and actually released at the site. Utilise literature, conduct toxicity testing if necessary, evaluate field and laboratory studies to quantify the uptake and effect/dose response of contaminants from the site.

- Risk characterisation and assessment

Using agreed upon or nationally prescribed models and methods determine and quantitatively describe the current adverse affects of the site integrating the individual characterisations from the previous stages of work. Also, evaluate the future adverse effects from the site in case no remediation is undertaken. In conducting this work, an uncertainty analysis should be performed to quantitatively evaluate the strengths and limitations of the risk assessment, including sensitivities of any mathematical models used and uncertainties in input parameters.

- Remedial objectives and goals

Establish the objectives and goals for site cleanup and remediation considering appropriate regulatory requirements, standards, and criteria for environmental and human health protection. Take into consideration the expressed concerns of human communities for site restoration, including planning for future land use and institutional control of the site required. Also, establish the risk levels acceptable for protection of human and ecological health and safety from contaminant releases from the remediated site.

- Analysis of remedial alternatives

Evaluate alternative means for site remediation and whether the alternatives will meet the remedial objectives and goals. This includes the use of sensitivity studies including risk assessments to compare the risks associated with the various remedial alternatives.

- Public consultation

Consultation will provide valuable input to the selection of alternatives and means of remediation, especially, on the analyses conducted and the potential remedies (including consideration of restoration costs), final disposition of the site when remediation is completed, acceptability of risks posed by the alternatives and necessity for future maintenance and long-term monitoring.

- Monitoring site operation and maintenance

Risk assessments continue to play a role in the evaluation of the chosen remediation alternative against the original criteria for site remediation. The results from long-term monitoring of environmental performance provide inputs for updated analyses to determine, if further restoration or intervention is required, or whether the site remediation is performing as designed.

It is vital that this analytical approach to risk management be integrated into the overall management of the remediation process. The risk analysis process is similar to that employed at any industrially contaminated site, but with the additional requirement to consider radioactive contamination and the analysis of the associated risks to the environment and the community.

CASE STUDY: USA – Procedures developed by the US governmental agencies for radiological surveys of contaminated sites and land areas

Methodological approach

In the United States, four Federal Government Agencies, the Environmental Protection Agency, the Nuclear Regulatory Commission, the Department of Energy, and the Department of Defense worked together to prepare a manual for radiation site investigations, the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [4]. The manual, available on the Internet at <http://www.epa.gov/radiation/marssim/filesfin.htm> provides an extensive step-by-step method to planning the site survey including methods for sampling and instrumentation as well as costs. It was written on the principle that a site to be released for use after cleanup must demonstrate that it has met governmental or other release criteria. The manual identifies certain phases of the work, first translating the release criteria into a corresponding derived concentration of radioactivity in the soil through use of environmental pathway modeling; areas for investigation are grouped in separate classes by likelihood and expected levels of contamination which help inform the statistically based sampling scheme. It then provides information on how to acquire scientifically sound and defensible site survey data on the levels of radioactive soil contamination as well as background levels of radioactivity by employing suitable field and laboratory techniques. It covers the survey of contaminated sites from buildings to open field areas. Next is a decision phase under which it is determined whether the survey data, after remediation, indicates that the site meets the release criterion within an acceptable level of uncertainty through application of a statistically based decision rule.

Discussions of survey methods below are derived generally from that report. Sampling schemes for radiological contamination may also be applicable to contamination from metals or other pollutants present at the site.

Historical site assessments

Whether a radioactively contaminated site to be assessed is part of a mine, distribution facility, or mill tailings impoundment, the possibility exists that radionuclide contamination may extend both, across the facility, and beyond its physical boundaries. Preliminary site investigations can determine the extent of radiation occurrence and movements both inside and outside facility boundaries, affected media (soil, water, air, buildings and equipment) and also establish background levels of radiation at sites not affected by the uranium production operations, such as where waste rock has been re-used for construction purposes.

US national regulations determine how background levels of radiation must be taken into account for making decisions on the extent and degree of site remediation. This guidance indicates whether a remediated site must be restricted from certain uses or may be released for general use by the public. The delineation of radiation background is an important step in site restoration as many cleanup requirements are based on the determination of that value. Statistical tests are used to evaluate data from final status surveys for contaminants that are present in background and when the contaminants are not present in background. A site background reference area should have similar physical, chemical, geological, radiological, and biological characteristics as the survey unit being evaluated, but should not be necessarily part of that survey unit (i.e., on the grounds of the uranium recovery site). Statistical tests should be conducted to verify that a particular background reference is appropriate for a survey.

In some instances, original radiation survey data may be available for the uranium operational site with which to compare current radiation levels, however, this is not usually the case. In establishing a baseline, reviews of historical operational documents, radiation licenses, maps, aerial or satellite photography, exploration records, and written correspondence of the uranium production facility may provide clues and documentation as to the extent of movements of raw ores, products, and wastes, and sometimes background radiation data. Geological and topographical maps, if available, will also yield information on possible pollutants dispersal across a site.

Scoping surveys

The objective of the scoping survey is to supplement the historical site assessment. Planning the survey involves reviewing the historical site assessment to determine the appropriate cleanup radiation level for the site, and a limited amount of surface radiation scanning, surface activity measurements, and sample collection (smears, soil, water, vegetation, paint, building materials, subsurface materials). These radiation measurements are used to examine areas likely to contain residual radioactivity. Any samples collected as part of the scoping survey should be subject to sample tracking procedures, including chain-of-custody for quality assurance and control.

Based on the classification of the area for contamination potential, grid patterns of 10 to 20 metre intervals on land areas may be sufficient to identify survey locations with a reasonable level of effort. For areas expected, or known, to be generally devoid of radiation, grids may be at larger spacings, such as 20 to 50 metres apart. Such grids can be physically marked by chalk lines, paint, or stakes. The use of global positioning system (GPS) technology may provide alternate sampling site record data.

Characterisation surveys

This type of survey is performed to satisfy objectives such as 1) determining the nature and extent of contamination, 2) evaluating remediation alternatives and technologies, 3) input to pathway analyses including risk and dose assessments, 4) estimating occupational and public health and safety impacts including the remediation process, 5) development of final status survey design, and 6) determining final corrective measures for the site. The design of the survey should be based on specific data quality objectives for the information to be collected and can usually be planned using the historic site assessment and scoping survey. Such a data quality objective process ensures that adequate amounts of data with sufficient quality are collected for the purpose of characterisation [5]. The survey should provide information on variations in the contaminant distribution in the survey area; the necessary number of data collection points can be determined using statistical methods. Selection of survey instruments and analytical techniques should be derived from knowledge of the final radioactivity cleanup goals and the known levels of residual contamination. Exposure rate measurements may also be needed to safeguard the occupational health and safety of the survey crewmembers.

Surveys of building surfaces and structures include surface scanning, surface activity measurements, exposure rate measurements, and sample collection, such as smears, subfloor soil, water, paint, and building materials including concrete, can be conducted onsite using a systematic approach and professional judgement.

Land area surveys for surface and subsurface soils and media involve techniques to determine the lateral and vertical extent and concentrations of radionuclides in the soil. The measurements can be obtained by either sampling and laboratory analyses, or *in situ* gamma spectrometry. Sample locations should be documented using coordinates (a grid) as discussed above. Groundwater monitoring well

locations should also be planned and recorded. Contaminant concentrations and sources should be mapped to show the relationship between contamination, sources, hydrogeologic features, and site boundaries. Air sampling may also be necessary for radioactive dusts and radon emissions. Vegetation may also be sampled and provide some indication of radionuclide uptake, but this may change once the site is reclaimed.

Documentation of the survey should provide a complete record of the radiological status of the site. A report including sufficient information to characterise the extent of contamination, including all possible affected media should be developed. This may, then, serve as the basis for discussion of approaches and alternatives for site decontamination.

Remediation support

After a decision is made on appropriate methods for decontamination and remediation of a site, and the actual remediation process begins, it may be useful to conduct limited remediation action support surveys to determine the effectiveness of a remediation method, determine when a site is ready for a final status survey prior to release, and provide updated estimates of site specific parameters for use in planning the final status survey. A remedial action support survey helps in monitoring how effective decontamination is proceeding to reduce residual radiation to acceptable levels; this guides cleanup in a real time mode.

Final status surveys

Final status surveys are performed to demonstrate that residual radioactivity at a site meets the planned release criteria for unrestricted release, or where appropriate, use with designated limitations. Statistical tests provide means of selecting the number and location of sampling of the site. One type of radiological measurement (surface scans, for example) may be sufficient to demonstrate that decontamination or removal is unnecessary, though it is possible that survey coverage may have to include the entire land surface area. Total survey is recommended for areas under 2 000 m², whereas some coverage between 10% and 100% may be suitable for larger sites, depending on the classification of the area to be surveyed. Independent confirmatory surveys may be performed by the responsible regulatory organisation to spot check the final status survey if remediation is performed by a third party or the company that undertook the uranium production at the site.

CASE STUDY: Portugal – Surface and groundwater evaluations carried out for preliminary site characterisation of the Cunha Baixa mine and vicinity

Site history

The Portuguese Mining and Geological Institute (IGM) is carrying out a number of studies under contract for the General Direction of the Environment (DGA) that broadly aim to investigate the environmental impacts of abandoned mines in Portugal. These studies serve to establish preliminary information for site characterisation prior to further remediation steps. The Cunha Baixa Mine located in the centre of Portugal, in Mangual de County, is the focus of the case study reported here [6-9]. Exploitation of uranium ores in Portugal is carried out exclusively by Empresa Nacional de Urânio (ENU), which owns both, the active and decommissioned mines in the country. Additionally, ENU also carries out environmental assessments and rehabilitation of these mines after they have closed, including monitoring.

The Cunha Baixa ore deposit comprises brecciated quartz veins that fill two main N40°E and N70°W striking fractures [10]. Uranium was exploited in the Cunha Baixa Mine for about 30 years. During the period of 1967-1983, underground stoping methods were used, but later, between 1984-1991, *in situ* chemical leaching procedures using sulfuric acid were adopted. In total, some 484 000 tons of ore with an average grade of 0.186% U₃O₈ were produced. More than one million tons of sterile waste and tailing materials were produced by the mine, which were partially used to fill a 300 x 100 metre open pit (located immediately above the underground works of the Cunha Baixa Mine) and also deposited nearby as coarse grained tailings [11]. About 1 km to the west of the Cunha Baixa Mine, another open pit exists which operated till mid-2001, the Quinta do Bispo Mine. Low-grade ores there are being treated using similar leaching procedures.

The water remaining inside the Cunha Baixa Mine is pumped continuously through the main shaft to the surface, where it is chemically neutralised with calcium hydroxide. Despite this, some chemical contamination by mine drainage was found in surface waters, as well as in certain groundwaters. Barium chloride is added to precipitate minor quantities of radium in the water. Slurries resulting from these operations, mainly composed of gypsum, are deposited in an old open pit nearby. The groundwater is used by the local population mainly for irrigation and as drinking water, while the land in the vicinity of the two mines is utilised for agricultural purposes. Contamination of these media by mine waste is the principal concern for the local population.

Geochemistry

Multi-element analyses (DC Plasma Spectrometry and FRX, complimented with fluorimetry for uranium) were carried out on a number of stream sediment, alluvial soil, rock and tailing samples collected around the Cunha Baixa Mine. Trace element composition of the mine tailings strongly contrasts with those of the geological basement (mainly granitic rocks). This is particularly evident for uranium and to some extent for zinc and copper, reflecting the influence of the ore mineral paragenesis (uranium minerals and some sulfides) that appears to be still imprinted in the tailings. These strong uranium enrichments (with an average of 318 ppm in the tailing material) also define an anomalous level when compared with some established baselines for uranium, such as, 2.7 ppm in the earth's crust [12], 3.9 ppm in granites [13], and 9.5 ppm in granites of Central Portugal [14].

Table 2.1. Average contents of U and other selected chemical elements in the tailings and rocks of the area of the Cunha Baixa Mine (values in ppm unless stated otherwise)

Sample type	U _t	U _i	Cu	Zn	As	Ni	Co	V	Cr	F	Fe (%)	Mn	P
Tailing (n=13)	318	161	41	120	<20	18	13	18	186	840	2.4	367	1 000
Granite (n=4)	9.3	7.4	8	66	<20	8	<10	7	170	1 192	–	394	–

Uranium turned out to be the only element geochemically anomalous in stream sediments. High concentrations were detected, either for total uranium (U_t), or for the more mobile phases, i.e., the leached uranium (U_i). Among the other metals of concern, only Zn, Cu and Mn show slight anomalies in places. Statistically, U seems to be independent from the majority of the other analysed elements.

As would be expected from U isotope series decay [15], ²²⁶Ra was also present. Analyses carried out in alluvium, stream sediment and tailings samples gave average values of 444, 1 313 and 2 647 Bq kg⁻¹, respectively, showing the presence of radioactivity in areas closest to the mines. Alluvial soils collected near (and downstream of) the mine sites are slightly contaminated by uranium. However, lower contents were found in the soils than in stream sediments (averages of 30 ppm of U

versus 478 ppm in downstream sediments due to high solubility of uranium in a wide range of pH) [16]. According to Neves *et al.*, (1999) [17] these soils are acidic, with weak ionic exchange capacity due to low organic matter content. Intense agricultural use of the alluvial soils, with frequent use of phosphate fertilisers, could also be contributing to uranium leaching and accumulation.

Table 2.2. Average contents of U and other selected chemical elements in stream sediments of the area of the Cunha Baixa Mine (values in ppm unless stated otherwise)

Sample type	Statistical parameters	U _t	U _l	Cu	Zn	As	Ni	Co	V	Cr	F	Fe (%)	Mn	P
1	M	118	75	67	130	20	14	10	11	110	900	2.2	689	1 131
	sd	262	139	55	88	15.2	15.2	11.2	10.4	58	250.4	0.6	638	406
2	M	478	235	77	224	26	19	22	26	150	895	2.7	912	1 658
	sd	461	217	41	140	19.6	15	17	26	66.6	268.6	0.7	591	498
3	M	14	10	32	86	11	6.4	5.5	7.1	80	630	1.9	430	994
	sd	2.6	2.7	16.1	12.7	3.9	2.3	1.5	2.9	20.6	176.9	0.4	173	248
4	M+2*sd	19	15	64	111	19	11	8	13	121	984	2.7	776	1 490

M= Arithmetic mean sd= Standard deviation

- 1) Overall data (n=61) using samples collected at random in the area
- 2) Values referred to anomalous samples closed to the mine sites (n=11)
- 3) Values referred to geochemically barren samples (n=11)
- 4) Reference statistical parameter for the local background (M+2*sd with data extracted from 3)

Table 2.3. Average contents of U and other selected trace elements in alluvial soils around the Cunha Baixa Mine (values in ppm unless stated)

		U _t	U _l	Cu	Zn	As	Ni	Co	V	Cr	Fe (%)	Mn	P
1	M	30	18	42	93	12	5	5	11	57	2	432	935
	Sd	33.7	11	24.4	15.4	6.3	–	1.2	3.4	15.7	0.3	83.5	249.6
2	M	12	10	47	93	~10	~5	~5	8	62	1.8	381	1 098
	Sd	2.2	2.1	24.9	26.7	–	–	–	3.6	8.6	0.3	91.4	462.2

M= Arithmetic mean
sd= Standard deviation

- 1) Alluvial samples nearby the mine workings (n=55)
- 2) Samples corresponding to local background

The effects of contamination appear to be more strongly imprinted in the neighbouring stream sediments. The spatial distribution of U along the main stream (and its tributaries) directly influenced by the two mines shows persistent chemical anomalies that occur to at least 10 km away. However, these anomalies occur irregularly along the main stream, suggesting the existence of superimposed chemical and mechanical processes in the secondary uranium distribution. This kind of secondary dispersal process for uranium has been found by other researchers [18].

Hydrochemistry

Some groundwater samples collected in wells and boreholes confirm the existence of strong anomalies for sulfate, Ca and other metals, including significant concentrations of U together with others of Mn, Zn, Co, Ni, Al, Be, Y, and Sr. Concentrations in the range of hundreds of ppb (ppm for sulfate) are common for most of the elements, in particular for those broadly located between the two

sites. Samples taken at greater distances (roughly between 0.5 and 1 km to the SE and NW, respectively) show less contamination and, in general, show low contrasting concentrations for the majority of the elements.

Table 2.4. Average values of selected hydrochemical parameters in groundwater around the Cunha Baixa Mine

Sample location	pH	SO ₄ ²⁻ ppm	Mn ppb	Zn ppb	Co ppb	Ni ppb	Al ppb	Be ppb	Y ppb	Sr ppb	U Ppb
Up to 1 km to NW of Quinta Bispo Mine	6.2	6.2	85	~9	<9	<29	<50	<5	<4	37	3.8
Up to 1 km to SE of Cunha Baixa Mine	6.0	17	29	93	42	<29	<50	<5	<4	66	21
Mine influenced samples	5.1	829	6 096	1 006	63	333	4 680	91	337	1 085	912

The chemical data suggest that pollution by the mining operation has occurred due to groundwater infiltration in the wake of the ore leaching process. In addition, some of the contamination probably stems from uranium and other metals that were released from the residual slurries and subsequently reached the groundwater. On the other hand, surface waters collected in the major streams of the drainage system do not show such critical patterns. With the exception of some samples taken close to the mine sites, the majority show “normal” concentrations and rapid dilution patterns downstream.

Hydrogeology

Granites comprise the main rock type of the geological substratum. The massifs are strongly fractured with faults, small fractures, fissures and diachases due to tectonic action. These structural features, which are particularly significant around the ore deposits, greatly increase the permeability of the rocks and determine their hydraulic behaviour. A preliminary hydrogeological study showed that water boreholes (deeper aquifers) closer to the mine sites appear to be typically located along selected fault strikes, thus tapping preferential water conduits. Moderate enrichment in some metals (Zn, Co, and U) was detected in many of the boreholes, some of which can be detected up to about one hundred metres in depth. Apart from these geological-structural controls, changes in redox and pH conditions, interactions between phases (rock/water), and the microbial destruction of organic matter can also contribute to metal dispersion and accumulation in groundwater [19].

On the other hand, the more superficial aquifers in general consist of porous rather than fractured rocks (altered granites, sedimentary deposits). Related to this, they reveal stronger enrichments in sulfate and in most of the analysed metals i.e. Mn, Zn, Co, Ni, Al, Y, Sr and U, together with lower pH values. These data are summarised in the following table.

Table 2.5. Average values of selected hydrochemical parameters in water bore holes and wells under the influence of the Cunha Baixa Mine

Sample type	PH	SO ₄ ²⁻ ppm	Mn ppb	Zn ppb	Co ppb	Ni ppb	Al ppb	Be ppb	Y ppb	Sr ppb	U ppb
Bore holes	6.4	4.5	65	334	11	<29	63	5	<4	27	190
Wells	4.7	1 065	7 819	1 199	49	424	5 998	116	433	1 388	1 118

The combined interpretation of the element distribution in stream sediments, alluvial soils, rocks, waters and tailings can assist in building a geochemical-hydrochemical-hydrogeological model of the uranium in the study area, which is greatly influenced by the presence of “mining signatures”.

Case summary

From this multidisciplinary study, the existence of a radionuclide and toxic metals problem that can impact human and environmental health has been demonstrated. Compounding this problem, about one million of tonnes of tailings with residual average contents of 320 ppm of U (accompanied by some ^{226}Ra) still exist in the Cunha Baixa open pit.

Significant efforts are currently being undertaken by the mining company to mitigate and control possible impacts from their previous extraction operations. However, the toxic character of uranium, radium, as well as other chemical elements with significant biological activity (namely Be, Sr and Y) [20-22], together with significant concentrations of a variety of other potentially harmful elements in waters (Al, Mn, Zn, Ni) constitute a matter of concern. Also, some alluvial areas adjacent to and downstream of the mine sites with uranium contamination will place constraints on future land use.

Scientific knowledge on the area studied is still scarce. Regarding this, proposals have already been made to more effectively characterise the nature and extent of contamination through:

- Detailed hydrogeological study of the mine drainage basin.
- Mineralogical and geochemical research (detailed identification of the existing U-minerals; partition of the uranium within the different mineralogical phases using chemical techniques for selective metal extraction).
- Investigations on the degree of hazard due to the most harmful elements.
- Epidemiological studies to investigate the degree and extent of certain human diseases in the area and possible correlation with toxic elements.
- Monitoring for water quality giving particular emphasis to ^{226}Ra presence.

These results strongly recommended the development of effective and sustained measures aiming to promote remediation of the main mine sites and surrounding contaminated areas. Therefore, following these studies (together with others focused on abandoned mines of the country) the Portuguese Government recently released about € 50 000 000 for mine rehabilitation. The priority was ascribed to the uranium mines to which most of the financial support was endorsed. The IAEA also supports a Technical Co-operation project with the Instituto Tecnológico e Nuclear, Sacavém (Lisbon) to investigate the radiological hazards arising from these mines. A scientific co-operation is actually underway between this institution and the IGM to investigate the environmental contamination and radiological risks associated to uranium mining regions in Portugal.

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3. DECOMMISSIONING, DISMANTLING AND DECONTAMINATION

Decommissioning

Decommissioning, as used by the nuclear industry, means the actions taken at the end of a facility's useful life to retire the facility from service in a manner that provides adequate protection for the health and safety of the decommissioning workers, the general public, and the environment [1]. These actions, which should be in conformity with the country's national laws and regulations, could range from merely closing down the facility and carrying out minimal removal of radioactive material, coupled with continuing maintenance and surveillance, to a complete removal of residual radioactivity in excess of levels acceptable for unrestricted use of the facility and its site. This latter condition, unrestricted use, is the ultimate goal of all decommissioning actions at retired nuclear facilities.

Decommissioning encompasses all activities that are aimed at an orderly return of a mining or milling site to its previous state or use to a sustainable state or use agreed upon [2]. Components of decommissioning are dismantling, the physical deconstruction and removal of infrastructure and decontamination, typically the removal of radioactive contamination.

A formal risk assessment procedure will help to reduce radiation and other health risks for workers and the surrounding population ensuing from the actual decommissioning operation.

Depending on the object, decontamination may precede dismantling or be undertaken as dismantling proceeds, where and when required. Certain dismantled materials may be classified as radioactive wastes and disposed off accordingly without decontamination, while other materials may be released for re-use or disposal in non-hazardous landfills. The respective activities are discussed below in more detail.

A special subject, discussed below in some length is the decommissioning of underground and open-pit mine workings (see also [3,4]).

Dismantling

General considerations

All dismantling operations are physically hazardous and strict attention should be paid to all relevant safety regulations and codes of practice, including those dealing with protection of workers from hazardous chemicals and radiation risks. In addition, the use of Quality Assurance and Quality Control procedures will be of benefit in assuring that every stage of the programme is planned to meet the regulatory requirements. This will also assist in avoiding potential future liabilities.

During the dismantling process, decontamination of certain structures or materials may be required. The dismantling process should also separate, as far as practicable, and as required by national laws, wastes or materials re-use. Scrap and concrete rubble may be released for re-use if applicable radiological release criteria are met. Otherwise landfilling at licensed sites may be required.

Before the dismantling of facilities is commenced, it is essential that the final disposal and relocation of materials have been planned as much as possible. For instance, the volume of dismantling/decommissioning waste should be estimated as far as possible to ensure that there will be adequate space available at the chosen disposal site [5,6].

Infrastructure and above ground facilities

Depending on the plans for the further use of the site, any buildings, mining machinery, mill structures, laboratories, chemical and product stores, airfields etc., may need to be removed as part of the decommissioning programme. Roads may also need to be removed, although they are often left to provide access for monitoring and surveillance staff visiting the site after the decommissioning programme has been completed.

In many instances, communities ranging in size from small to large cities have been developed in association with mining operations, or became dependant on them. The cessation of mining and milling operations may have a substantial socio-economic impact on such communities and such effects should be taken into account when planning the overall remediation process. Often, infrastructure associated with the former mine or mill has become an integral part of the region's development. Such items include:

- Sewerage systems and sewage treatment plants.
- Drinking water supply systems, including wells, treatment plants, and mains.
- Power stations, transmission lines, and transformer stations.
- Gas mains.
- Communication infrastructure, such as telephone cables, TV/Radio towers, relay towers etc.
- Domestic refuse dumps, landfills etc.
- Recreational facilities.

In such instances, transferring ownership and/or responsibility for maintenance to the local community will be considered [7]. If so, the items to be handed over would be checked thoroughly to ensure that they are in an acceptable condition, and fit and safe for the proposed use. The involvement of the local community and other stakeholders in determining which elements of the infrastructure need to be retained is essential. Also, plans for organising and funding the maintenance may also need to be drawn up at this time.

The removal or transfer to the local community of infrastructure may take place in successive steps during the lifetime (including the time required for decommissioning) of the mining or milling operation in order to reduce its footprint to the amount necessary.

There is also a duty of care on the part of the organisation responsible for the remediation programme in terms of its obligations to the community who will assume possession of the site after the completion of works. This duty of care also covers the surrounding population to ensure that the risk of any residual liability on site is minimised.

Underground facilities and mine workings

Inherent in any mining operation is the excavation of underground spaces or open pits as part of the extractive processes. In addition, certain parts of the facilities and infrastructure of mines and mills may be placed underground for a variety of technical or operational reasons. Typically, these features include gas, water and electrical mains, sewerage systems, service and communication tunnels, fuel tanks and bunkers, explosives magazines, silos and other underground storage facilities, etc.

Uranium mine workings present a number of different classes of hazard that must be identified and assessed before a comprehensive and appropriate decommissioning plan can be drawn up and implemented. Hazards may be physical, chemical or radiological. Examples of physical danger include the risk of people or livestock falling into open cuts, shafts, tunnels and underground workings. Water-filled mine pits may pose additional chemical or radiological hazards. Such features may be viewed by the local community as locations for water-based recreation, as resources for agricultural use, including irrigation and drinking water for livestock, or for industrial uses such as process water, dust suppression etc. Such uses would increase the risk to the community and the environment, particularly in arid areas. The issues of remediating water resources and acid mine drainage is discussed in more detail below.

As with the above ground facilities, it has to be determined, which facilities are to be retained for further use. When the facilities are to be decommissioned, a decision has to be taken whether they have to be dismantled, or whether backfilling and burial is sufficient and feasible. The decision will be based on the envisaged future land use and any conflicts arising out of the underground features remaining. For instance, underground features may seriously impede the construction of foundations of new buildings. Local building regulations may also stipulate what decommissioning action has to be taken.

In most countries, the mining laws will regulate the decommissioning of mine workings. This applies in particular to the sealing and backfilling of shafts and other types of access to mines in order to prevent inadvertent and intentional access. The mining laws, typically, will also stipulate that collapsing underground mine workings may not cause any damage on the surface and suitable precautions, such as backfilling, will have to be taken based on the assessment of the mining engineers. In most cases these assessments are part of the normal mine operation and would be complemented by a surface subsidence monitoring programme. These programmes may have to be extended a considerable time beyond the actual decommissioning of the mine in order to provide evidence in liability cases.

Similarly, for open-pit mines the stability of slopes, berms etc. will have to be ascertained and suitable reprofiling measures undertaken, if required. Backfilling with mining or milling residues might be considered (see below).

Decommissioning may also include the removal of re-usable materials, such as steel structures, machinery, etc.

In any case, the underground facilities will have to be checked for the presence of radiological and other potential contaminations, e.g. lubricants, fuels, transformer oils, explosives etc., and decontamination initiated, when necessary.

Decontamination

Objectives

Uranium mining and milling sites and related infrastructure will be, to a greater or lesser degree, contaminated with radionuclides and, perhaps other hazardous elements, such as heavy metals and arsenic. Hence, a certain degree of decontamination will likely be required. An important objective of decontamination is to reduce the footprint of areas restricted under radiation protection regulations.

The level of residual contamination allowed to remain is determined by the future use of the infrastructure or the materials and the technical feasibility for decontamination. The concepts of

clearance, exemption and exclusion from regulatory control for radioactively contaminated materials according to international and national codes of practice may also determine the level of decontamination required. Equally, such considerations may affect the ability of an operator to recycle or reuse decontaminated equipment or materials.

If equipment and material are intended to be re-used at another location, decontamination is typically required. Throughout all forms of decontamination, the rules and regulations relating to worker safety must be strictly observed. In most circumstances, workers will be managed under the national codes of practice relating to radiation workers. The operator should determine the possible radiation dosages that would be received by workers and/or members of the public as result of such activities, and how such dosages would be controlled.

There may be appreciable risks arising from the presence of hazardous materials in older buildings. These materials may, either form part of the structure (e.g. asbestos), or be associated with the operation (e.g. PCB-laden transformer fluids). If this is the case, then the decommissioning project will need to employ specialist contractors to deal with the decontamination operation and any hazardous wastes generated in the manner required by applicable regulations. Work conditions may be such that other activities on site have to be suspended until the hazardous materials have been removed. There will also be a need to develop and implement a method for the disposal of these materials that is acceptable to the regulatory authorities.

Decontamination techniques

The most common decontamination techniques employed are briefly described in the following sections. Throughout the decontamination programme, it is essential that appropriate steps are taken to ensure that the correct safety regime is in place in order to protect the health and safety of the workforce. It is likely that these measures will be set down in regulations at the local, national or international level, or any combination thereof.

- Scraping or jack hammering
Components and machinery may be encrusted with radioactive sediments or scale derived from the raw material, process chemicals and reagents, or oxidation or reduction products, or a combination of all or some of these items. Such deposits may be found in counter current decantation (CCD) vessels, pachucas or other reaction vessels, storage tanks, pipes and storage containers, calciners, and so on. Often, thick deposits are removed by chiselling and scraping with hand tools, or use of power tools, such as jack hammers. These techniques may also be used to remove contaminated lining materials from such locations. These lining materials may include rubber or plastic based coatings, or possibly asbestos, brickwork, or ceramic tiles, etc. The residues from such activities must be managed in an appropriate manner in accordance with local laws and regulations.
- Sand or grit blasting
In many instances, surface contamination may be best removed by high-pressure sand or grit blasting. The cleaning medium nowadays is rarely sand, but more often garnet, zirconia, sponge, or similar materials, soda, or dry ice, etc. There will be local regulations governing the safe practices required to operate sandblasting equipment. A prime concern is the ultimate safe disposal of the spent cleaning medium and the associated contaminants removed during the cleaning process. In some cases, the cleaning materials, such as zirconia or metal slags ground into grit and used for sand blasting, may have their own natural radioactivity which should be taken into account in the health and safety, and remediation

plans. These materials must be treated as safely, as all other radioactive waste generated in the decommissioning process.

- Washing and high-pressure hosing

Some forms of contamination may be amenable to being removed by simple washing with or without the addition of complexing agents, detergents and surfactants. The collection, concentration and disposal of the wastewater and contained contaminants are the major issues to be addressed. The waste is radioactive and the water will need to be treated before it can be discharged to the environment. Again, the concentrated solid waste containing contaminants will have to be managed as for other radioactive waste by placing it in a suitable containment. The waste may be removed from the wastewater in several stages, e.g. by filtering followed by evaporation, ionic exchange, precipitation or other forms of chemical processing.

- Chemical solvent washing

In some instances, contamination can be removed by washing with industrial solvents that are also paint strippers. The application of such a procedure must be in accordance with appropriate worker health and safety regulations. Residues from the cleaning process need to be managed appropriately as radioactive waste. Care must be taken to ensure that solvents, either clean or contaminated, do not escape to the environment. Similarly, the residues from such activities will constitute a radioactive waste that will have to be managed in an appropriate manner in accordance with applicable laws and regulations.

- Use of strippable coatings

In some instances, surface contamination may be removed by use of strippable coatings. These are special materials (paints, varnishes, polymers, resins etc.) that are applied to the contaminated surface to be mechanically stripped off after a short time of curing. The contamination is removed together with the coating. The stripping of the coating may be aided by use of solvents or other chemicals.

- Treatment of waters

Various decontamination techniques require process waters that have to be treated for contaminants after use. The method of treatment depends upon the type of the contaminant, the volume of water, and the flow rate of the water. Large volumes may be evaporated in ponds or tanks, and the residual evaporites collected as a sludge or crystalline mass for management and disposal like other radioactive waste. Substantial volumes may also be treated by use of ion-exchange resins, reverse osmosis plants, filtration and precipitation methods. The use of precipitation methods to remove radionuclides from solution is well known, the most common being bulk precipitation using lime. Such precipitation will remove most heavy metals from solution. There are also other contaminant-specific methods in use, for example the use of barium chloride to remove radium from uranium mill process waters. In all such precipitation processes the precipitate is managed as a radioactive waste with an appropriate disposal strategy. Similarly, ion exchange and reverse osmosis processes will also produce sludges or precipitates that will require management and disposal. More details on water treatment and the management of the ensuing residues are given in Chapter 6.

Treatment of mobile equipment

All mine sites and processing facilities have a wide range of mobile equipment and machinery used in operations. This may range from lorries, excavators and loaders to earth-moving and road construction machinery, drill rigs, tankers, pumps, generators, lighting sets etc. All such mobile plant or equipment must be thoroughly checked for the presence of radioactive contamination before being released for removal from the site. It is important that there is a suitable method in place to ensure that all such equipment is inventoried, checked and documented, including certification of cleanliness or decontamination as appropriate. The decontamination methods employed will be specific to the item of machinery and the nature and level of contamination in question. The documentation process should be under the overall guidance of a radiation safety officer for the site concerned.

Treatment of fixed plant and equipment

Any fixed plant or infrastructure items that are to remain on the site should be decontaminated *in situ* to the required degree of cleanliness. Any plant that cannot be adequately decontaminated for technical or economic reasons should be dismantled and removed to a suitable disposal site. Some items of plant may be dismantled for transport off site to be re-used. As for mobile plant, all such items will need to be decontaminated in an approved manner and certified as clean and decontaminated by a radiation safety officer before they can be transported.

Protection of water resources during decommissioning

At all stages of the decommissioning process, stringent precautions should be taken to ensure that no contamination of water resources occurs. This applies to both surface and groundwater resources. Water supplies for decontamination work should be recirculated within leak-free systems to the greatest extent practicable. Ponds and reservoirs should be lined, if possible, to prevent seepage to groundwater. Surface activities should be confined to areas where all run-off is contained and prevented from discharging to the environment except under conditions of strict control and supervision. At remotely located sites that have been closed, or where operations are suspended, and there is no active supervision, the use of permeable reactive barriers may be considered as an additional means of water resource protection. Protection of water resources is covered in more detail in Chapter 6.

Relocation of equipment and plant, including resale

Before any decontaminated plant or equipment is sold, re-located off site following sale, or selected for re-use, it is essential to check it for contamination and to have it certified as clean in accordance with the relevant national and international laws, codes of practice and regulations. The standards for cleaning and transport off-site will follow international standards and will also be set in each jurisdiction. It may also be necessary to consider, if the conditions of any international agreements or conventions relating to cross-border transportation of intractable or radioactive waste may be applicable to the situation [8,9].

Management of materials that cannot be decontaminated

In the course of the dismantling process, it is common to find that items cannot be decontaminated for economic or technical reasons. Any items of infrastructure, plant, machinery, or other equipment that cannot be decontaminated to a satisfactory state should be consigned to a suitable radioactive waste disposal facility. Such items may include concrete slabs and building blocks, pipes, small semi-sealed reaction vessels, pump casings, structural steel, linings for ovens or calciners etc.

Materials that cannot be decontaminated may be buried, either in a suitable and approved repository off site, or in parts of underground or open pit mines approved for disposal. This last option assumes that returning radioactively contaminated material to a conventional uranium mine is approved through the agreed land use strategy and meets the requirements of the radiation dose assessment.

Transport of contaminated materials and equipment

It must be borne in mind that relocating such materials may call for the use of specialised equipment and means of transport, and could require moving the materials over considerable distances, if a suitable repository site is not available locally. Such activities can, possibly substantially, add to the costs of the operation. The overall risk assessment of the decommissioning operation also needs to take into account the additional health and safety risks from such relocation operation. Extended lorry traffic will also add to the nuisance for the adjacent population.

The IAEA in conjunction with other international organisations has developed a comprehensive body of guidelines and regulations for the safe transport of radioactive materials [10,11]. Additionally, cross-boundary transport is regulated under bi-lateral agreements and various international conventions, such as the Basle convention [9].

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4. WASTE MANAGEMENT

Types of waste

Mining and milling of uranium ores results in a variety of wastes and residual materials, such as top soils, overburden, un-mineralised rock materials, ores with sub-economic levels of mineralisation or high levels of contaminants, mill tailings, water treatment sludges, and many different types of processing waste. Additionally, the decommissioning of mining and milling facilities and the environmental remediation of such sites results in different waste materials of different type and nature requiring appropriate management.

Waste materials

Waste rocks and overburden materials

The first wastes generated in the development of a site are usually organic rich top-soils. These are produced during the initial site clearance and excavation and should be stored separate from other excavated materials for use in the revegetation phase of the remediation programme. Obviously, the area to be cleared is typically smaller for deep mines than for open-pit mines. Frequently, little attention is paid to the conditions under which these soils are stored. If soil materials are to be of any practical use, they must either be used as soon as possible after they have been excavated, or they must be managed actively to ensure that the associated flora and fauna, which assist in establishing vegetation, retain their viability [1,2].

In open-pit mining the next class of waste materials generated is usually weathered rock, followed by other barren rocks, often described together as overburden. These usually make up the largest volumes of all materials requiring storage or disposal. In deep mining, the amount of barren rock to be excavated is typically smaller and results from activities to provide access to the ore, e.g., open up shafts; drifts; adits.

Waste rock is a term used generally to describe a “clean” waste with less than a specific level of uranium mineralisation, which may sometimes be defined by law. For example, under the legislation in force in the Northern Territory of Australia, non-uraniferous material must contain less than 0.02% U_3O_8 (= 0.017% U), whereas in the USA, the corresponding level is 0.05% (= 0.042% U). In France, Decree 90-222 considers that, if a rock has an uranium content above 0.03% (300 ppm) U, the material must be managed in an appropriate manner. Additionally, the USA has set guidelines on the target cleanup levels for radioactively contaminated soils that may be applied to the restoration of closed uranium mines and mills – a maximum of 5 pCi.g⁻¹ (0.35 Bq.g⁻¹) above background for combined ²²⁶Ra, ²²⁸Ra, thorium and uranium.

While the uranium content in these materials may not be significant in economic or mining terms, the radionuclide content (mainly uranium and radium and associated progeny) may be sufficient to pollute surface or groundwater, or present a direct exposure hazard (dust, radon) to the adjacent community. Waste rock often also is a relative term, referring to the ore of interest. The materials may indeed contain other minerals of interest. They may also contain minerals of environmental relevance that generate acid or contain toxic elements including heavy metals and arsenic.

The issue of management for very low-level radioactive materials is currently being discussed in the USA, the European Union and elsewhere. These materials are termed Naturally Occurring Radioactive Materials (NORMs) or Technologically Enhanced NORMs (TENORM), and include uranium mining and milling wastes. Disposal of these classes of materials may be subject to national codes and requirements for cleanup.

These waste rock materials are usually the only materials that are acceptable for use in the construction of structural cappings and final landscaping. Cases are well documented in the U.S. where uranium mine waste rock has been used in house construction, putting the occupants at risk of increased radiation exposure.¹ However, unless they contain no constituents of environmental relevance, they have to be used in such a way that releases of heavy metals or acid are minimised and that no adverse environmental impact to surrounding areas results.

Sub-economic materials and low grade ores

These are intermediate materials between waste rock and the ore that is recovered. What is considered to be below economic value may change over time as a function of price that can be achieved for the final product and the milling technology available. Hence, many mills revert to stockpiled sub-economic materials at times of high demand or towards the end of their life. If no milling is considered, the final management of these materials as part of the remediation process requires attention to their potential for causing adverse environmental impacts. In particular, there is a risk that the mineral paragenesis may have potential to cause environmental detriment. The most common instance is the presence of sulfide minerals in sufficient quantities to cause acid rock drainage. This can be a major environmental hazard as the impact may spread through the aquatic environment, as well as through the soil. The final placement of waste with acid generating potential should be selected to ensure that this risk is eliminated as far as possible, or minimised by effective reduction of the acid generating processes, and containment of acids and residues. Typically, this requires dump sites with bottom liners, engineered drainage systems, and at least low-permeability, engineered cappings.

Mill tailings

Mill tailings are the most common type of processing waste associated with uranium production, as well as being the most voluminous. Tailings are the result of the milling process that consists of the successive crushing and grinding of ore grade rocks to produce a relatively uniform sized sand-like material. The material then is subject to leaching by either, alkaline or acidic reagents to dissolve and extract the uranium. Mill tailings have a size fraction distribution from 0.5 mm to, about 80% passing 0.2 mm diameter, similar to that of fine sand. Tailings are rarely inert, as not only have they been finely divided, which makes them inherently more reactive, but they may also contain residues of

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process chemicals including, for example, oxidising agents, neutralising agents and leaching solutions. Typically also, some radioactivity may remain, e.g. radium with only uranium and, perhaps, thorium being removed. The final containment of tailings is usually the largest issue in uranium mine site closure and remediation. The issues are the sheer physical volumes, the difficult geotechnical properties stemming from the narrow grain-size distribution, and the radiological and toxicological risks to the environment and human health.

Waste from heap leaching operations

Heap leaching is a method for recovering uranium from simply run-of-mine or crushed ores of typically low grade, without going through the milling process described above. Heap leaching may be performed along various schemes. In any case, pads or polders with an impervious bottom liner to collect the pregnant solution will be constructed. These heaps may either be left in place after the leaching is complete or the material may be removed to a disposal site to make room for fresh ore.

The chemistry of uranium does enable both alkaline and acid leaching processes to be successful, the choice depending on the ore and host rock mineralogy. Although the relatively coarse sized materials, comprised of rocks of a wide size range from boulders or cobbles to gravel, may be less reactive than the milled materials, many of the radioactive and chemically active constituents, such as sulfides will remain in the residues. Consequently, these should be regarded as having potential to cause environmental and health detriments.

The best management strategy is to ensure that these waste are managed in such a manner as to exclude air and water penetration and that leachates are prevented from reaching the (aquatic) environment.

Waste and residues from in situ leaching (ISL) operations

Uranium may be recovered by injecting acid or alkaline solutions into the ore bearing strata and recovering the pregnant solution via boreholes. Typically this is done from the surface, but it has also been done in combination with deep mining in the past.

In situ leaching operations generate very little solid waste, as there is no waste rock or mineralised material, other than that from drilling the boreholes, brought to the surface. However, the recovery of the uranium will generate solid and liquid wastes, including:

- Solids and sludges from the neutralisation of solutions.
- Spent ion exchange resins.
- Salt residues and used filters from reverse osmosis plants.
- Scales from pipework, pumps, valves and filters etc.
- Residues from evaporation ponds.
- Excess, neutralised leachants.

Where permitted by country regulation, waste solutions may be returned underground by injection into the aquifer, provided that there is no contamination of water resources. In other cases, waste solutions can be treated to produce an effluent of a quality suitable for discharge. This may be achieved by using such treatments as reverse osmosis, ion exchange or bulk precipitation. Solid residues should be managed in a manner approved for low-level radioactive waste disposal.

Sludges from water treatment

The management of water contaminated during remediation operations and decommissioning should be included in the waste management programme. Often, the water will be treated by one of a number of methods. Some of these treatment options are discussed in Chapter 6. Many of these procedures will result in some form of residue, for example precipitates, sludges, evaporites or ion exchange resins that cannot be recharged and recovered.

It is important that the management plan for any water treatment programme (that will continue after remediation is completed) includes consideration of the final repository of the sludge, dewatering of the sludge and transport of sludge to the containment site.

Residues from decontaminating and dismantling infrastructure

As has been pointed out earlier, when facilities are decontaminated and/or dismantled, there is likely to arise a wide range of wastes. These can include the physical remains of infrastructure that cannot be recycled or re-used, such as building materials, structural steel, road surface materials, parts of the mine and mill equipment and machinery. A further waste will be the cleaning materials and agents used in decontamination of the facilities, such as sand and grit from blast cleaning, contaminated water from high pressure hosing and washing down of plant and equipment, stripping paint, paint chips from cleaned equipment or ionic exchange resins used in decontamination activities.

In most cases, a conditioning method that ensures contaminants are immobilised is used to manage these wastes. This is often achieved by incorporating solid waste and sludges, such as sandblasting residues and filtercake, into cement mixes, which are cast into blocks. The presence of the cement, or other suitable binding agents, reduces the mobility of potential contaminants. Some materials may be placed in metal drums or similar containers. All of these waste items, conditioned or not, have to be disposed of in a safe and approved way. Typically, they are placed into designated locations of mill tailings impoundments, into approved low-level waste repositories constructed for this purpose on site, or are sent off site to such repositories.

Contaminated soils

During site operation, soils on the site and off-site may have become contaminated by radionuclides and heavy metals originating in the ores, but also by materials such as lubricants and fuel oils. These soils have to undergo a proper remediation procedure or be disposed of in an orderly fashion. A variety of *in situ*, on site and off sites method for treatment are available [3]. *In situ* remediation techniques have only limited applicability to radionuclides, effecting either immobilisation or removal by plant uptake, followed by harvesting. *In situ* bioremediation may be the technique of choice for the destruction and removal of organic contaminants, such as fuel oils. In other case, the soils will need to be collected, usually by machinery such as scrapers, graders and bulldozers, and transported to a suitable site for final disposal and containment, or for treatment. A typical treatment for radionuclides, to be performed either on or off site, is soil washing. The resulting contaminated (aqueous) liquids have to be treated and the residues to be disposed of as discussed elsewhere.

Throughout the soil remediation process, dust suppression and runoff sediment containment measures must be operated. Transportation and handling of these materials must be carried out in accordance with the relevant codes of practice on worker health and safety and transport of radioactive materials.

Sundry wastes and operational wastes left on site

- The mining and milling of uranium ores and the subsequent decommissioning and environmental remediation generates sundry radioactive and non-radioactive wastes not covered by the above categories. All operational waste, including unused process reagents, fuels, packing materials, etc. should be removed from site for re-use or consigned to a containment during the decommissioning process. It is important that materials are reused or recycled as much as possible. Also, care should be taken to ensure that such materials are not left behind in the remediation process to contaminate the site. Although the main concern may be the potential for radioactive contamination, the site remediation process should take account of all other potential contaminants with the potential to cause adverse environmental impacts, such as organic chemicals and heavy metals. Examples include: Used wood from the timbering of the mine.
- Laboratory waste (glassware, clothing, etc.).
- Scales from pipework, pumps, valves and filters, etc.
- Oils and lubricants from plant and machinery.

Such wastes need to be managed according to the applicable rules and regulations and disposed of in approved facilities on-site or off-site, if the materials cannot be recycled or re-used after decontamination. The sale of such materials may provide some income to offset the costs of the remediation programme as well as save the cost of disposal of these materials.

Engineered disposal facilities

Objectives and requirements

Mining and milling wastes will have been placed into various types of engineered disposal facilities during the operation life. In the course of the decommissioning and in preparation for closeout, these facilities will need to be checked for their suitability as long-term repositories. Aspects and features to be considered include:

- The geotechnical stability of retaining structures, such as dams, of the impounded material and any cappings.
- Bottom liners to prevent the escape of seepage waters.
- Engineered drainage systems to collect seepage.
- Cappings to prevent the infiltration of rainwater and the erosion of impounded materials by wind and water.

Depending on the operational state of the mine, availability of technical and financial resources, and technical feasibility, backfilling into the mine of waste material may be the preferred option. This may be particularly suitable for open-pit mines and has been practiced as part of the operational scheme in Australia and in a remediation context in Germany. It has the advantage of reducing the footprint of the affected land dramatically.

Relocation of tailings and other waste materials into facilities that meet certain environmental and geotechnical standards may be required, but a formal risk assessment has to balance the various radiological, non-radiological and industrial risks associated with such operation.

Impoundments for mill tailings

The proper impoundment of mill tailings requires particular attention owing to the properties of these materials, as discussed earlier. Various reviews have been published, describing such facilities [4-9], and the basic characteristics, advantages and disadvantages for each type [10] in more detail.

On site containments may be developed if suitable locations are available and if it does not impede the planned land-use. If available, a worked-out open-pit mine may be suitable. Rules for on-site burial of waste materials are usually set out in local or national laws, codes of practice and regulations [11]. The primary concern is that the integrity of the containment should be guaranteed for a period of time that is in accordance with the national regulatory requirements, ideally without further maintenance or intervention. For example, in Sweden, the time period is 10 000 years. Such objectives favour below ground waste disposal and containment. However, it is important that the pit or containment is suitable for the purpose. The same design criteria and objectives as for engineered disposal facilities off-site apply, for instance with respect to maintaining the integrity of the containment and radon emanation.

Following, various arrangements for tailings impoundments are discussed in brief.

Lakes

In Canada and in some parts of the former Soviet Union, uranium mill tailings have been deposited in the past into lakes and water-filled voids. The long-term behaviour of tailings in such locations has led to concerns about the potential for adverse impacts on the surface and groundwater quality. However, water cover does reduce radon emanations and prevent problems of acid drainage, if the tailings are reactive and sulfidic and remain below water in an anoxic environment.

Ring dykes and valley fill systems

Ring dyke systems are perhaps the most common form of tailings storage facility. The embankment is frequently constructed on the ground with little surface preparation. They are built as self-containing structures, i.e. circular or rectangular, closing upon themselves. Such systems are often not built as water retaining structures, and are built with drains to enhance the dyke stability and to collect the seepage water. The type of deposition may be sub-aerial or sub-aqueous. The method of emplacement is usually based on the coarse size fraction of the tailings that has been separated out by cycloning. In the “upstream” method, extension of the tailings pond is achieved by placing the new tailings upstream from the crest of the dyke whereas better stability may be reached by the “downstream” method. Such above ground structures may be rather obvious in the landscape and present an aesthetic challenge at the time of closeout or remediation.

Valley fill systems of tailings storage are often used in mountainous areas. The principal feature is a dam or embankment built across the valley. The tailings are deposited on the upstream side, either sub-aqueously, or sub-aerially. The major concern with such structures relates to the risks associated with flood flows down the valley leading to overtopping of the embankment, which in turn could result in failure of the embankment and subsequent dispersion of the tailings.

In earlier times, tailings have sometimes been allowed to flow into unconfined and unconsolidated waste rocks, heap etc. adjacent to or in the close vicinity of the mill. Due to fine grain size, these sites may have been a source for dispersal of tailings by both wind and water. Such

practices are no longer acceptable and situations of this type should be managed in an appropriate manner.

Open pits

In recent times, there is an increasing tendency to place as much of the tailings below ground level as possible to limit the risk and environmental liability associated with storage at the surface. Tailings have been returned to pits in several locations usually at the time of milling (or possibly after relocation at the end of processing). Tailings have been separated out into coarse and fine fractions (slimes) in the past, but modern methods use whole tailings. Increasing numbers of modern tailings disposal systems use paste or thickened-tailings technology. Tails thickeners increase the concentration of solids and reduce the amount of water being placed into a given volume of the facility [12,13].

There may also be additions to the tailings, such as cement or other pozzolanic materials to improve their geotechnical strength and reduce the mobility of contaminants contained in the materials.

The placement of tailings below ground level is regarded as a prime option, as it does offer great security against later dispersal of the material. The nature of the pit, in particular the groundwater conditions, both quantity of flow and quality of the water, the location of the pit, the availability of liners and the nature of the tailings are all factors that should be taken into consideration when the management plan is being prepared. In particular, the potential for groundwater contamination, the design of a capping over the containment that will allow for subsidence and settling of the tailings mass, and the determination of the acceptable elevation for the surface profile of tailings in the pit should all be established in the design phase.

Another consideration when dealing with pits is the potential for the rock walls to generate acid drainage if they are left exposed. The emplacement of the tailings may offer a partial solution to this issue, especially if the mass will become saturated with groundwater and subsequently create an anaerobic environment, thereby reducing the potential for acid generation.

Owing to their small grain-sizes and the narrow grain-size distribution, tailings usually exhibit low permeability for water fluxes. In any case, “the pervious surround method” for open pit disposal, diverts groundwater flows around the impoundment and allows for improved consolidation due to improved drainage. As the tailings are filling the open pit, a layer of coarse permeable rock is built around the face of the open pit. This layer works as a large, continuous drain linked to a pumping system, which allows dewatering of the tailings and consequently better consolidation of the pile.

After final remediation, the water table is allowed to recover its natural level but, particularly in the case of “pervious surround”, the tailings remain isolated from the groundwater flow.

Underground disposal

Material of low shear strength, such as slurries from water treatment or mill tailings can be conveniently pumped underground. This has the added value of filling remaining voids in backfilled mine workings; to provide support for further mining operations in adjacent workings, to provide disposal space where there has been insufficient space available at the surface, and to reduce the potential long-term environmental liabilities associated with near surface disposal sites. However, the bulking factor associated with the milling and crushing of rocks means that it is usually possible to

return only 60 to 65% of the tailings to the voids from which they were mined. Paste technology can help to maximise the amount that can be returned to the workings, provided a technique for delivering the paste is available.

Another option is to create “silos” in the barren rocks above the ore body by either, raise boring or stoping. The tailings would then be placed in the silos, most probably as a cemented paste. The waste rock from excavating the silos would be impounded at the surface. The basic idea behind this scheme is to replace hazardous with less hazardous materials in the surface impoundments. Nevertheless, the properties of the excavated materials must be checked to make sure that they are amenable to safe disposal. Such a scheme has been followed at Jabiluka mine development project in Australia, as it is a regulatory requirement for all uranium mines in the Alligator Rivers Region that uranium mill tailings are to be contained below ground level at decommissioning.

Underground disposal solutions are likely to be costly in comparison to surface solutions, but in particular circumstances they may be the economically most viable solution. If the ore body is sufficiently high grade and the mine location is environmentally sensitive, for example, then any extra costs associated with underground disposal may be acceptable to the operator.

Impoundments for solid wastes

The impoundment of waste rocks from uranium mining follows established mining and geotechnical engineering practices as for other types of mining. Apart from problems of geotechnical stability of slopes, the two main issues associated with such impoundments of loose rock, are the generation of acid drainage by the oxidation of pyrites and other sulfides, and the dispersal of radionuclides and other toxic elements due to erosion by water or wind.

The geotechnical problems are solved by appropriate grading of slopes, berms, etc. The generation of acid drainage and erosion can be combatted by covering the waste rock heaps with inert materials. These cappings minimise infiltration of atmospheric precipitation and inflow of oxygen. Vegetation further helps to increase the cohesion of top layers and to reduce the erodability. The cover materials should provide an adequate substrate for revegetation.

Cappings

Close-out and remediation programmes of waste impoundments, where waste materials are to remain above ground, will require some form of capping to be constructed, as indicated above. The most appropriate materials to be used are the excavated “clean” and other local rocks and soils, if these are of suitable quality. The capping will have to serve several functions including:

- To contain the waste and prevent its dispersal through action of wind or water.
- To prevent intrusions by burrowing animals and human intrusion.
- To reduce direct gamma radiation exposure.
- To act as a radon barrier.
- To limit entry of water and so to reduce leaching of, or chemical changes in, the waste.
- To enhance settling and thus to reduce the time until a stable geotechnical and hydraulic state within the waste pile is achieved.
- To act as erosion protection.
- To provide a growth substrate for vegetation.

Cappings may need to be constructed in several layers to ensure that each of the above functions can be successfully achieved. For example, there may be a requirement to provide a) a barrier layer of rocks, b) a layer limiting infiltration and acting as radon barrier, which be usually constructed from compacted weathered rock or clay, and c) a surface layer (“rip-rap” cover) for erosion protection.

Detailed characterisation of the different types of materials available is necessary in order to select the most suitable one. The relevant properties may have been studied during the operation, but it is advisable to re-sample the rocks and soils in storage in order to assert that present conditions are comparable to those found initially. Methods and parameters to be investigated are discussed below. In particular, the presence or absence of sulfides must be ascertained and the potential for development of acid rock drainage. The weathering characteristics of the chosen rocks are important parameters with respect to the potential release of contaminants contained in them and with respect to erosion resistance and long-term stability.

The materials for the capping should ideally be sourced from the site or from nearby areas. This is to reduce the impacts of transport in the region, as well as ensuring that the soil properties of the final capping will match the surrounding countryside to the greatest extent practicable. This should in turn make successful revegetation easier to achieve, as plant communities on the revegetated site will be able to blend more closely with the surrounding vegetation.

Characterisation of wastes and materials used for engineering purposes

Petrographical and mineralogical characterisation

Mineralogical characterisation of the ore is undertaken during the exploration phase, forming the basis for determining the amount of resources and the optimum ore recovery technology [14]. It is worthwhile to characterise impounded rocks and tailings altered by the leaching procedure [12,15] in order to assess its effect and the effect storage might have had, together with their remaining radiological and toxicological inventory. Of particular interest are:

- Any neoformed clay and other minerals.
- The mineralogical association and leachability of the potential pollutants (residual radionuclides, heavy metals etc., and the acid generating potential).
- The distribution of the different potential pollutants within the storage/disposal pile.
- Quality of the pore water in contact within the impounded materials.
- Possible evolution of material since first disposal.

Studies undertaken on French mill tailings from acid leaching concluded that:

- Pore water is in equilibrium with the minerals.
- Radium and uranium content is low and corresponds to the quality of the seepage water draining out of the tailings pile.
- Less than 1% of radium was leachable due to fixation on newly formed clay minerals. No radium migration has been observed in the overlying granite and natural evolution leads to an even better chemical containment [16-19].

However, studies in other countries sometimes came to less favourable conclusions.

Assessment of the source term for pollutants would include a radiological assessment of the materials with gamma and radon monitoring on site and in the vicinity.

Geotechnical characterisation

Impounded waste materials and materials used to construct retaining structures and cappings need to be subject to geomechanical testing in order to ascertain their geotechnical stability and suitability for the purposes. Standard geotechnical laboratory and field methods are applied to samples from existing structures and from materials proposed for new structures. Extended tests, such as lysimeter experiments might be necessary. The purpose is in particular to:

- Ascertain the stability of the dykes confining impoundments, rockwalls of open pits, berms and slopes of landscaped impoundments.
- Derive data for modelling water and soil gas (including radon) balances in the impoundments.
- Derive data for predicting the settling of impounded materials and to make adjustments to the thickness of the cappings in accordance with the planned final contour.

The main parameters to be determined are typically:

- Grain size distributions and other characteristics that will allow classification of the material according to the (national) geotechnical systems.
- Proctor indices and the compaction characteristics.
- Shear strength, shear angle and compressive strength (confined and unconfined tri-axial tests with or without drainage).
- Cohesion indices (from e.g. Atterberg tests)
- Oedometric test and settling characteristic.
- Permeability, hydraulic conductivity and water content.

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5. REMEDIATION OF WASTE MANAGEMENT FACILITIES

Objectives and strategies

Waste rock and tailings impoundments and sites of former mines and mills not in compliance with applicable criteria and standards may need remediation. The objective of remediation is to remove any potentially harmful effects on the environment and human health and to render impoundments stable over prolonged periods of time. The methods and objectives for remediation are similar to those followed in ordinary closeout of such facilities. In addition to the mineralogical, geochemical and geotechnical characterisation as discussed earlier, additional information must be gathered in order to develop the final plan for remediation and close-out:

- Agreed final land use.
- Physical characteristics: tonnage and area of the rock piles and maximum area which can be used for final disposal site, maximum height for contouring, maximum permitted slope angles, erosion characteristics for proposed combinations of waste rock and slope, and possible limitations on use of erosion control structures of final cappings.
- Availability, quantity and quality of soil for use in revegetation, availability of suitable seeds and/or plant stocks for use in revegetation.
- Experience with revegetation of similar rock types in the region.

Methods for remediating selected problems are discussed in more detail below.

Remediation of tailings impoundments

Two types of systems are being used for the final close-out of tailings impoundments, one involves a dry cover, while the other, relies on a permanent water cover mainly to prevent radon emanation.

Dry cover

Removal of the free water and stabilisation of surface

Tailings usually are disposed as slurry and water expelled during consolidation will collect on the surface of the impoundment. To implement a dry cover, supernatant water is pumped off to be discharged after treatment. The surface of the impoundment may have to be stabilised first to allow construction of the cover. The cover is applied progressively, following the (natural) drainage, and the surface drying process and the resulting surface stability.

To improve the drainage of the tailings mass, the natural process may be enhanced by insertion of vertical wick drains. This will lead to more rapid settling, thus reducing the time taken for the mass to reach the target density. It will also reduce the risks associated with the period of relative geotechnical instability of the mass. By using wicks, a lower final water content may be achieved than can be reached by natural drainage, especially if the tailings are impounded in a pit.

Another way to enhance dewatering of the tailings is by distributing a thin layer of cover material increasing the surface stability using a layer of (synthetic) geotextile and an iron netting. This applies a small load on the tailings, thus enhancing the expelling of waters to the surface. The geotextile in combination with the netting prevents the occurrence of cracks.

The close-out of valley fill systems proceeds similar in that the tailings mass may require forced consolidation before it can be safely handed over to the surveillance and monitoring phase. The structural integrity of embankments itself is of vital importance, and strengthening of the dykes may be required to meet long-term containment standards. The foundation conditions for the location should be re-examined to ensure that they are suitable for a perpetual storage facility. For a ring dykes, the general conditions would apply.

In the case of tailings having been allowed to spread without any confinement, relocation of the tailings to a properly engineered site should be undertaken, if no confinement can be constructed *in situ*. Relocation may be by lorry, conveyors, or in a pipeline as slurry, depending on the distance to be covered, the quantity, chemical nature of the tailings and their physical state, particularly the water content.

Recontouring and landscaping of above ground tailings facilities

Recontouring of above ground tailings facilities has the double objective of improvement of long-term stability and landscape integration. This can be achieved by relocating material from inside the impoundment, mainly to reduce slopes, or to reinforce the toe of dykes.

Emplacing the cover over the tailings mass will increase their settling, and must be adequately predicted to make suitable allowances in the contouring and the cover thickness. Differential settling can result in depressions on the tailings pile, encouraging in accumulation of surface water and, hence, increased infiltration rates, or result in unsuitable slope angles that enhance erosion rates.

Capping

The construction of a suitable capping, including erosion protection to the top and sides of the structure, may then proceed. The tailings containment should be designed to last far into the future. Some national regulatory requirements fix a minimum period for the structure to function that may vary from 200 to 1 000 years. In projecting the expected lifetime, consideration must be given to the containment of any weathering products and all radionuclides, protection of surface and groundwater resources, and the prevention of pollution spreading from the site in form of aerosols or suspensions.

The capping should be constructed of materials that will not become a source of any additional pollution themselves, either by erosion or in the form of weathering products generated. The capping materials must also be compatible with the agreed final land use.

Water management issues and sludge disposal

Water management issues include all the considerations regarding the accumulation and drainage of the different types of water and how they should be treated:

- Surface water coming from outside the impoundment should be diverted to limit drainage water volumes requiring treatment.
- Surface run-off originating in atmospheric precipitation on the site may only need to be controlled for suspended matter (sediment control). This will be important in the initial period immediately after the construction of cappings has been completed. Later, it may be possible that such waters can be discharged without any further treatment.
- Usually water draining from underground (mine) workings or waters seeping out from the impoundment have to be treated for extended periods of time.

Revegetation – Maintenance

Revegetation is an important part of the covering process that improves landscape integration, improves resistance to erosion and limits net infiltration by enhancing evapotranspiration.

Revegetation can be allowed to develop naturally, or may be established by classical agricultural or forestry methods. An effective way is “hydroseeding”, i.e., spreading a suspension of seeds in nutrient solutions with added organic gels etc., achieving even good results on areas with little or no topsoil. Work in some locations, particularly the humid tropics, has found that a final surface capping of clean waste rock is a suitable growth medium for plants. This can be important, if soil supplies for rehabilitation work are either insufficient or even totally unavailable

Apart from stimulants for vegetation growth, special treatment with lime may be necessary in case of acid generating topsoils.

In the case that trees are allowed to grow, surface rooted species are preferred. There may be a risk that deeper rooting species will threaten the integrity of multi-layered capping systems by allowing air and water exchange with the surface.

Although passive controls are preferred, some maintenance should be planned in order to cope with surface disturbance (local erosion, settling, etc.) that may occur during the first few years. The periodic monitoring extends to surveying the integrity of the surface cover and interventions to repair the vegetation cover or the topsoil cover may be undertaken as needed.

Water cover

Given suitable topographical and climatological conditions, a permanent water cover over tailings can be established [1-3]. Similar to dry covers the objectives are to:

- Stop wind erosion of the dry beaches and to reduce radon emanation.
- Provide a barrier to intrusion.
- Prevent acid formation in case of acid generating potential in the tailings. The permanent water cover prevents access of atmospheric oxygen and may foster the development of anaerobic conditions in the tailings, which also reduces the mobility of many contaminants of concern.

Two main types of disposal facilities may be considered for the water cover option:

- In case of above ground impoundments, tailings are usually transported as a slurry and allowed to settle at the point of discharge, with the coarse part of the tailings forming a beach and the slimes settling slowly in the centre of the decantation pond.
- In case of below grade disposal in open pits, tailings may have been transported as a thickened paste and disposed of using the pervious surround method.

A number of prerequisites and design criteria have to be fulfilled:

- Assurance that the water cover will be maintained in the future; i.e., that a natural positive water balance between drainage (seepage) and recharge by atmospheric precipitation or surface runoff and groundwater infiltration from the surrounding catchment area is maintained. This applies to both, open pit and above ground disposal facilities. Hence, in most cases, this option is restricted to temperate or humid climates.
- Geotechnical stability of the dykes and other retaining structures and design of the drainage system to cope with possible flooding. Of particular concern is the loss of stability of dams and dykes due to scouring erosion in case of overflow during storm events.
- The impounded tailings have to be levelled (e.g. by dredging) to prevent parts of the material becoming exposed in case of variation of the water level.
- A subaqueous cover of the tailings with inert material may be necessary to reduce diffusive exchange with the supernatant water.
- Drainage and seepage waters from the impoundment may need to be managed over some time, involving water quality checks and intervention with treatment, if necessary.
- Above ground impoundments with water covers are likely to require more monitoring and maintenance to ensure their functioning, than similar pit disposal sites.

In the past, tailings have been disposed of into natural lakes, and it will rarely be possible to relocate tailings efficiently or economically. Remediation work in these cases should concentrate on ensuring that the tailings will remain contained. This may require the addition of a capping of layers of sand and rock or similar materials. Water quality monitoring programmes should also be put in place.

Tailings stored underground

Where tailings have been placed below ground during operations, or at the time of decommissioning, there is likely to be little further scope and need for remediation. The placement of tailings below- or underground is likely to provide the best long-term management solution from the point of view of both, reducing potential legal liability, as well as providing the greatest long-term environmental safety. However, the possibility of leaching and suffusion by permeating groundwater has to be considered. Possible options for prevention and remediation include the sealing of open mine workings and the creation of underground barriers by injecting grouts etc.

Remediation of waste rock piles

Waste rock arising from mining operations is usually placed above ground and the dumps are eventually reshaped according to a final contour that is designed to improve geotechnical stability and to limit surface erosion of this artificial landform. The potential for adverse environmental impact

from the weathering of the excavated and stockpiled rock, for example, the tendency to develop acid rock drainage etc., will need to be assessed thoroughly before a final development plan is adopted. An engineered capping may be required to reduce erosion rates and to provide a substrate for subsequent revegetation.

Remediation of stockpiled sub economic materials

As is the case for other mineralised materials, the potential for adverse environmental impacts and health risk from such stockpiles has to be assessed. In addition to the geotechnical and geochemical data required for non-mineralised materials the following should be assessed:

- Gamma radiation levels from the rocks.
- Radon emanation rates.

There must be agreement with the regulatory authorities on the standards that are to be applied for the containment of such materials. For instance target gamma dose rate in relation to the critical group at the remediated site, target radon emanation rate, minimum covers of “clean material” to be installed over the radioactive materials may be specified. If the materials are to be relocated, a specific order for placing them into the containment (e.g. most radioactive material lowest, etc.) may significantly reduce the risk of mobilisation of contaminants and ensuing adverse environmental impacts.

Remediation of heap leaching waste

Heap leaching waste may form piles, which have to be reshaped for proper integration into the landscape and to meet the geotechnical and erosion stability requirement mentioned before.

It may be advantageous to preserve drainage systems to enhance heap and contour stability and collect seepage water. However, capping will reduce further leaching by reducing water infiltration rates, prevent the dispersion of radioactive material due to water and wind erosion, reduce radon emanation and prevent exposure from direct gamma emissions. A monitoring programme may need to be initiated to check surface run-off and seepage water quality and, if necessary, contaminated waters may need to be treated.

In particular cases, relocation may be appropriate. Heap leaching waste may be used as first cover for mill tailings, if they have suitable radiological properties and do not contain residual acid generating material. In the case of Écarpière in France [4] this has allowed the reduction of areas that need to be monitored and subject to use restrictions.

Sundry and operational wastes

Storage and disposal sites for sundry and operational waste as discussed previously may require remediation following established procedures for conventionally contaminated sites. Depending on the nature of the contaminants, the wastes may be conditioned and disposed of at designated locations on site, or may need to be sent to licensed (hazardous) waste disposal sites.

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6. WATER REMEDIATION

Scoping of the problem

Water is one of the principal pathways by which contamination may be dispersed into the environment from uranium mining and milling operations. Mining, be it open-pit or underground mining, almost always requires, owing to the presence of groundwater, the dewatering of the zone to be mined. A variety of processes may render these waters contaminated.

Contaminated water may also occur as a consequence of surface water runoff from, and seepage through, waste rock piles and ore stockpiles, and is expelled from tailings during their settling process. The radioactivity of this water is generally derived from uranium, thorium, radium and lead, either dissolved or attached to suspended particles. Where pyrite and other sulfidic minerals are present, acid may be generated during their oxidation. Acid generation, also known as acid mine drainage (AMD) or acid rock drainage (ARD), is a concern in all types of mining. The acid dissolves and increases the mobility of heavy metals and metalloids such as manganese, iron, nickel, zinc, cadmium, arsenic, or selenium. It also mobilises the radionuclides present in uranium ores. AMD requires neutralisation before it can be discharged into the environment. Explosives residues and degradation products may also add nitrites, nitrates, ammonia and a variety of organics to the mine waters. The high sulfate concentrations and the acid itself may preclude the release of untreated mine drainage waters.

Mill sites in dry areas may produce little or no liquid effluents due to extensive recycling of process waters. Runoff water from mill sites in wet climates may contain radionuclides and may require treatment before release into watercourses. Typically, contaminated water from uranium mills is discharged into the tailings management facilities. Water contaminated during mining and milling operations, which cannot be reused, is treated as waste. The composition of this wastewater is determined by the process technology and the ore grade. Water treatment has to reduce the concentration of contaminants to levels that are in compliance with the discharge regulations in the respective country. Additionally, monitoring of the released water is required to ensure that all constituents are within regulatory limits.

The environmental remediation of any uranium production facility should include treatment of all associated wastewater and the remediation of contaminated groundwater and surface water, including the respective bottom sediments.

Any remediation programme would begin with a site characterisation and establishing (perhaps retrospectively) the baseline conditions as has been detailed above. Characterisation activities may need to go well beyond the actual site in order to capture the migration of contaminants or the potential for it.

Quality objectives for aquifers and the surface water courses will be set according to land-use plans, both in the short- and the long-term, and national regulatory requirements.

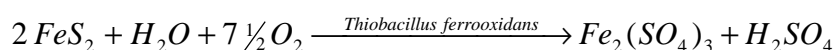
This overall water quality assessment will allow a determination of the degree of treatment and remediation needed.

Treatment technologies are selected according to the nature of the contaminants, their concentration in the untreated wastewater and their maximum allowable concentration in the final effluent. A general objective of mine effluent treatment is the production of an acceptable water quality of the discharge with low volumes of residues.

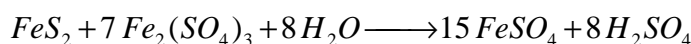
Conventional contaminants in water affected by uranium mining and milling

Biological leaching of uranium occurs naturally, as rainwater and runoff circulates across the rock surfaces of open pits and underground uranium mines. The bio-geochemical processes are interlinked and involve the following major reactions:

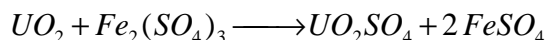
- Bacterial oxidation of pyrite



- Chemical oxidation of pyrite by ferric sulfate



- Chemical oxidation and solubilisation of uranium by ferric sulfate



- Bacterial reoxidation of ferrous sulfate



Other microorganisms found in such waters and involved in relevant redox and acid-base reactions are *Thiobacillus thiooxidans* and *Thiobacillus acidophilus*.

As a function of the various uranium ore treatment processes, different chemical components may be discharged to the environment as liquid effluents:

- Bicarbonates Due to addition of lime in the neutralisation process.
- Sulfates From the oxidation of pyrite and other sulfides waste rock, heap leaching residues and tailings.
- Chlorides Stripping agent in solvent extraction processes and from back-washing of ionic exchange resins.
- Nitrates Residues of explosives used for rock blasting.
Fertilisers used in revegetation.
(Biochemical) oxidation of nitrites or ammonia (see below).
- Nitrites and Ammonium Degradation of organic pollutants and eutrophication of stagnant waters (nitrites, however, are readily oxidised).
- Calcium Residue from lime addition.

- Sodium Solvent extraction or ion exchange processes as stripping agent (NaCl).
- Iron Particularly from the oxidation of pyrite (FeS₂) and other ferrous sulfides, dissolution of siderite by AMD and weathering of various minerals in waste materials.
- Manganese Naturally from various weathering processes, but it is also, added as oxidant in some leaching processes.

Regulatory requirements for groundwater remediation and surface water discharge in different countries with uranium mining

Treatment of contaminated mine and mill effluents is usually mandatory. National laws and regulations set effluent release criteria. The maximum permissible concentration limits for individual contaminants, however, differ from country to country. Examples of effluent concentration limits in selected countries are listed in the table below.

Some countries have defined specific radionuclide concentration or activity limits for surface water discharge from uranium mining and milling facilities and for groundwater remediation. Often, however, drinking water quality standards are applied to discharged mine water as maximum allowable release limits [1].

Table 6.1. Examples of national effluent concentration limits

Country	Regulated Contaminants									
	U _{nat} mg·l ⁻¹	²²⁶ Ra Bq·l ⁻¹	Pb mg·l ⁻¹	Zn mg·l ⁻¹	Cu mg·l ⁻¹	Ni mg·l ⁻¹	As mg·l ⁻¹	SO ₄ mg·l ⁻¹	Cl mg·l ⁻¹	pH
Czech Rep.	0.1	0.3	0.1	0.2	0.1	0.15	0.1	300	350	6-9
France	1.8	0.37					0.1	2 000		6.5-9
Germany	0.2 -0.5	0.2-0.4					0.1-0.3	2 500-7 500	1 000-1 500	6.5-8.5
Spain			0.2	3	0.2	2	0.5	2 000	2 000	5.5-9.5
USA		0.18	0.015	5	1.0		0.05	250	250	6.5-8.5

The following factors need to be taken into account in deriving permissible effluent concentration limits:

- Nature of the effluent to be treated
 - Acid mine water.
 - Runoff from ore stockpiles, mill area and waste rock stockpiles.
 - Effluents from tailings ponds.
- Concentration of contaminants in the final effluent
 - Radionuclides (natural uranium, ²²⁶Ra and ²³⁰Th).
 - Annually discharged activity.
- Effluent flow rate and dilution factor
 - Maximum allowable concentration of constituent of interest in the watercourse.
 - Background concentration of receiving watercourse.

- Evaluation of seasonal changes in radionuclide concentration produced by leaching of naturally exposed ore bodies and mineralised zones.
- Water quality standards set for release
 - As a reference, international recommendations, national guidelines and specific regulations should be followed.
- Doses to population
 - Based on limits for the general population or critical groups as stipulated in national and international regulation a target dose will need to be set for planning purposes.

General approach to uranium mine effluent treatment

Technical criteria

The design criteria for water treatment plants are dictated, in the first place, by the nature of the effluent to be treated, i.e. the type and concentration of the contaminants, and by the accruing flow rates in relation to the target quality objectives. However, in addition to these basic requirements, cost/benefit considerations regarding factors, such as the background concentration of the surface water into which the effluent will be discharged, official water quality classification of the receiving surface water, and volume reduction of residues have to be taken into account.

Many treatment technologies are capable of achieving concentrations that are well below the natural background level of the receiving surface water bodies, and it may not be necessary to prescribe effluent release concentration limits. Depending on the water quality classification of the receiving water, concentration limits of contaminants such as sulfates, chlorides, iron, calcium and magnesium may be established within certain limits. However, the accumulation of contaminants, such as heavy metals and radionuclides, in bottom sediments may need to be taken into account.

The technical concept for a specific water treatment process takes into account the consideration that volumes and concentration levels of contaminated effluents are changing with time during decommissioning and remediation. This evolution may require different technologies and differently sized plants for the various stages of the decommissioning and remediation process.

Treatment of large volumes of contaminated water ($>50 \text{ m}^3 \text{ h}^{-1}$) is currently (and likely for some time in the future) based on conventional chemical processes. For smaller volumes of contaminated water, e.g. seepage from a covered waste rock pile, low-tech and low-maintenance, self-regulating processes that run with a minimum of human supervision and involvement would be ideal. Technologies such as biological treatment in wetlands, or passive treatment, through reactive barriers, may have some promise for the future.

Residue management and disposal

In developing a conceptual plan for uranium mine and mill effluent treatment, the aspect of handling and disposal of sludges and other residues is of importance. Treatment processes are designed to concentrate and isolate radioactive and chemical contaminants. For safe disposal, the contaminants may need to be further immobilised. The residues and sludges from the treatment need to be disposed of in an appropriate waste disposal facility licensed to accept such material.

Provided the license conditions for the site allow it, this can be in the on-site tailings impoundment or in an engineered low-level radioactive waste disposal cell. Alternatively it may be

necessary to transport the material to an appropriate facility located away from the site. Typically, more stringent clean-up requirements mean that higher volumes of residues will be generated and, therefore, more capacity for safe storage is required. Both the immobilisation of residues and the construction and licensing of suitable disposal cells are expensive. It is therefore important, to choose a technology that allows minimising the volumes of residues while meeting the required standards of clean up. Cost-benefit analyses help to find an optimum solution that satisfies both the demand for as-low-as-reasonably possible contamination levels in the effluent and the cost of residue disposal.

Provided license conditions allow this, an on site disposal area integrated into the tailings management facility can be constructed with spare material from building the final capping. If sufficiently isolated, underground disposal in a dedicated section of underground workings may be considered.

Water treatment techniques

Water treatment technologies make use of different chemical, physical and biological processes for contaminant removal. The method of choice depends on the chemistry of the water to be treated, its volume, the prescribed effluent concentrations, the requirements on the residues to be disposed of, and the overall cost of the process.

The remainder of this chapter summarises the most common, as well as some of the more unconventional, methods used in uranium mine closure and remediation.

Precipitation methods

The most widely used methods in uranium mine and mill water effluent treatment are precipitation methods. They have been in use since industrial uranium ore processing began in the late 1940s. Precipitation methods are quite efficient as they use small amounts of chemicals and are low-cost. Their disadvantage is the large volume of residues produced.

It should be noted that from a physico-chemical point of view a distinction between precipitation, co-precipitation and adsorption is often difficult. All three processes may be responsible together – to a varying degree – for the removal of ions from solution at any one time.

Lime treatment

Lime treatment is the method of choice for treating acidic waters from uranium processing plants that rely on sulfuric acid leaching for uranium extraction from the ore. It is used for the treatment of acid mine drainage, as well as for treating supernatant and seepage water from acid uranium mill tailings and other disposal facilities.

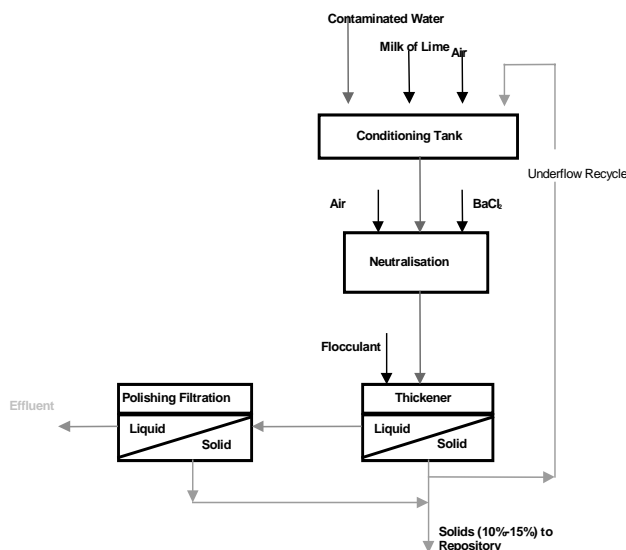
In the lime treatment process, a 15% to 20% milk of lime (calcium hydroxide) slurry is added to the acid effluent. Normally, enough milk of lime is added to raise the pH to 10. For agitation and to oxidise ferrous iron, trivalent manganese and arsenic, air is blown into the precipitation tanks. In the process, in addition to gypsum, most metals are co-precipitated as either sulfates or hydroxides. Uranium is precipitated as calcium diuranate. Solid/liquid separation is carried out in thickeners. Residual metal concentrations in the thickener overflow are low enough to meet the effluent release regulations in most countries. Before final release, the effluent pH should be adjusted to a value of

between 6 and 8. Addition of dilute sulfuric or hydrochloric acid may be needed for this. The thickener underflow, which contains the metal precipitates, is stored in a disposal cell.

Because of its non-selective nature, the lime treatment process is also called a bulk neutralisation process. Bulk neutralisation tends to generate voluminous precipitation products, which are difficult to dewater. Conventional bulk neutralisation processes with single-stage lime addition and no recycling of solids, normally produce underflow densities of not much higher than 2% solids. This low density may be acceptable in an uranium production plant that operates also a tailing pond, where further solid/liquid separation can take place over time, and from where liquids can be recycled to the plant and used as process water. However, after decommissioning of a mill, the tailing pond may no longer be available and the residues have to be conditioned so as to take up as little space as possible. Minimising the time to completion of the operation may be further constraint. Therefore, forced dewatering may be mandatory. This can be achieved by running the low-density thickener underflow over drum or disk filters, or through centrifuges, but both the capital and operating costs for either process are high. For this reason, the thickener underflow density should be maximised to the greatest extent possible. A careful cost-benefit analysis will further help to offset the various constraints against each other.

To increase thickener underflow densities, the characteristics of the precipitation product should be optimised. Experience has shown that multi-stage lime addition and solids recycling hold the key for improving the solids characteristics, which subsequently leads to better thickener performance. In the so-called High-Density Sludge (HDS) process, up to 90% of the thickener underflow is recycled to a conditioning tank at the head end of the bulk neutralisation stage [2]. There, it is mixed with fresh contaminated water and milk of lime is added to raise pH to approximately 4.0. After passing the conditioning tank, the slurry runs by gravity through a series of air agitated tanks, where more milk of lime is added to raise the pH further. Normally, the pH is raised to 10; if magnesium has to be removed, further lime addition to obtain a pH of 11.5 will precipitate magnesium hydroxide. A properly selected thickener will aid in the process of producing high underflow densities. The HDS process is capable of producing underflow densities up to 15% solids. The flow sheet of the HDS process is shown below [3]. Such precipitation is also possible with sodium hydroxide, but it produces larger volumes of sludge.

Figure 6.1. Flow sheet of the HDS process



Ferric chloride treatment

Although most of any arsenic present is precipitated as calcium arsenate during bulk neutralisation, the residual concentration of dissolved arsenic normally remains above accepted release limits. To bring arsenic down to the required concentration, ferric chloride solution is added to the slurry during bulk neutralisation. Ferric chloride (FeCl_3) acts in two ways to remove arsenic: Firstly, the iron combines with arsenate (AsO_4^{3-}) to form a ferric arsenate (FeAsO_4) precipitate, which has a very low solubility. For this reaction to occur, arsenic has to be pentavalent and pH has to be < 7 . In the second mechanism, arsenic species are removed from solution by co-precipitation on ferric iron hydrolysis products that form voluminous precipitates. Ferric hydroxides have a large reactive surface area and are capable of adsorbing a variety of ionic species, including arsenic, heavy metals and radionuclides. Ferric chloride treatment is capable of reliably reducing the arsenic concentration to less than $0.1 \text{ mg}\cdot\text{l}^{-1}$.

Barium chloride treatment

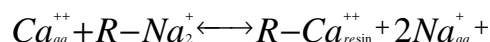
Barium chloride treatment is widely used in the uranium industry to remove radium, both at operating mines and for treating contaminated water from decommissioned sites. Radium concentrations of $< 0.3 \text{ Bq}\cdot\text{l}^{-1}$, as required for mine or mill effluents in most countries, can easily be achieved.

If contaminated waters contain sulfate ions, as it is the case for almost all effluents that originate from acid leach processes or for acid mine drainage, radium removal is easily achieved by adding barium chloride. Barium sulfate has a low solubility and readily precipitates, co-precipitating Ra at the same time as $(\text{Ba,Ra})\text{SO}_4$. The precipitation reaction performs best at a pH values between 6 and 8. The addition of only 30 to 60 milligrammes of BaCl_2 per litre is required to achieve a 95 to 99% radium removal. The barium/radium sulfate precipitate is crystalline, however, given the short process times, only very small crystals can grow, which settle slowly. They are difficult to retain by filtration. It is, therefore, common practice to co-precipitate radium with other more abundant species, e.g. during bulk neutralisation, or together with the precipitation of arsenic by ferric chloride.

Ion exchange

Ion exchange is a well-known water treatment technology. It involves organic or inorganic solids that have chemically reactive site or functional groups, which carry either negative or positive ionic charges when dissociated. Appropriately, ion exchange resins are distinguished into exchangers for cations (when negatively charged) or anions (when positively charged). Attached to the reactive groups are displacable ions of the opposite charge (counterions), i.e. the exchangers are “loaded”.

Ion exchange is a reversible reaction, by which the counterions on the resin are exchanged for dissolved ions of the same electric charge sign. An example for cation exchange is the familiar water softening reaction:



The exchange reaction is driven by the relative concentration (activity) of the competing ions, their electric charge, and their relative affinity for the exchange site in questions. The affinity is *inter alia* a function of the ionic radius and the chemical nature of the reactive group of the resin.

When the resins are “spent”, i.e. are loaded with the ions to be removed from solution, these ions can be recovered by “regenerating” the resins through backwashing them e.g. with strong acids. The counterion in this case is the H^+ ion, which typically has the strongest affinity for the exchange places.

Most industrially used ion exchangers are based on synthetic resins, but also inorganic substrates, such as zeolites are being used. Detailed technical information is available from commercial suppliers of ion exchangers.

Ion exchange technology is rather expensive. Its application is, therefore, limited to special cases requiring either high efficiency or the separation of one or more specific contaminants. Especially, if the separated contaminant is intended for further use or for separate storage, ion exchange resins are well suited.

Ion exchange is, or was, commonly used for removing uranium from tailings pond effluents in former eastern bloc countries. Ion exchange for uranium removal, for instance, is applied in the WISMUT-operated water treatment plant at Helmsdorf in Germany [3]. It is also used in Lodève (France) to treat water from an abandoned uranium mill tailings pond, in preparation for its final remediation, and in Portugal to treat mine effluents.

Ion adsorption

Ion adsorption, from a physico-chemical point of view, is similar to ion exchange, except that no regeneration is envisaged. Dissolved contaminants are scavenged by the reactive surface of a suitable adsorber. For instance, an uranium-specific high molecular polymer (molecular weight >200 000) called GOPUR 3000 [4] has been developed in Germany for the removal of uranium from effluents. It is added as a dilute, acidic solution (normally 2%) to the contaminated water. At pH values between 4 and 11, the polymer is insoluble in water and precipitates forming voluminous flocs. Their reactive surfaces are capable of adsorbing, or actually complexing, the uranyl ion. The loaded flocculant can be removed from the water by conventional solid/liquid separation techniques.

If the uranium or other contaminants do not have to be extracted for further use, the ion adsorption technology offers significant operational and cost advantages over the ion exchange technology. Since the uranium in the loaded polymer can be separated by conventional liquid/solid separation techniques, this water treatment can be operated as a continuous process. Ion exchange columns require periodic stripping, regeneration and washing. This adds to the capital, operating and management costs.

Preventive Strategies

The objective of preventive strategies is to avoid generation of acid effluents from (decommissioned) mines and waste management facilities and to reduce the source term for contaminants. The planning of mine closure and closeout of waste management facilities should give priority to preventive strategies whenever possible. The preventive strategies have one or more of the following objectives to reduce the generation of acid and the source term for contaminants:

- To limit the oxygen supply.
- To limit water infiltration.
- To limit water circulation.

While these objectives are the same for underground and open pit mines, waste rock piles and tailings ponds, the actual technical measures may differ.

Underground facilities

The preventive strategies applicable to underground mines consist of three elements:

- *Active management* of the quality of the water in the different parts of the mine by avoiding the mixing of good and poor quality water.
- *Flooding* of open mine workings may be unavoidable once the drainage systems have been decommissioned. It has the advantage of preventing access of atmospheric oxygen. Sulfide oxidation reactions will stop once the oxygen dissolved in the water has been consumed. The flooding may either progress naturally or may be augmented by (neutralised) process waters.
- The objective of flooding can only be reached by limiting groundwater circulation in the open mine workings through *permeability reduction* and/or *hydraulic isolation* of the mine. This intentionally limits the supply of oxygen by limiting the quantity of water flowing through the mine and avoids changes in the water table, which would draw air into the mine.

Certain technical measures may be required, including:

- Sealing of shafts, boreholes and other access facilities.
- Sealing of fracture and fissure zones.
- Damming up of individual parts of the mine to prevent circulation.

The development of a geochemical environment that limits contaminant migration can be encouraged by chemically active backfills, as has been experimented with at the Königstein mine in Saxony, or by reactive barriers upstream.

Surface impoundments of waste materials including tailings

Preventive strategies commonly applied to surface impoundments are for instance:

- Surface water diversion by channels.
- Limiting infiltration of atmospheric precipitation by capping.
- Selective placement of waste materials to foster e.g. neutralising reactions, or to limit access by infiltrating waters.
- Reactive inter-layers, e.g. crushed limestone, to control pH.
- Encouraging the development of anoxic conditions by addition of bacterial growth media, such as manure or wood chips.

Open pits

The most common preventive techniques for open pits are:

- Clay seals to prevent infiltration into underlying strata.
- Liming to lift up pH values.
- Sealing of boreholes to prevent infiltration into underlying strata.
- Backfilling to avoid accumulation of surface runoff.

Groundwater treatment following ISL operations

In situ leach (ISL) or solution mining is the process of extracting uranium by injecting reagent solutions through wells into a water-saturated ore body and recovering the pregnant solutions through other wells after they have passed through the host formation and dissolved the uranium ore. The uranium bearing solution is then pumped to a surface facility, where the uranium is recovered from the solution, e.g. by ion exchange.

As with other mining activities the planning and operation of ISL uranium mining is highly dependent on the specific site conditions of each uranium deposit. The main technical factors to be considered are the ore characteristics, the host aquifer's mineralogical and hydrogeological properties and water quality. Current aquifer uses, such as drinking water extraction, and any administrative restrictions, such as groundwater protection zones, have to be taken into account.

Two different leaching systems are used for ISL mining: acid and alkaline. Acid systems typically use sulfuric acid, but a mixture of nitric and sulfuric that was available as waste product was used for some time in the former East Germany. In addition to solubilise metal ions, sulfuric acid acts as an oxidant. Sulfuric acid systems vary from the highly concentrated acid used at Straž, Czech Republic, to the very low concentrations now being used in some projects in Uzbekistan. Alkaline systems rely mainly on atmospheric oxygen as an oxidant and carbonate as a complexing agent.

Until recently, acid systems were used only in the Commonwealth of Independent States (CIS), central and Eastern Europe. At the end of the 1990s acid leaching was tested and is now being used in Australia.

In the USA, only alkaline systems are used for environmental reasons and because of the carbonate content of the host rocks.

The regulatory regimes and groundwater restoration requirements are different in each of the countries. For the Australian sites, a strategy has been adopted which requires control and monitoring of groundwater. ISL is only employed in aquifers with a very high initial salt content – making them unsuitable for drinking water extraction and where it has been demonstrated that water contaminated by the leaching process can be hydraulically isolated from other parts of the aquifers. This use has been authorised following a stringent environmental impact assessment process. The sites are also located in remote areas with no permanent population. In the USA, groundwater quality must be restored to pre-mining conditions. This is accomplished through a strategy based on pump-and-treat technology, complemented with other methodologies. At the densely populated ISL mine locations near Straž, Czech Republic, and Königstein, Germany, where acid *in situ* block leaching was performed, the residual acidic solutions are pumped to the surface for treatment and discharge or reinfiltration.

Most of the ISL mine sites in the countries of central Asia are located in remote, un-populated areas. Many of the mines were developed in aquifers with low water quality due to high salt contents. For most of these mine sites, natural attenuation is relied upon to control residual ISL solutions.

Several of these restoration strategies and techniques are described in following case studies in more detail. In addition, the IAEA has addressed the issue in a dedicated report. [5].

Case studies

The following case studies describe methods for treating contaminated water from uranium mines, tailings impoundments and other waste management facilities.

Australia

Removal of radionuclides and other dissolved species in a natural wetland system

The Ranger Uranium Mine is located in the tropical region of northern Australia. The mining and milling operations produce varying qualities and quantities of wastewater, some of which have to be treated before discharge into the environment. The mine water management system incorporates various water retention ponds, which collect the wet season rainfall run-off from rock piles within the project area. In order to treat these waters, Energy Resources of Australia (ERA) has constructed and maintains a wetland filter in the catchment of Retention Pond 1 (RP1) at the mine site. Its effectiveness in removing radionuclides was investigated during two periods, 1989/1990 (with wastewater from the former Retention Pond 4-clean waste stockpile runoff) and 1995/1996 (with wastewater from Retention Pond 2-ore stockpile and mill area runoff).

The objectives were to: develop a “natural” technique able to achieve a water quality that could be safely discharged into the environment; determine the controlling factors on the beneficial effects of the filter; and investigate and relate to performance criteria the chemical properties of the sediments formed during the wetland filter process. Treated waters were irrigated on undisturbed bushland within the mining lease boundary. Direct release of waters to the creek system was not acceptable to all the stakeholders, and was therefore not permitted.

Table 6.2. **Approximate wet season concentrations of selected solutes in Retention Pond 4 of Ranger Uranium Mine and in regional backgroundwater from Magela Creek**

Location	SO ₄ (mg.l ⁻¹)	Cl (mg.l ⁻¹)	Ca (mg.l ⁻¹)	Mg (mg.l ⁻¹)	I (µg.l ⁻¹)	Br (µg.l ⁻¹)
RP4	260	10	6	80	170	380
Magela Creek	0.5	2.6	0.4	0.7	3	20

Location	Re (µg.l ⁻¹)	Mn (µg.l ⁻¹)	U (µg.l ⁻¹)	²²⁶ Ra (Bq.l ⁻¹)	pH
RP4	50	120	140	0.3	7.5
Magela Creek	< 0.1	2	0.1	0.006	6.0

Design and performance of the treatment facility

The natural wetland filter consists of an overland flow area and a “billabong” (seasonal waterhole) for improvement of effluent water quality through removal of nutrients, raising of pH, elimination of suspended solids, and adsorption of heavy metals and radionuclides. It began as an experimental system in 1989-90 and was modified in 1995 by increasing the embankment height and by additional excavation of a disused clay burrow pit. Currently, the filter comprises eight cells of varying sizes with a combined surface area of about 56 000 m² and a volume 45 000 m³. The effective minimum flow path is approximately 1 240 m.

The system is effective at removing Mn and U (96% and 54% respectively during the 1995 dry season). Elimination of Ra is not significant in the billabong, but processes occurring during the overland flow may be responsible for a reduction in the concentrations by a factor of about two. The filter is almost totally ineffective at removing Mg and SO₄²⁻; as can be expected, other solutes like Ca, I, Br are also not removed.

The table below lists main data for each cell for comparison, showing the effectiveness of the wetland system for the removal of some contaminants.

Table 6.3. Mean analytical data for all sampled sites

Site	Distance from inlet (m)	Mn soluble ($\mu\text{g}\cdot\text{l}^{-1}$)	Mn particulate ($\mu\text{g}\cdot\text{l}^{-1}$)	U soluble ($\mu\text{g}\cdot\text{l}^{-1}$)	U particulate ($\mu\text{g}\cdot\text{l}^{-1}$)	Fe soluble ($\mu\text{g}\cdot\text{l}^{-1}$)	Fe particulate ($\mu\text{g}\cdot\text{l}^{-1}$)
Wetland inlet	0	273.9	29.1	709	10.9	18.5	96
Outlet Cell 1	127	253.0	30.8	677	10.1	22.3	80
Outlet Cell 2	257	164.8	27.9	615	11.3	19.1	83
Outlet Cell 3	295	137.5	15.1	575	7.8	22.1	78
Outlet Cell 4	615	64.8	15.6	479	5.2	20.8	52
Outlet Cell 5	685	63.0	7.0	420	8.5	47.6	121
Outlet Cell 6	828	44.7	7.1	417	4.1	45.7	98
Outlet Cell 7	1 068	25.8	4.8	334	3.1	39.9	84
Outlet Cell 8	1 298	9.9	2.5	324	2.8	30.0	139
Year	Efficiency Mn removal			Efficiency U removal			
1995	96%			54%			
1996	84%			78%			

Other aspects of relevance

One of the most important aspects to be considered in connection with wetland filters for water treatment is rainfall. Results for samples collected after rainfall events suggest a remobilization of U and Ra.

Owing to the complex chemistry of uranium, the mechanism for removal of U cannot be asserted with the same confidence as for Mn. It is necessary to underline the strong dependency on retention time for U removal. Although elevated pH values should reduce wetland efficiency, it appears not to be a critical factor for the concentrations of U here.

Sediments formed are moderately to slightly acidic, have a very low to moderate CEC, and a low organic content. Although the system's efficiency for removing Mn and U is high, being newly constructed and due to its immaturity, it has not reached equilibrium with respect to the biotic processes and the recycling of biologically derived material. It is anticipated that the operational efficiency will continue to improve with time.

Care must also be taken to manage the wetland filter during the dry season. The system needs to be kept moist to ensure that the essential plants do not perish due to desiccation. Also, if the sediments dry out, the resulting oxidation leads to extensive remobilisation of previously adsorbed solutes, particularly the heavy metals that the system is designed for to capture. At the Ranger mine, drainage water is used to maintain the wetland filter system during the dry season.

Czech Republic

Treatment of acidic waters from ISL operations

Remediation of the Hamr-Straž site involves the treatment of contaminated groundwater. The waters are mainly contaminated with varying concentrations of sulfuric acid, whereby a distinction is made between weakly and strongly acidic solutions.

Weakly acidic waters from ISL operations

The co-existence of two production systems – classical deep mining and *in situ* leaching (ISL) – in the Hamr-Straž area (in the North of the Czech Republic), operated by DIAMO (a state-owned enterprise) requires pumping large volumes of acid mine waters. The water recovered from the mines has to be treated before it can be discharged into surface watercourses. The main contaminants are uranium, radium, ammonia, heavy metals (Ni, Zn, Mn) and free sulfuric acid. The concentration of total dissolved solids (TDS) reaches up to $10 \text{ g}\cdot\text{l}^{-1}$. The treatment of this type of acidic waters is based on precipitation and sorption.

A sorption step for recovery of uranium is placed as the first step before the lime treatment. The treatment plant (called NDS – Neutralisation Decontamination Station) ensures the elimination of ammonia, precipitation of Ra and separation of heavy metals in the form of insoluble precipitates.

The technology of the NDS is divided into sequential operations:

- Neutralisation and sedimentation.
- Chlorination, destruction of residual chlorine.
- Sludge filtration.

Neutralisation and sedimentation

Neutralisation is performed in two steps: Milk of lime is added to raise the pH to 6-7 in the first step. At the same time, Ra is precipitated as sparingly soluble $(\text{Ba,Ra})\text{SO}_4$ by adding BaCl_2 . In a second step, more lime is added to further raise the pH to 11.5-12. This operation is the main factor influencing the effectiveness of the following sedimentation and filtration behaviour of sludge.

The precipitation conditions also control the effectiveness of heavy metals (Al, Fe, Zn, Mn, Ni) removal.

The mixture of sludge and water is separated in gravitational sedimentation tanks. Flocculant is added to improve the sedimentation conditions. The clear solution recovered from both steps is pumped into a collection tank before chlorination.

Chlorination

In a flow-through reactor, chlorine gas is added to oxidise ammonia ions into gaseous nitrogen.

Sludge filtration

Sludges from the sedimentation tanks are thickened by filtration using a filter press. The cake (approx. 30% of solids) is transported to the Straž mill tailings pond.

Strongly acidic solution from ISL operation

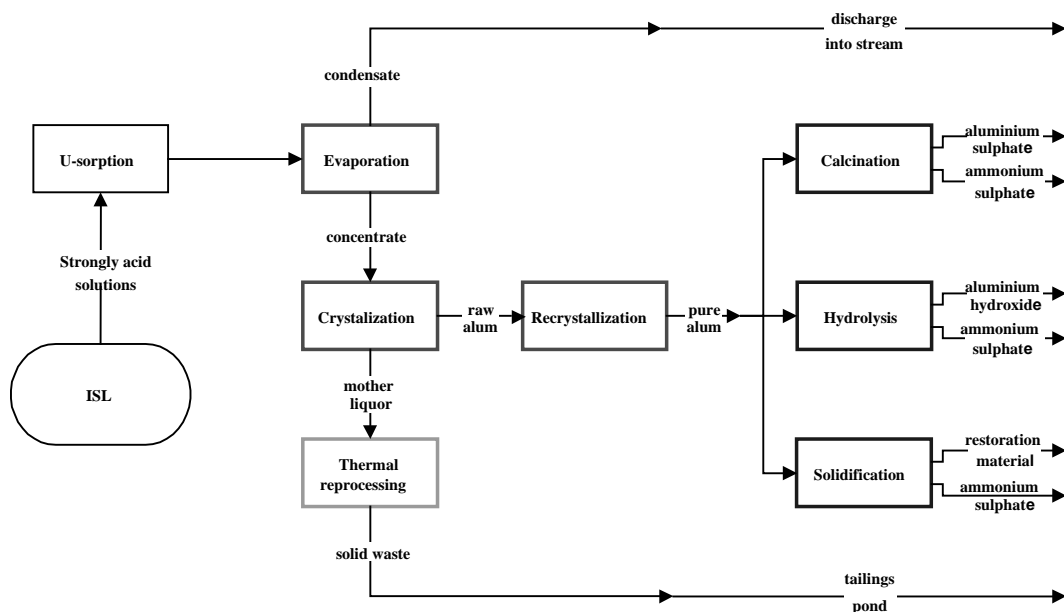
The restoration of water from Hamr-Straž ISL mines requires the treatment of large volumes of contaminated groundwater with TDS contents of up to $80 \text{ g}\cdot\text{l}^{-1}$, of which about $10 \text{ g}\cdot\text{l}^{-1}$ is free sulfuric acid. Based on the chemical composition of these solutions, it was decided to use a complex scheme of treatment for salt removal. The sequence of operations for acidic solution treatment consists of:

Evaporation

This takes place in heat exchangers and falling film vapour compression evaporators.

- Crystallisation and re-crystallisation of ammonium aluminium sulfate (alum)
In a crystallisation tank, the solution is combined with a solution of ammonium sulfate sufficient to make up a stoichiometric solution of ammonium/aluminium sulfate. A large amount of alum crystals is produced after the flash cooling.
- Reprocessing of alum to aluminium compounds
The products of crystallisation are *de facto* waste, if they are not further processed. It was therefore necessary to find a method for their processing into commercial products, or into a form, which could be safely disposed off. Aluminium sulfate and Aluminium hydroxide are the chemical compounds produced.
- Treatment of mother liquor
The treatment of the concentrate has the main objective of minimising the solid wastes to be disposed of. The method (in planning) comprises a 3-stage process of thickening by evaporation, crystallisation, and separation of the solids. The solid product is processed into materials, which will be used for the tailings remediation. The liquid residue will be dried and residual solids will be calcined. The solid products will be deposited in the Straž mill tailings impoundment.

Figure 6.2. Schematic flowsheet for treatment of strongly acidic ISL solutions at Straž



France

Treatment of water from the COGEMA Uranium mill tailings after site remediation

Between 1981 and 1997, the 4 564 000 tonnes of ore mined in the Lodève region were processed by alkaline leaching [Na_2CO_3 at $\sim 90 \text{ g}\cdot\text{l}^{-1}$, oxygen 6 bars, 140°C , 18 h] to produce 12 850 tonnes of uranium.

In 1998, mining site remediation studies showed that two major types of water would have to be treated:

- Water from underground mine working.
- Water seeping out of and surface run off from milling residue disposal areas.

In 1998, the characteristics of these two types of water were as follows:

Table 6.4. **Lodève remediation study results, 1998**

		Water from underground mine workings	Water seeping out of mill tailings disposal areas
Flow rate	(m ³ .h ⁻¹)	40-60	0-70
pH		6.3-7.4	7-9
U	(mg.l ⁻¹)	1-40	30-400
Ra	(Bq.l ⁻¹)	0.1-3	0.2-1.1
SO ₄	(mg.l ⁻¹)	400-900	200-3 000
As	(mg.l ⁻¹)	0.005-0.11	0.01-1

Due to the Mediterranean climate of Southern France, the water flow rate may be extremely variable.

Based on the license conditions (release authorisations) in force at the site and earlier changes in the regulations, particularly the ministerial directive of 2 February 1998 (Arrêté Ministériel), COGEMA established the following quality objectives for the treated discharge water:

- pH > 5.5 and < 9
- TDS < 30 mg.l⁻¹
- U < 1.8 mg l⁻¹ (as stipulated by the site license)
- ²²⁶Ra < 0.37 Bq l⁻¹
- SO₄ < 2 015 mg l⁻¹
- As < 0.1 mg l⁻¹, (as stipulated by the ministerial directive of 2 February 1998).

COGEMA chose to recover uranium from the water. By doing this, the volume of sludge produced during the water treatment process is reduced considerably.

Treatment tests and choices of process

Treatment for uranium

Under normal operating conditions, uranium is recovered using the water treatment system. Under emergency conditions of higher flow rates, the same system produces water of a quality suitable for release.

Normal procedure

The normal procedure consists of the following steps:

- Water clarification by sedimentation + sand filter.
- Adjusting the pH to around 8 to reduce limescale.
- Uranium extraction on ion exchange resin in a “down-flow” mode.
- Elution of the uranium.

Back-up procedure

Should resin treatment prove impossible or too slow to cope with high flow volumes, provisions have been made for uranium removal by precipitation. The design for the $130 \text{ m}^3 \cdot \text{h}^{-1}$ plant foresees the following treatment steps:

- Removal of carbonates and precipitation with lime (pH around 12).
- Co-precipitation (or adsorption) of residual uranium by ferric salt.
- Flocculation with by a polyacrylamide solution and sedimentation. The thickened sludge is disposed with other ore treatment residues.
- Acidification with sulfuric acid (H_2SO_4) to give a pH of around 8.5.

High emergency flow rates

To treat unusually large water volumes, direct feeding of the resin containers can accommodate a higher flow rate.

Sludge production and disposal

Under normal conditions, uranium fixation, and Ra and As precipitation produce negligible amounts of sludge compared to the lime treatment (about 0.1 m^3 of sludges or 0.01 t dry weight for each m^3 of water treated). For disposal, sludges are regularly pumped to an impoundment built (from the material for final capping) on top of the tailings disposal facility.

Treatment for radium

For normal radium concentrations, around 5 g of BaCl_2 per m^3 of water are added prior to the sedimentation step to obtain clarified water with a ^{226}Ra content of less than 0.37 Bq l^{-1} .

Treatment for arsenic

If necessary, a ferric salt can be added at a ratio of 7 moles Fe to 1 mole As, effecting the precipitation of around 50% of the arsenic. The arsenic precipitate is eliminated together with the other suspended solids.

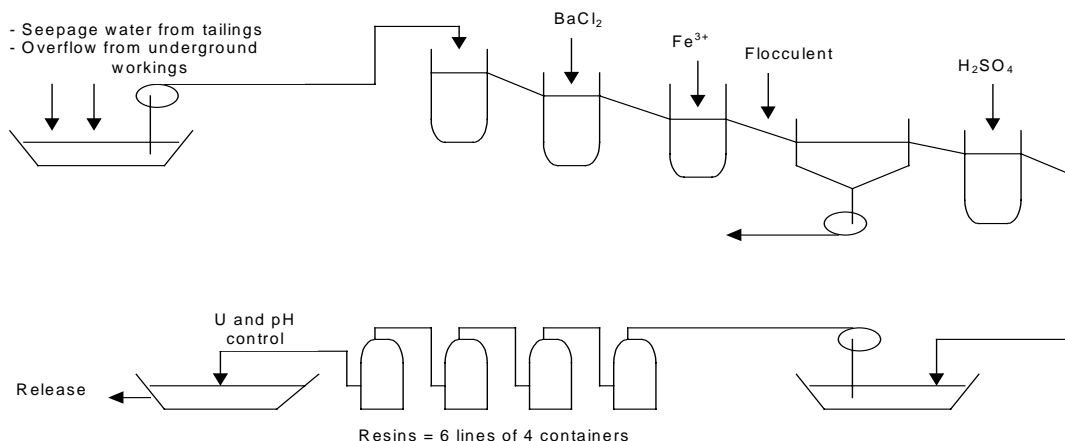
Results

The process was operated efficiently since commissioning. The treated water complies with the release standard. From October to December 1999, the average throughput was about $60 \text{ m}^3 \text{ h}^{-1}$, compared to an average of $37 \text{ m}^3 \text{ h}^{-1}$ for the year 1999.

Table 6.5. Water quality at the Lodève water treatment plant

	Inflow			Releases			Quality objectives
	Oct. 99	Nov. 99	Dec. 99	Oct. 99	Nov. 99	Dec. 99	
^{238}U ($\text{mg}\cdot\text{l}^{-1}$)	42.35	23.06	31.31	0.50	0.90	0.80	<1.8
^{226}Ra ($\text{Bq}\cdot\text{l}^{-1}$)	0.48	0.42	0.18	0.27	0.27	0.16	<0.37
As ($\mu\text{g}\cdot\text{l}^{-1}$)	37	59	16	51	51	9	<100

Figure 6.3. Schematic flowsheet of the water treatment plant in Lodève



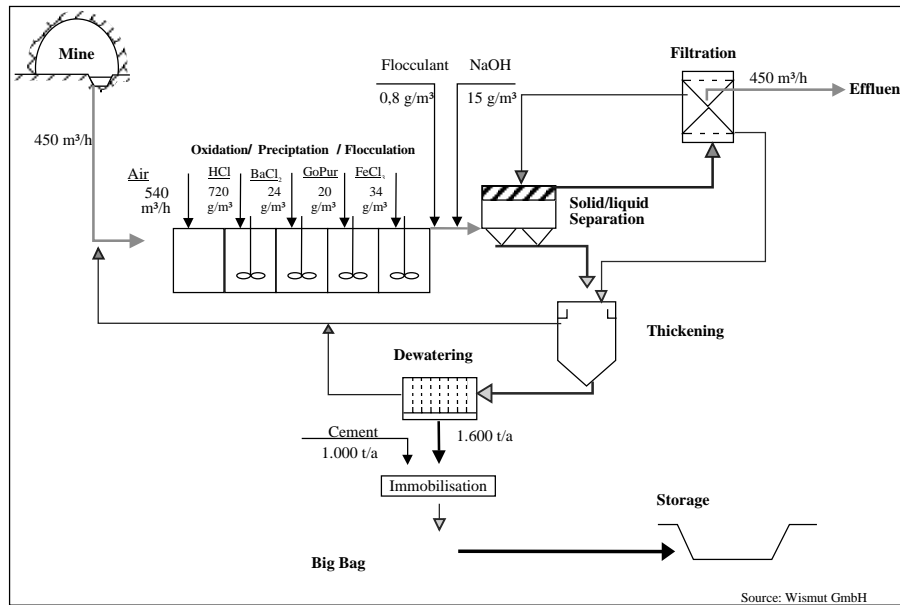
Germany

Treatment of mine flooding waters

The water treatment plant at the Schlema-Alberoda mine of WISMUT GmbH was built for the treatment of flooding water. Flooding of the mine began in 1992 and is planned to come to a temporary stop in 2002 at some 60 metres below the level of natural overflow. As the mine waters contains uranium, radium, arsenic, iron, and manganese at concentrations that make it unfit for direct discharge, it has to be treated bring concentrations down to an acceptable level. Once this has been achieved, the mine will be allowed to flood completely and to overflow naturally.

Due to the peculiar chemistry of the flooding water, WISMUT chose an ion adsorption process for the removal of uranium, combined with radium removal by barium sulfate co-precipitation and addition of ferric chloride for arsenic precipitation [3].

Figure 6.4. Schematic flowsheet of the Schlema-Alberoda water treatment plant



The figure shows a flowsheet of the process, which consists of the following steps [6,7]:

1. Lowering of pH to approximately 3.4 by addition of hydrochloric acid and oxidation of iron and manganese by aeration; at the same time any uranyl-carbonate complexes are destroyed.
2. Adjustment of the pH to between 5.8 and 6.0 by addition of sodium hydroxide.
3. Precipitation of radium and barium/radium sulfate by addition of barium chloride.
4. Separation of uranium by adsorption onto the reactive surface of the high molecular weight polymer GOPUR 3000™ [4].
5. Addition of sodium hydroxide to adjust pH at 6.2; precipitation of iron as iron hydroxide.
6. Precipitation of arsenic as ferric arsenate by ferric chloride addition.
7. Oxidation of manganese by addition of potassium permanganate.
8. Flocculation of precipitates by flocculant addition.
9. Liquid/solid separation in lamella clarifier.
10. Filtration of the clarifier overflow.
11. Discharge of the treated effluents into the Zwickauer Mulde river.
12. Concentration of solids in the clarifier under flow in a thickener tank.
13. Dewatering of the thickened slurry in a filter press to produce a filter cake containing 40% solids by weight.
14. Immobilisation of contaminants by mixing the filter cake with cement.
15. Transfer of the immobilisation product into “big bags”.
16. After curing, hauling the bags to a specially prepared repository for disposal.

The plant has a design capacity of $950 \text{ m}^3 \text{ h}^{-1}$. A first stage with a nameplate capacity of $450 \text{ m}^3 \text{ h}^{-1}$ is already in operation. The second stage is under construction.

Contaminant concentrations in the mine water and the treated effluent are summarised in the following table, together with the licensed effluent maximum quality limits.

Table 6.6. **Contaminant concentrations in raw and treated mine water at Schlema-Alberoda**

	Unit	Mine water*	Effluent	Effluent quality limits
Uranium	mg·l ⁻¹	7.2	0.4	0.5
Radium	Bq·l ⁻¹	3.8	0.03	0.4
Iron	mg·l ⁻¹	11.3	0.8	2.0
Manganese	mg·l ⁻¹	5.9	1.9	2.0
Arsenic	mg·l ⁻¹	1.9	0.07	0.3
Sulfate	mg·l ⁻¹	2 003	2 041	2 500
pH		6.8	7.3	6.5-8.5**

* Average values for January to March, 2000 [7].

** Permissible range.

Former Soviet Union – Commonwealth of Independent States (CIS)

Aquifer contamination from ISL operations

There is a distinction between ISL operations employing well fields with well-defined hydraulic boundary conditions, as in the case of sites in the USA and in some parts of the CIS, and other ISL operations in which the conditions are not so well defined such as sites owned by WISMUT (Germany) and DIAMO (Czech Republic).

There are two distinct operational periods with respect to the potential migration of contaminants away from ISL well fields:

- The period of active leaching, where the spread of any contamination halo is delimited by the hydrodynamic setting of the well field – if properly designed. In this case, groundwater contamination is confined to the area within the well field.
- When the uranium recovery is terminated and the artificial cone of depression diminishes as pumping is stopped, the natural hydraulic regime will gradually be re-instated. This can cause contaminants to migrate away from the ISL well field.

In properly operated leach fields there are only limited concerns regarding the spread of contamination into the aquifers. The examples of ISL mining show that the outer limits of the contamination halo usually does not extend more than 50 to 100 metres from the well field. Still, continuous monitoring of the chemical composition of the groundwater through appropriately drilled monitoring wells is warranted.

Groundwater remediation for sulfuric acid ISL operations

The process of groundwater remediation can be typically divided into two steps:

- Removal of contaminated process fluids by active flushing.
- Dispersion of residual contamination under the re-instated natural hydraulic regime.

Several methods for active flushing of an ISL well field exist. They can be used individually or consecutively.

Pump-and-treat with inflow of natural groundwaters

By this method five to ten pore volumes of water are extracted using the production wells, while the surrounding isolation wells are shut off to allow ingress of groundwater. The water is treated on the surface to neutralise acids, to recover uranium, and to remove contaminants. Typically, this requires a multi-stage unit for the adsorption and desorption of uranium, and the precipitation of lime pulp. This process potentially generates large quantities of waste solids and slurries, for which a safe method of disposal has to be found.

Air stripping of contaminated process liquids

This method consists of stripping the leached out well field from the leaching solutions by injecting compressed air. Air at a pressure exceeding the hydrostatic pressure is applied to the injection wells and the porewater is expelled and recovered by pumping of recovery wells. Uranium and other contaminants are recovered from the stripped solutions, while the acid solutions themselves can be recycled for other ISL fields, if available. Air stripping results in an initial recovery of 70 to 80% of the porewaters within the well field, and hence of 70 to 80% of the contamination within the accessible pore space. After the pressure is taken off, groundwater fills the pore space under the natural hydraulic gradient. However, owing to some pore plugging by air entrapment and geological homogeneity, parts of the well field will remain water unsaturated. Also, air stripping predominantly affects the upper parts of the well field. The advantage is, on the other hand, less dilution compared to the pump-and-treatment method, resulting in better process efficiency and smaller volumes to be treated. The air stripping can be repeated for enhanced recovery.

Flushing by recirculation

An ISL operation can be phased out progressively by maintaining the pumping regime, but gradually neutralising the production fluids before re-injecting them. As in the pump-and-treat-procedure, the uranium and other contaminants are recovered or precipitated into the waste sludge. This technique requires the lifting and treatment of, depending on the permeability and heterogeneity of the host rock, five to ten pore volumes. As contaminant concentration decrease, so will the expected process efficiency. This kind of flushing method was also proposed for, and has been applied to some degree to the “block leach” mine in Königstein (Germany) and the ISL mine at Straž pod Ralskem (Czech Republic).

It should be noted that all methods leave behind some residual contamination in pore spaces that are not accessible under the applied external hydraulic conditions. The respective fractional volume depends on the permeability and heterogeneity of the host rock material and can be significant. Predicting the remediation efficiency in this respect appears to be quite difficult.

Restoration by natural attenuation

Relying on natural attenuation for groundwater restoration is an alternative to employing an active pump-and-treat methodology. Natural attenuation is defined as the natural processes of biodegradation, dispersion, dilution, sorption, volatilisation, and/or chemical and biochemical stabilisation of contaminants occurring in soils and groundwater that effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

When the natural hydraulic conditions are re-instated following leaching, any residual contamination will gradually disperse under the concentration gradients between accessible and less accessible pore spaces. In the accessible pore spaces the contaminants will be subject to dispersion, but also to natural attenuation due to e.g. sorption or precipitation. The efficiency and the long-term characteristics of this attenuation will depend very much on the nature and characteristics of the aquifer, including flow rates, permeability, tectonic patterns, host rock mineral composition, sorption capacity, etc.

In cases where the aquifer down-stream of an ISL well field has sufficient acid neutralising capacity, where this aquifer cannot be used for other purposes, e.g. owing to its high salinity, and where water legislation permits it, the well field may be left to natural recovery. While the acids are destroyed through neutralisation by carbonates or clay minerals, contaminants, such as radionuclides and heavy metals, are only retarded, diluted and dispersed. The acceptability of such method depends very much on whether concentrations below concern can be maintained for prolonged periods of time and, hence, on the stability of the hydrogeochemical system. Low contents of acid neutralising minerals and natural adsorbents and slow natural groundwater flow can significantly delay the process and thus increase the remediation period.

The process of groundwater natural attenuation and restoration, and the migration of residual leaching solutions are monitored through a system of observation wells. After decommissioning, the restored aquifer and the observation wells are transferred to the appropriate authorities.

Increasing the groundwater flow rates can shorten the time required for neutralisation and removal of contaminants from solution, if enough buffering minerals are available. For this purpose, additional wells are drilled outside the production well field downstream the aquifer. The purpose is to draw residual solutions through parts of the aquifer previously untouched by the ISL and to use their acid neutralising and sorption capacity. Re-injecting pumped groundwater from the downstream side may further increase the hydraulic gradient. The costs of such system are limited to drilling the additional wells and to the pumping. No surface water treatment is required because other parts of the aquifer would receive the contamination.

In summary, relying on dilution by dispersion and natural attenuation to reduce unacceptable concentrations in the aqueous phase requires a careful evaluation of the hydrogeochemical conditions and their likely long-term development. A demonstration (e.g. by modelling) is required that no unacceptable down-stream concentrations will occur.

This method has been successfully applied to some ISL projects in Uzbekistan, Kazakhstan and the Russian Federation.

Uzbekistan

The most comprehensive study of the aquifer restoration by natural attenuation following sulfuric acid ISL mining has been performed over a period of 13 years from 1977 to 1989 at the Ore Lode 10 of the South Bukinai deposit [8]. The deposit was discovered in 1961 and is located about 20 km south of Zafarabad and 30 km northeast of Navoi in Uzbekistan.

The deposit extended over 70 000 m² in an aquifer 15.5 m thick and at a depth of 150 to 165 m below surface. It contained 1 733 000 t of ore at a grade of 0.024% U, corresponding to *in situ* reserves of 500 tU. At a recovery efficiency of 84%, Lode 10 yielded 420 tU during the eight years of ISL mining from 1968 to 1975. Two hundred thirty wells were drilled over a grid of 20x20 m to

25x25 m. Sulfuric acid consumption averaged 40 kg t⁻¹ of ore. In total, 65 000 t of acid were injected and the pumped solution volume was 7.7 million m³ with an average acid concentration of 8.5 g l⁻¹.

The principal U minerals are pitchblende, sooty pitchblende (UO₂UO₃) and coffinite. The carbonate content is commonly less than 2.5% CO₂, but can locally be as high as 5% CO₂. The ore lodes are of the roll-front type, hosted in six arenaceous horizons within Maastrichtian and Campanian strata represented by sandstones with dolomitic and siltstone intercalations.

At the completion of ISL mining, the aureole of residual leaching solutions occupied the entire ISL site, covering an area of 110.3 km². Their composition was similar to the composition of production solutions. TDS concentrations increased by a factor of ten, pH values dropped to 1.5. After ISL mining was stopped, slow neutralisation of residual solutions and precipitation of solids occurred. The following principal changes of aquifer composition and aureole size occurred during an 11-year period:

- Within the ISL site contour, pH increased by a factor of 2.9, TDS dropped by a factor of 2.8, and the sulfate ion concentration was reduced by a factor of 2.4.
- The surface area of the plume of residual solutions decreased by a factor of 2, the total amount of principal contaminants decreased by a factor of 3.6 (SO₄ by 2.9), the concentrations of TDS by 2, and the pH increased from 2.0 to 4.8.
- The plume of residual solutions migrated about 30 to 50 m to the east due to influence of an adjacent site with active ISL mining and under the general hydraulic gradient.

The principal factors affecting the changes in acidity and TDS were the plume displacement and the dilution by neutral native water.

Hydrochemical modelling of the processes showed that complete restoration of the aquifer to a condition approaching the initial composition would occur over the next 15 to 20 years.

To intensify the remediation, an experiment forcing the displacement of residual solutions through the media unaffected by ISL was performed. Three additional wells were drilled outside the ISL site for extracting groundwater from the adjacent aquifer. The water was reinjected through 7 to 10 injection wells in order to shift the plume to the east. During the 20-month experiment 693 290 m³ of groundwater and residual solutions were pumped and circulated.

Fifteen additional wells were drilled after the experiment to monitor the aquifer. The results show that the average TDS and sulfate ion concentration decreased to background values.

Table 6.7. Average aquifer characteristics within the ISL site

Monitoring period	pH	TDS [g·l ⁻¹]	Total TDS [t]	SO ₄ [g·l ⁻¹]	total SO ₄ [t]
1969 (before ISL)	7.3	2.4	520	1.14	250
1975-76 (end of ISL)	2.0	18	3 910	10.2	2 210
1977 (after ISL)	3.7	9.2	1 995	5.2	1 130
1980 (3 years after ISL)	4.7	8.8	1 910	4.8	1 040
1987 (before the experiment)	5.8	6.5	1 410	4.2	910
1989 (after the experiment)	6.9	4.0	870	2.1	455

Table 6.8. Average aquifer characteristics within the aureole of residual solutions

Monitoring period	Plume limit for pH <7			Plume limit for TDS >5 g·l ⁻¹		
	Area [x1000 m ²]	pH	SO ₄ [g·l ⁻¹]	Area [x1000 m ²]	TDS [g·l ⁻¹]	SO ₄ [g·l ⁻¹]
1975-76 (end of ISL)	110.3	2.0	10.2	110.3	18	10.2
1977 (after ISL)	136.5	3.7	5.2	104.0	9.9	5.6
1980 (3 years after ISL)	89.0	4.0	5.1	67.0	10.9	6.1
1987 (before the experiment)	70.5	4.85	4.7	62.0	9.0	5.4
1989 (after the experiment)	44.2	5.5	2.7	23.6	6.15	2.9

The results from monitoring also indicate that radionuclide concentrations were almost constant during 11 years of observation (from 1975 to 1987). After the plume shifted, the concentrations of U, ²³⁰Th, ²¹⁰Po and ²¹⁰Pb dropped significantly, i.e. by a factor of 10 to 50, and are now below the maximum permissible limits. The ²²⁶Ra concentrations were still above the maximum permissible limits, but below the initial concentration measured in the groundwater before the ISL mining began.

Spain

Treatment of acid water in open pit mine

Nature of the effluents

Since 1974, ENUSA has been exploiting an uranium deposit close to Ciudad Rodrigo, in the province of Salamanca. It is an open pit mine, which yields 90% of the uranium produced in Spain.

Owing to the presence of pyrite in the ore body, natural leaching of uranium takes place induced by rainwater and surface runoff trickling across the faces of the open pit. Significant volumes of wastewater are generated (2 000 m³·day⁻¹), with characteristics such as acidity (pH about 3), uranium content (50 ppm U₃O₈) and radioactivity (1 100 Bq·l⁻¹ of gross alpha activity) that make them not suitable for direct discharge into natural water courses in the area.

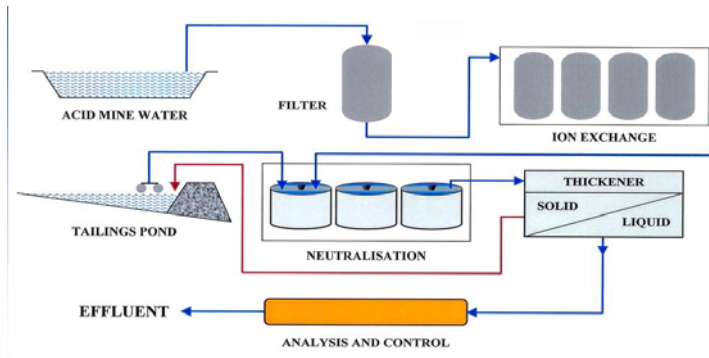
In addition, liquids from the tailings ponds and surface runoff have high concentrations of aluminium, manganese, ammonia and sulfates. These concentrations increase with the retention time of liquids in ponds.

Water treatment techniques

To comply with the specific requirements set by the regulatory authorities, ENUSA, in 1986, started up a plant for the treatment of acid contaminated water collected from the mine and the tailings pond. The process includes ion exchange in fixed bed columns for the recovery of uranium, followed by acidity neutralisation with lime and, finally, treatment with barium chloride to remove radium. The anionic exchange resins are usually styrene and di-vinylbenzene copolymers with quaternary ammonium as functional groups, and with a strongly basic character.

At the end of the process, the slurry containing heavy metal and radionuclide hydroxides is sent to a thickener for liquid/solid separation. The underflow (solids) is released into tailings impoundments and the overflow (liquids) is analysed and stored for discharge under regulatory control.

Figure 6.5. Schematic flowsheet for the water treatment process at Ciudad Rodrigo



Other relevant aspects

The water treatment operations are complemented by other technical measures to reduce liquid effluent volumes to be discharged into natural watercourses. These include:

- Building surface water diversion channels to prevent runoff into the open pit.
- Construction of evaporation ponds to take advantage of an evaporation rate in this area that is higher than the precipitation rate.
- Removing water from the bottom of the open pit by pumping and storing it in ponds, for re-use in mining and milling operations.

Data on radionuclides and critical parameters

The following table describes the characteristics of waters before and after treatment. The process effectiveness is assessed against the maximum discharge limits set by regulatory authorities.

Table 6.9. Data of radionuclides and critical parameters

Parameter	Untreated waste water	Upper limits	Final effluent
pH	3-3.5	5.5-9.5	8
Uranium ($\text{mg U}_3\text{O}_8\cdot\text{l}^{-1}$)	50	–	0.01
Radium ($\text{Bq}\cdot\text{l}^{-1}$)	37	–	0.05
Gross Alpha Activity ($\text{Bq}\cdot\text{l}^{-1}$)	1 100	–	0.5
Aluminium ($\text{mg}\cdot\text{l}^{-1}$)	10-30	1	< 0.3
Manganese ($\text{mg}\cdot\text{l}^{-1}$)	200	2	0.1
Sulfates ($\text{mg}\cdot\text{l}^{-1}$)	8 000	2 000	1 700
Ammonia ($\text{mg}\cdot\text{l}^{-1}$)	70	15	10

United States

Approach to groundwater treatment for alkaline ISL operations

ISL mines were once considered “unconventional” mines but they have become the predominant form of uranium mining in the United States in recent years primarily due to their typically low production costs and minimal environmental impact. Because the uranium is recovered through a series of wells, rather than through open pits or shaft excavations, surface disturbance is far less and geologic strata overlying the ore body, including any aquifers, are left undisturbed. Production areas or wellfields are surrounded by monitoring wells to detect vertical or horizontal movement of leaching solutions away from the area being mined.

After a wellfield is exhausted, the aquifer has to be restored. During aquifer restoration operations, relatively large volumes of wastewater are generated, particularly when groundwater sweep is the method being utilised. Waste disposal systems at ISL mines are principally designed to manage waste generated during restoration and usually consist of a combination of evaporation ponds, deep well injection and surface discharge (usually via irrigation). Each of these methods has advantages and disadvantages both in terms of cost, site suitability, operational flexibility and regulatory feasibility. Waste disposal is of paramount concern to regulatory agencies in the USA and therefore it is subject to considerable scrutiny and regulations. Because the waste disposal methods can have significant cost impacts, the evaluation and selection of the best method(s) is a critical concern to mine operators. Major considerations of the three primary liquid disposal methods are discussed below.

Evaporation ponds

Use of evaporation ponds at ISL mines in the USA as the primary means of liquid disposal and treatment declined significantly over the last decade due to increasingly stringent regulatory requirements. Evaporation ponds now should typically be double lined and incorporate leak detection and collection systems. They also create disturbance areas with reclamation liabilities. Federal regulations and policies promulgated by the US Nuclear Regulatory Commission (USNRC) prohibit the proliferation of low-level radioactive waste disposal sites. Therefore, pond residues must ultimately be shipped off-site to approved disposal facilities. The major advantage of evaporation ponds is that no treatment of waste streams is required, resulting in low operating costs.

Injection wells

US regulations prohibit the injection of ISL waste into aquifers containing less than 10 g·l⁻¹ of Total Dissolved Solids (TDS). Consequently, suitable receiving formations are not present at all sites or may be so deep as to render deep well injection uneconomical. Where suitable receiving strata exist at reasonable depths, such as the relatively shallow and permeable brine (saltwater) aquifers in Texas, deep well injection is commonly the preferred disposal method. Initial capital costs are relatively high and operating costs can also be a significant consideration, if substantial pre-treatment before disposal is required, or well acceptance capacities are low. In comparison with evaporation ponds, reclamation costs are relatively low.

Remediation process

A wide variety of aquifer restoration processes have been used in the USA with differing degrees of success. When ISL technology was in its developmental stage, many companies experimented with different lixiviants including solutions like sulfuric (H₂SO₄) and nitric (HNO₃) acids. Many of the earlier mines in Texas used an ammonium bicarbonate lixiviant, and it was also tried experimentally in Wyoming. Almost without exception, ore bodies leached with these solutions proved very difficult to restore to pre-mining or acceptable conditions, regardless of the restoration method. Consequently, the industry moved toward the use of sodium bicarbonate based lixiviants using oxygen and carbon dioxide because groundwater restoration proved much easier to accomplish and more economical. The following discussion describes the typical aquifer restoration process now used at the vast majority of ISL mines in the USA. The methods are usually selected based on their effectiveness in both reducing contamination and controlling the cost of the restoration process. Additional information is given in various IAEA publications. [9-11]

Step 1: Groundwater sweep

Restoration is initiated in a wellfield when uranium concentration (i.e. “headgrade”) in the production fluid has dropped to a level, where recovery is no longer economically feasible. The first step in the process is normally referred to as the groundwater sweep phase during which lixiviant injection into the ore body is discontinued, but fluid continues to be pumped from the recovery wells. This action removes contaminated water from the formation and draws in surrounding uncontaminated groundwater into the ore body aquifer. Contaminated water removed during this process is either injected into a new wellfield or disposed of in evaporation ponds, deep disposal wells or through irrigation. Groundwater sweep used to be considered sufficient to completely restore the aquifer but the large volume of water that has to be removed and disposed of, coupled with the fact that the dilution efficiency of the process decreases, as the water quality approaches baseline conditions, makes additional restoration steps necessary. The groundwater sweep step is more effective during the earliest stage of restoration, when the water quality differential between contaminated and unaffected groundwater is the greatest. Typically, one to three pore volumes of formation water are removed during this step. A pore volume is defined as the volume of water in the portion of the ore body that is being restored.

Step 2: Water treatment

In this phase, contaminated water remaining in the formation after groundwater sweep is pumped to the surface and fed into a water treatment unit in a continuous process. Clean water produced from the water treatment unit (permeate) is pumped back to the wellfield and reinjected into the ore body aquifer. The brine, or reject water from the treatment unit, is disposed of in either evaporation ponds or deep disposal wells. Most operations use a reverse osmosis (RO) unit to purify the contaminated water although electrodialysis (ED) units have been successfully used at some mines. Treatment of the contaminated groundwater continues until the water quality within the mined portion of the aquifer is restored to or near restoration requirements. This process normally requires the removal, treatment, and reinjection of two to six pore volumes of water from the area being restored. At some mines, the completion of this second step may be sufficient to return groundwater quality to acceptable conditions. However, at a majority of mines, it is necessary to go to another step that involves the addition of chemicals to the water being re-injected as described in the following paragraph.

Step 3: Reductant addition

During the ISL mining process, the addition of chemicals and an oxidant into the ore body aquifer creates an imbalance in the natural geochemical environment. The host formation is changed from a reduced state to an oxidised state that remains, to some degree, during aquifer restoration. As a result, uranium and other heavy metals continue to solubilise, making it difficult to return (and stabilise) these chemical species to baseline levels. Introduction of a chemical reductant, such as hydrogen sulfide (H₂S), into the solution being re-injected during this step helps to restore pre-mining geochemical equilibrium by inhibiting further oxidation reactions. The reducing action usually causes dissolved concentrations of uranium and other heavy metals to stabilise at acceptable levels. Typically, two to three pore volumes of groundwater are recirculated during this restoration phase. Use of reductants has been a standard procedure for many years in Texas and is now routinely used in Wyoming and Nebraska.

Step 4: Circulation

A final step in the restoration process at some ISL mines is to simply circulate formation water through the ore body aquifer for one or two pore volumes following step three to make water quality homogeneous throughout the wellfield. This action tends to eliminate spatial and temporal variations in water quality during the stabilisation-monitoring period.

Stabilisation monitoring

Once the operator believes that aquifer restoration has been completed in a wellfield or production unit, restoration verification data are submitted to the appropriate state and federal agencies and a period of stabilisation monitoring is initiated. During this period, designated representative wells are normally sampled on a monthly basis for parameters that indicate water quality stability, or lack thereof. Wyoming and Nebraska require a minimum six-month stabilisation-monitoring period that can be extended by the regulatory agencies if there are concerns about water quality deterioration. Texas does not have a specified stabilisation-monitoring period.

In situ leaching site restoration experience

Since the start of ISL uranium mining in the USA there has always been a concern about the effectiveness of meeting the requirement of restoring wellfield groundwater to pre-mine quality. Although the uncertainties may not have been completely eliminated, experience gained during the 1980s helped ISL project operators to substantially reduce the risk associated with wellfield restoration. By the end of 1987, about 30 commercial and pilot uranium solution mining wellfields had been restored in Wyoming, Texas, Colorado and New Mexico [12]. However, there have been a number of new mines started up over the last two decades. Furthermore, very few mines have actually been completely shut down and the facilities fully remediated due to the length of time it takes to restore groundwater to acceptable limits.

One project that is completing restoration, is the combined Holiday and El Mesquite Fields, in the Duval and Webb Counties, Texas. The production commenced in 1977 with an expectation of 17 years of production and that the fields would produce from an ore grade of 0.07% U_3O_8 , using a sodium bicarbonate injected lixiviant. Production from the fields averaged 750 tons of uranium per year with an estimated extraction efficiency of 93 to 95%. Wastewater was collected at two storage ponds at the El Mesquite project before injection into deep disposal wells. In joint participation with Electricité de France (EdF), COGEMA Mining is the operator of the properties.

The El Mesquite project lease area comprises 2 900 acres including 5 wellfields, three satellite locations, processing plant, yellowcake dryer, administrative buildings, laboratory, warehouse, and maintenance shop. Total wellfield area is 108 hectares. Production facilities include two wastewater storage ponds each originally measuring 62 m wide by 62 m long, backwash pond, two non-hazardous waste disposal injection wells, and several small landfills. In addition, seven reverse osmosis units and related equipment for groundwater restoration are situated on the process pad.

The Holiday lease covers 600 hectares including 10 wellfields and two satellite locations. No other surface processing or waste facilities are located on this lease. The total Holiday wellfield area is 68 hectares.

Following requirements of the Texas Bureau of Radiological Control, uranium production at the Holiday and El Mesquite project areas has ceased and negative pressure is maintained by pumping at the mine areas to prevent excursions or plume migration beyond mine lease boundaries. Areas, which were mined out at an early point in the mine history, were subjects of groundwater restoration activities. Production ceased at the Holiday/El Mesquite facilities in 1996. At this time, all of the active wellfields were placed in official restoration status. As of October 1, 2001, ten out of the fifteen wellfields have been restored and approved by Texas Natural Resource Conservation Commission (TNRCC) in accordance with TNRCC regulations. Additionally, the associated injection and production wells have been plugged and abandoned in accordance with TNRCC's requirements.

Restoration in all the wellfields has been accomplished by groundwater sweep and reverse osmosis treatment. Groundwater sweep consists of pumping or withdrawing fluids from the mine area (without re-injection) thus allowing uncontaminated water from outside the mine area to flow into the mine area. This pumping action creates a negative pressure in the aquifer and prevents mining solutions from escaping the mine area.

Reverse osmosis treatment consists of pumping the groundwater through membranes that separate the contaminants into a brine stream and allowing the clean water to pass through as permeate water. The permeate (clean) water is re-injected into the mine area. All wastewater and brine generated from the RO units are stored in the waste ponds and eventually disposed off in injection wells.

The State of Texas requirements for groundwater restoration include restoring the groundwater back to a condition (quality) whereby it can be used for whatever purpose the groundwater was capable of being used for prior to mining. At Holiday and El Mesquite, the groundwater prior to mining is of a quality that is usable as livestock watering, (with some localized exceptions due to elevated ^{226}Ra , which is present in the groundwater within the uranium orebody). Therefore, COGEMA's goal after mining is to clean the groundwater to as close to background conditions as possible, leaving the groundwater in a condition similar to that prior to mining. In all of the wellfields restored to date, only a few water quality parameters were left at levels higher than their original baseline concentrations. However, the overall quality of the restored groundwater was, in every case, still capable of being used for the pre-mining use of watering livestock, and therefore was approved by the TNRCC, and the public (several opportunities for comment and hearings are provided to the general public during the approval process for a restored wellfield).

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7. LONG-TERM STEWARDSHIP AND MONITORING

Long-term stewardship

When mining facilities are closed, stewardship and monitoring activities are often required for an extended period of time to assure that performance goals are achieved [1]. It has become a standing principle of the uranium industry and governmental authorities in countries all over the world to ensure that the public and the environment are protected from the effects of radiation exposure during operation and after uranium related facilities have been closed and decommissioned.

The long half-lives of uranium, radium and their daughter products may be a cause of long-term concern for communities, where the facilities are located. In the planning for decommissioning, a number of steps should be taken to evaluate the radiation risks posed to the public and the environment. Risk assessments can provide some degree of assurance that remnant radiation levels will meet the applicable standards for health protection of the public. A concern may be whether remnant radiation from the closed facility could still impact the environment even thousand of years into the future. State-of-the-art closure methods based on proven engineering methods and geological barriers provide means to protect the public and the environment from radiation emissions by reducing the exhalation of radon gas over the site, by preventing dispersal of radionuclides into the groundwater and erosion which could carry radionuclides off site, and by resisting unauthorised intrusion into the site. Nevertheless, proof that decommissioning and remediation efforts have been successful can only be obtained through a process of long-term monitoring of air, dust, and water pathways at the site with respect to emissions of radiation, including direct gamma exposure.

The primary goal for long-term stewardship of radioactive waste and property containing radioactive material, is to ensure the protection of the public and the environment. For a variety of reasons, technical, administrative or funding, final decommissioning and remediation solutions may have to rely on institutional controls to ensure their integrity and provide maintenance. Stewardship can also be part of a programme to reassure the public. In some circumstance long-term stewardship may be the only form of “remediation” for a site needed.

An inherent problem, however, with institutional controls is institutional memory, or the willingness and ability of the chosen institution to continue managing a site over a prolonged timespan measuring in, perhaps, centuries. Assurance of continued funding can pose another serious problem. Consequently, the ultimate objective should be to design closure and remediation solutions that would require a minimum of active controls, both with respect to the duration and extent.

Methods of providing long-term stewardship through institutional control of former radiation sites are generally classified as either “active” or “passive”. Considerations of whether controls should be “active” or “passive” are undertaken in the planning process.

Active controls

Active controls involve some form of either, continuous or intermittent, human activity to maintain the condition of the site, detecting any radiation exposure of the public or to the environment, and cleaning up radiation leakage from the site caused either by intrusion or natural processes. The controls include restriction of access to the site by physical barriers, e.g. fences, or by warning signs, restrictions on land use, e.g. through zoning regulations, long-term environmental monitoring, site maintenance, and remediation in the event of a radiation spill or leak.

Air, surface and groundwater monitoring, site inspections, ground radiation surveys, aerial gamma surveys, and periodic sampling constitute potential means of evaluating the long-term performance of a site under active institutional controls.

Experience with uranium mining sites all over the world, however, indicate that active and institutional controls are likely to fail, for instance, when there is enough pressure to redevelop the land.

Passive controls

Passive controls rely on engineering and management solutions that do not require human intervention and that have an amount of redundancy of controls built into them. The first levels of “defence” typically are passive chemical and physical engineered barriers, preventing the water- or airborne migration of radionuclides and direct radiation exposures. This requires some robustness in design and construction. The design has to take into account natural phenomena that can lead to failure, such as erosion, and provide adequate margins of safety against their occurring, e.g. by underground placements as opposed to the construction of above ground impoundments. The redundancy in barriers also provides defence-in-depth in case of failure of one barrier.

Such engineering measures can be supported by administrative measures, e.g. land use restrictions. While it is difficult to maintain active use restrictions over more than a few decades, as many redevelopment projects on former industrial sites have shown, certain critical land uses can be made unattractive by engineering design or by putting land uses in place that typically have a more spiritual link with the land, for instance cemeteries or nature reserves.

However, the use of long-term monitoring of land, soil, air, and water conditions may still be required, perhaps less to verify the actual performance according to design than to reassure the public of this.

Long-term monitoring methods

Scope of programmes

Long-term monitoring, maintenance and control are components of a long-term stewardship or institutional control programme established for the oversight of former uranium recovery sites [2,3]. For developing a monitoring and maintenance programme the following questions have to be answered:

- How frequently must monitoring take place?
- What has to be measured?
- What kind of equipment will be used?
- What measurements will trigger a response action?
- Who is responsible for the monitoring and emergency actions?

Monitoring of a remediated uranium recovery site allows the assessment of the completeness and effectiveness of the remediation programme. Although this takes place using basically the same means that were used in characterising the site (see Chapter 1) and to check compliance with environmental protection criteria during the operational and remediation period, the monitoring network is adjusted to conditions following remediation. The frequency (e.g., quarterly, semi-annually, annually, biannually, every five years) of measuring or sampling under the monitoring programme is determined based on national requirements, site location, potential impacts, frequency and risks of natural events on the site (water or wind erosion, severe weather, geological events such as earthquakes, biological agents), potential natural resources that could be affected by radioactive pollution (water bodies, subsistence forage or animals, air resources), and community concerns.

Site inspections

The purposes of site inspections are to confirm the integrity of visible natural and man-made features at the site, to identify changes or new conditions that may affect site integrity, and to determine the need, if any, for maintenance or follow-up inspections and monitoring. Inspectors evaluate the effectiveness of site-specific institutional controls and ensure that the site remains in full compliance with regulations, guidance, or other requirements. Observations on the progress of revegetation can help to identify planting techniques and species that result in the greatest success. Observations and measurements of soil settling and consolidation will provide important information on changes in subsurface waste impoundments and mine workings. Records and photographs of sites are compared with others from previous inspections to determine, if any changes or site damage may have occurred that might be detrimental to site's integrity. Follow-up radiation monitoring surveys can help determine if there have been releases since the final status survey after the completion of remediation [4-7].

Geotechnical monitoring

Restored sites may need to be assessed for changes in surface and underground geotechnical stability over time. Geotechnical monitoring utilises topographical surveying of the site with elevation stakes, benchmarks, etc. either using traditional triangulation methods or, more recently, global positioning systems (GPS). The surveying marks are resurveyed at regular intervals to determine, if any horizontal or vertical movement due to settling or erosion has occurred that might affect the integrity of the site. These surveys measure movements of dykes, slopes, berms and other engineered features to determine, if there has been any instability in retaining structures and waste piles. All drainage control equipment is usually preserved after remediation to ensure that in the future drainage flow rates can be measured and samples be taken. Suspended materials in the drainage waters may indicate erosion. At some sites, groundwater monitoring using piezometer wells needs to be performed to ensure that water accumulation within waste containment cells does not cause slopes etc. to become unstable and fail. Testing of well casing, piping, and surface facilities is necessary to ensure integrity of the monitoring wells and to assure their continued usefulness.

Groundwater monitoring

Monitoring typically also will extend to the groundwater quality on site and off the site. Infiltrating atmospheric precipitation may leach contaminants from waste impoundments, which then may leak into the underlying groundwater systems or be discharged with any drainage waters. Groundwater samples are collected from permanent monitoring wells, from drainage discharges, streams, seeps, or springs hydraulically down-gradient from the site.

It is common practice to establish wells that were drilled as part of site characterisation studies as permanent monitoring wells. They can provide long-term time series of changes in the water chemistry from the time before the site was remediated. Wells that are located in upstream or in unpolluted areas outside the site boundary provide the background reference for monitoring any contaminant migration off the site. Monitoring is used also to document changes in local groundwater regimes caused by uranium processing-related, and their return to a natural state after operation have ceased. Samples taken for laboratory analysis follow standard chain-of-custody and laboratory analysis procedures.

Surface water monitoring

Surface water monitoring is accomplished through site inspections and routine sampling, both for quality and quantity.

Remote sensing by aerial or satellite photography of the site may help to detect changes in watercourses. Site inspections include examination of the route surface waters takes across or around a site, observing erosion patterns, changes in the state of riverbanks etc. Flow measurement may also be taken. The operational state of water treatment and leachate collection systems should also be monitored either by visual inspections or remote transmission of operational data. Surface water bodies may also need to be sampled at regular time intervals to obtain quality data.

Ambient air monitoring

Air monitoring is primarily concerned with radon releases, but in arid climates wind erosion of covers may pose a problem and sampling of dusts may help to establish erosion rates.

Sampling by using of on site passive dust filters and pumped air collection devices allows the assessment of the flow of radioactive dusts and radon daughters at a site. Active collection during periodic inspections also is used for such monitoring. Provisions have to be made that the same locations are utilised for each such inspection each time [8-10].

Radon is an important source component of the exposure and may comprise much of the dose, requiring a continuing evaluation of the effectiveness of the site remediation to limit that dose. Radon emissions from the site may need to meet certain requirements of guideline limits; for example, in the United States remediated uranium mill sites have a limit on release of radon to the atmosphere of $20 \text{ pCi}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ($0.74 \text{ Bq}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). This measurement can be averaged over the entire surface area of the disposal cell. An occasional higher reading or “hot spot” is allowed.

Ecological monitoring

Monitoring of biota on and around a site can be a powerful tool to assess low-level releases into waters and the air for certain radionuclides and heavy metals. Some radionuclide and heavy metals accumulate in flora and fauna thus providing a time averaging means to monitor releases, if uptake rates are known. Monitoring of food chain organisms, vegetation, and predator species at the site and its surroundings provides a measure of the success of the remediation effort, in particular for those sites that are to be returned to a natural state, rather than to be re-used as industrial sites.

The quantification of the number of individuals and the species distribution, by comparison with similar undisturbed areas, allows personnel to assess how quickly and effectively a site is achieving a “natural” state. Limnologic studies of lacustrine or river fauna and flora, on and off site boundaries, offer a way to determine the overall environmental impact of discharges and releases.

Monitoring schedules

The time period over which a monitoring programme has to be extended depends on a number of factors that are linked to the expected engineering performance, the planned sites use, and any institutional controls imposed. At a minimum, it must be extended over the time where institutional controls are deemed necessary, serving as an instrument to verify their effectiveness.

The frequency with which the various elements of monitoring, such as site inspections, sampling, remote measurements, surveying etc., have to undertaken depend on a variety of factors such as: the level of remediation achieved, the nature or size of the radiological, toxicological and other hazard of the site, its proximity to human habitation and other site to be protected, the site's vulnerability to breaching institutional controls, the size and frequency of adverse natural events, e.g. flooding, occur, etc. Where hazards and risk are comparatively low and sites are remote from people, sites may need to be revisited only once a year or even once every few years. The frequency might also need to be adjusted to the availability of funds.

Typically, the first round of monitoring is undertaken shortly after a remediation programme is completed, say within a year or less. This has more of the nature of a quality control survey, to assert that the project has been completed to specification. The follow on monitoring events take place at intervals as discussed above. It may not be necessary to undertake a full survey every time, for instance, minor and major inspections may be staggered, with differing levels of inspection effort or different items on checklists. It may also be efficient to monitor only a few key parameters, which then would trigger more detailed surveys if and when preset values are transgressed. Such schemes would help to reduce the cost of monitoring over time.

The length of monitoring is dependent on the expected long-term evolution of the risk posed by the site. Repository or remediation designs may have been established with projected lifetimes of 200 or 1 000 years, for example. Site monitoring could, in theory, continue indefinitely. However, an initial monitoring on an annual basis might indicate so little change that monitoring frequency can be reduced to every other year or even every five years. Conversely, community concern due to influx of new populations near a site or signs of change, e.g. increasing erosion, might vindicate more frequent surveys.

In the United States, uranium mill tailings sites must meet requirements for tailings control for 1 000 years, whereas disposal cells are designed to be effective for at least 200 years and require only minor custodial maintenance. Inspections at these closed sites are currently occurring on an annual basis and, over the last decade, the facilities have met all regulatory requirements.

The US EPA oversees highly contaminated sites, which are to be remediated under the "Superfund" programme. While there are less than 100 radiation sites on this list across the USA, long-term monitoring with or without other institutional controls may be required as part of the remedy for specific sites. Periods of monitoring, particularly for groundwater contamination, may be indefinite, but inspections can be as long as five years apart once a site is cleaned up. The Uranium processing site in Colorado, which was expected to be completely remediated in the year 2000, is being monitored for groundwater and radon emissions. The monitoring is expected to continue for at least another 10 years. The Long-Term Surveillance and Maintenance (LTSM) Programme, managed by the US Department of Energy, conducts oversight and monitoring activities for 25 low-level radioactive materials disposal sites. For each site, the LTSM Programme ensures that disposed materials remain isolated from the environment, that the safety of the public and the environment is maintained, and that all applicable regulations are met.

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8. POLICIES AND REGULATIONS

Conceptual framework

Given the increased awareness of environmental and health issues, many countries have adopted, or are in the process of adopting, policies aimed at improving and reinforcing such aspects as:

- Health and safety of workers and the public.
- Protection of the human and biological environment.
- Sustainable economic, social and environmental development.
- Consultation and public participation in environmental decision making.

All the above aspects are relevant to the situation at uranium mining and milling sites. However, there are additional considerations in the case of uranium mining activities, such as the long-term radiological risks and the link with issues of radioactive waste. As a result, the policies dealing with the uranium mining industry, as well as the laws to be applied, may not be so straight forward, with aspects of mining law, environmental law, toxic and waste law or radioactive waste laws all entering into the equation. In addition, there is the particular issue of long-term stewardship and institutional control that may be required at these sites because of the radiological hazard posed over a long period of time by uranium mining waste material.

Sustainable development deserves special mention. This has been defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1]. Many countries have endorsed the goal of sustainable development and are actively supporting efforts to achieve it through various environmental policies and regulations. In case of mining, sustainable development has been defined as ensuring that the mineral raw materials needs of society are met, without compromising the ability neither of future societies to meet their needs, nor of the natural environment to sustain indefinitely its quality e.g. climate systems, biological diversity and ecological integrity. In achieving this, there is a need to strike a balance between the environment, the economy and society. The specific case of uranium mining cannot be considered in isolation, and an objective comparison with other branches of the energy supply sector is called for. This should take into account the typically smaller scale of the uranium mining industry, compared with fossil fuel extraction and the absence of greenhouse gas production in nuclear electricity generation. The issues of waste management and remediation of mining sites need to be considered in this context. The more effective and complete the remediation at these sites, the more sustainable is the practice and more convincing is the argument in favour of nuclear energy as a whole.

Laws and regulations

National legislation

All countries with an uranium mining industry have laws and regulations related to the operation, decommissioning, and remediation of the mining and milling facilities. However, these laws and regulations usually apply to mining, radiological protection or environmental protection in general

rather than the specific case of remediation of uranium mining and milling sites. Some countries including Australia [2], Canada [3], and United States [4], have laws and regulations specifically relating to the remediation of these sites. Germany [5] is another example, having passed a law relating to the clean-up of the extensive old mining sites in the east of the country, although the legislation only establishes the institutional framework for the remediation rather than remediation criteria. A summary of the status and development of laws and regulations relating to remediation of uranium mines and mill tailings sites for some countries is provided in the country-specific section of this report.

International Conventions

There are a growing number of international conventions, imposing environmental obligations on signatory governments. A non-exhaustive list of those with possible relevance to uranium mining and milling activities is shown below. In each case, the administering international organisation is also indicated.

- The *Convention on Environmental Impact Assessment in a Transboundary Context*, or *Espoo Convention* (UN Economic Commission for Europe – UN/ECE).
- The *Convention of Access to Information, Public Participation in Decision Making and Access to Justice in Environment Matters*, or *Aarhus Convention* (also UN/ECE).
- The *Convention on the Protection of the Environment through Criminal Law* (Council of Europe).
- *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* (IAEA).

The *Convention on Environmental Impact Assessment in a Transboundary Context* [6] includes nuclear installations, radioactive waste management facilities as well as major mining projects for the extraction and processing of metal ore in the list of projects that must be subjected to an assessment. The Convention provides for certain rights and duties of contracting parties when the environmental impact of an activity has a transboundary effect and for certain procedures to be followed when considering the environmental impact of a given project. The Convention was signed in 1991 by 55 countries and ratified by 21 countries, all of which are IAEA Member states. The Convention entered into force in October 1997.

Similarly, the *Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters* [7] lists within its scope both nuclear installations and radioactive waste management facilities, though in the case of mining, only open-pit operations are specifically mentioned in the text (other mining activities will be covered if they are subject to an Environmental Impact Assessment procedure, with public participation, under national legislation). Its objectives are to contribute to the “protection of the right of every person of present and future generations to live in an environment adequate to his or her health and well-being” and to guarantee “the rights of access to information, public participation in decision-making, and access to justice in environmental matters”. The Adoption of the Convention in June 1998 was combined with the Fourth Ministerial Conference, “Environment for Europe” Declaration of 52 ECE Ministers for the Environment. Two years later, it had been signed by 39 states, all of which are IAEA Member States. The Convention has not yet entered into force.

The *Convention on the Protection of the Environment through Criminal Law* [8] makes it a criminal offence, punishable through domestic laws, to discharge, emit or introduce a quantity of

ionising radiation into air, soil or water, or to discharge hazardous waste, which causes death or serious injury, lasting deterioration to health or substantial damage to the environment. The Convention was opened for signature on 11 April 1999. By October 2000, eleven Member States of the Council of Europe, all of which are IAEA Member states, had signed it. The Convention has not yet entered into force.

The *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* (or, simply, the *Joint Convention*) [9] applies also to uranium mining and milling waste, and to corresponding decommissioning and closure activities. This Joint Convention was approved by an International Diplomatic Conference in Vienna on 5 September 1997. The Convention would enter into force when 25 countries, 15 of which with at least one nuclear power plant (NPP), have ratified the text. The status of ratifications was achieved on 18 June 2001, standing at 25 countries of which 17 have at least one NPP. The Convention contains a chapter on “Safety of Radioactive Waste Management” including treatment of operational and institutional measures after closure. There is also a chapter on “General Safety Provisions”, including legislative and regulatory framework, regulatory body, quality assurance, operational radiation protection, emergency preparedness, responsibility of the license holder, human and financial resources, and decommissioning. Another article addresses transboundary movements of waste.

Other international conventions that may affect uranium mining and milling activities include the 1972 World Heritage Convention, the 1989 Biodiversity Convention and the 1997 Kyoto Protocol, the 1989 Basel Convention on Hazardous Waste, and the 1990 IAEA Code of Practice on Transboundary Movements of Radioactive Waste.

International standards and guidelines

One of the statutory functions of the IAEA (under Article III) is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State’s activities in the field of nuclear energy. The regulatory-related publications by which the IAEA establishes safety standards and measures are issued in the IAEA Safety Standards Series.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA’s safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, the final decisions and legal responsibilities in any licensing procedures rest with the States.

While the non-radiological aspects of industrial safety and environmental protection are not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these, as well.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the current safety standards are applied to such facilities are taken by individual States. Furthermore, while the safety standards of the IAEA are not legally binding, they are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules, such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

International standards, guidelines and general recommendations applicable to environmental remediation activities of uranium mining and milling facilities are presented and discussed in a number of publications from the IAEA:

- International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources, Safety Series No. 115, 1996.
- The Principles of Radioactive Waste Management, Safety Series No. 111-F, 1995.
- Establishing a National System for Radioactive Waste Management, Safety Series No. 111-S-1, 1995.
- Safe Management of Wastes from the Mining and Milling of Uranium and Thorium Ores, Safety Series No. 85, 1987 (currently under revision).
- Regulations for the Safe Transport of Radioactive Material, 1996 edition (Revised), Safety Standards Series, No. TS-R-1 (ST-1, Revised), 2000.

Recommendations of the International Commission on Radiological Protection (ICRP) [10] are routinely incorporated into the IAEA's own recommendations. A number of ICRP publications issued over the last few years are relevant to the radiological aspects of remediation at uranium mining and milling sites, most notably ICRP publications:

- ICRP Publication 60, *Recommendations of the International Commission on Radiological Protection*. Annals of the ICRP 21 (1-3), 1991.
- ICRP Publication 61, *Annual Limits on Intake of Radionuclides by Workers Based on the 1190 Recommendations*. Annals of the ICRP 21 (4), 1991.
- *Risks Associated with Ionising Radiations*. Annals of the ICRP 22 (1), 1991.
- ICRP Publication 62, *Radiological Protection in Biomedical Research*. Annals of the ICRP 22 (3), 1991.

- Addendum to ICRP Publication 53 – *Radiation Doses to Patients from Radiopharmaceuticals*. Annals of the ICRP 22 (3), 1991.
- ICRP Publication 63, *Principles for Intervention for Protection of the Public in a Radiological Emergency*. Annals of the ICRP 22 (4), 1991.
- ICRP Publication 64, *Protection from Potential Exposure: A Conceptual Framework*. Annals of the ICRP 23 (1), 1993.
- ICRP Publication 65, *Protection against Radon at Home and at Work*. Annals of the ICRP 23 (4), 1993.
- ICRP Publication 66, *Human Respiratory Tract Model for Radiological Protection*. Annals of the ICRP 24 (1-3), 1994.
- ICRP Publication 67, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 2*, Annals of the ICRP 23 (2-3), 1993.
- ICRP Publication 68, *Dose Coefficients for Intakes of Radionuclides by Workers: A Replacement of ICRP Publication 61*. Annals of the ICRP 24 (4), 1994.
- Summary of the current ICRP principles for Protection of the Patient in Nuclear Medicine. Appears as supplement in the Annals of the ICRP 24 (4), 1994.
- ICRP Publication 69, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 3. Ingestion Dose Coefficients*. Annals of the ICRP 25 (1), 1995.
- ICRP Publication 70, *Basic Anatomical and Physiological Data for Use in Radiological Protection. Part 1. Skeleton*. Annals of the ICRP 25 (2), 1995.
- ICRP Publication 71, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides, Part 4. Inhalation Dose coefficients*. Annals of the ICRP 25 (3-4), 1995.
- ICRP Publication 77, *Radiological Protection Policy for the Disposal of Radioactive Waste*. Supplement to the Annals of the ICRP 1997 (28), 1997.
- ICRP Publication 81, *Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste*, 2000.
- ICRP Publication 82, *Principles for the Protection of the Public in Situations of Prolonged Exposure*, 2000.

Implementation process

The Environmental Impact Assessment (EIA) or, simply, Environmental Assessment (EA), has become a powerful tool to help integrate environmental factors into the decision-making process for a project. The EIA process provides a systematic approach for identifying the environmental effects of a proposed development. By identifying potential adverse environmental effects before they occur, EIAs allow decision-makers to modify plans so that these effects can be minimised or eliminated.

In the 1980s, the World Commission on Environment and Development (known as Brundtland Commission) gave new impetus and focused public demand for reforming the EIA process in many countries. In its report, “Our Common Future”, the Commission concluded that EIA processes would be more effective, if they were mandatory and entrenched in legislation. Many countries have now incorporated the EIA process into national law (see, for instance, the Canadian example [11]). Others, while currently practising EIAs, are in the process of introducing legislation to provide EIAs with a statutory basis, thus reducing legal uncertainties and the need for court interpretation.

For new mining and milling projects, progressive remediation and eventual decommissioning are assessed routinely as a part of the EIA process in many countries. For older facilities that have been shut down, the situation is less clear and will depend on particular local circumstances. New formal EIAs may be required before these rehabilitation activities can be carried out. Alternatively, some other form of assessment may be more appropriate in order to determine the risk to the local population and the intervention level for remediation measures. This will necessarily require a thorough investigation and monitoring of the affected site (if data are not already available from operational records) and a careful cost-benefit analysis of the possible strategies, since some of these remediation measures are costly and may lead to undue financial burden on the operator of the facilities, or the State itself. The adopted strategy must be selected in accordance with the applicable legislation governing environmental protection in general and radiological exposure to the critical group in particular, as well as regard for present and future generations. This may result in the need for long-term stewardship or institutional controls to be established (see Chapter 7).

Public involvement

Informing stakeholders as well as consultation with, and participation by, the public in the process itself have become key aspects in many environmental assessments for development projects and in drafting environmental legislation. The development of new uranium mining sites and the decommissioning and remediation of existing facilities are no exceptions to this trend.

Although the process of public consultation may vary from country to country, and indeed may not be specifically described in the legislation, the objective should remain the same. It is to ensure that the process itself is as open and transparent as possible and that all interested parties have the opportunity to comment on the proposed activity and put forward their views. This is especially important and necessary in the case of controversial projects. Only when all stakeholders accept that the process has achieved these aims, will it be possible for the proposed activity to be generally acceptable. In fact, the public may have a significant input in certain remediation objectives, e.g. deciding on the future land use.

Scope

Nine of the countries covered in the country-specific section of this report are either Member States of the European Union (EU) or candidates for membership. Consequently, it is pertinent to review the EU legislation that is or will be of relevance to uranium mining and milling remediation activities in these countries.

The usual legislative instrument employed by the European Institutions is the Directive, by which Member States are required to amend or adopt national legislation by a specified deadline in order to achieve the aims set out in the Directive. Though Directives are binding on Member States, the precise method of adoption of the prescribed measures is decided at the national level.

The legal base for most of the EU legislation in the nuclear sector is the EURATOM Treaty [12]. Though radiological protection is covered extensively in the Euratom Treaty and associated Directives, the only specific mention of radioactive waste in the Treaty occurs in Article 37, which states: "Member States shall provide the Commission with such general data relating to any plan for the disposal of radioactive waste in whatever form as will make it possible to determine whether the implementation of such plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State." In its recommendation 1999/829/Euratom, the European Commission has stated that this Article should cover any planned disposal or accidental release of radioactive substances associated with (amongst others) the mining, milling and conversion of uranium and thorium.

There is also a considerable body of EU legislation dealing with environmental issues. Under the Treaty establishing the European Community (EC Treaty) [13], as amended by the Treaty of Amsterdam, environmental considerations must be taken into account in the other EU policy areas. This is evidence of the increasing concern within the EU over environmental issues in general. In addition, the European Community is a signatory to both the Espoo and Aarhus Conventions, and a project of adherence to the Joint Convention is currently under consideration by the Commission services.

On the more practical side, the Commission, through its various funding mechanisms (principally the PHARE and TACIS programmes), has financed numerous studies and implementation projects in the field of remediation at uranium mining and milling sites in the EU candidate and other countries in Central and Eastern Europe. A full description of these activities can be found in a recent paper [14].

The principal EU Directives having a possible bearing on remediation activities at uranium mining and milling sites are discussed below.

The Environmental Impact Assessment (EIA) Directive

Council Directive 85/337/EEC and its amendment 97/11/EC [15] on the assessment of the effects of certain public and private projects on the environment, together, the EIA Directive, is one of the key items of European environmental legislation. Member States had to comply with the provision of the amended Directive by 14 March 1999. The amended Directive provides a list of projects for which an EIA is obligatory and a list of projects for which Member States have discretion in the application of the Directive, the discretion being based in either a case-by-case examination of thresholds or criteria set by the Member States themselves. The list of projects for which EIA is obligatory is the same as the list annexed to the Aarhus Convention.

The EIA Directive requires that certain information be supplied by the project's developer. This includes notably "a description of the measures envisaged in order to, avoid, reduce and, if possible, remedy significant adverse effects". The Directive also specifies that the public be given access to the relevant information and be allowed the opportunity to express an opinion. This access to information by the public is one of the fundamental elements of the EIA Directive, and has been developed even further in the Espoo and Aarhus Conventions.

Under the terms of the EIA Directive, it is clear that remediation aspects will form an essential part of the necessary mitigation measures studied for a new mining site. However, "stand alone" remediation projects are not mentioned in the Directive. This limitation is also apparent in the Espoo and Aarhus Conventions since the annexed list of applicable projects is essentially the same in all three legal texts.

The Basic Safety Standards Directive

Council Directive 96/29/Euratom [16] of 13 May 1996, lays down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. The origin of these measures lies in the provisions of Chapter 3 of the Euratom Treaty. The Directive presents the most recent set of basic safety standards, and effectively transposes into law the recommendations of ICRP 60. Member States must comply with the provisions of this Directive by 13 May 2000. Ongoing uranium mining is included in the scope (Title II) of the Directive, and the legislation provides for radiological protection to the workforce and public from related activities.

Past mining practices are also covered by the Directive (Art. 48), but not to the same extent as current mining activities. Article 53 of the Directive, concerning past practices, regulates only intervention measures (like demarcation of the site, monitoring of exposure, etc.). The remediation measures themselves are not regulated, and the Directive does not contain any specific binding target values in this respect. However, the Commission is planning to publish a report [17] giving guidance for remediation projects from the radiation protection point of view.

The Drinking Water Directive

Council Directive 98/83/EC [18] of 3 November 1998, on the quality of water intended for human consumption prescribes a total indicative dose of $0.1 \text{ mSv}\cdot\text{y}^{-1}$ (excluding tritium, potassium-40, radon and radon decay products) for drinking water. This Directive entered into force on 25 December 1998, and Member States have two years from this date to incorporate it into national legislation and a further three years to ensure that drinking water standards comply with those set by the Directive (i.e. until 25 December 2003). The Directive has specific provisions for monitoring and remedial action in the event that the prescribed limits are surpassed. The provision of this Directive will have direct relevance to remediation at affected sites.

The Waste Framework Directive

Council Directive 91/156/EEC [19] amending 75/442/EEC establishes a framework for the management of waste in the European Community. Excluded from the scope of this Directive are radioactive waste and waste resulting from prospecting, extraction, treatment and storage of mineral resources and from the working of quarries.

These wastes are excluded from this Directive since they are already covered by other Community legislation. However, in the case of mining waste, it is clear that no other Community legislation applies, therefore this waste is covered by the present Directive. In the light of the incident at the Baia Mare goldmine in Romania, it is likely that new legislative initiatives will soon be forthcoming in this area, and the Commission services are in the process of preparing a Communication in which the Commission's view will be presented, though the extent to which uranium mining waste is also covered remains to be seen. The situation regarding radioactive waste is less clear, and the Commission's legal service may be required to rule on whether this waste is already adequately covered by other Community legislation, e.g. Basic Safety Standards.

The Landfill Directive

Council Directive 99/31/EC [20] of 26 April 1999, on the landfill of waste entered into force on 16 July 1999, and Member States have two years from this date to transpose it into national law. The Directive does not cover landfills that have already been closed before this date. Also, it is not yet clear whether or how the Directive will apply to waste at uranium mining sites, e.g. mill tailings, low-grade ore heaps, since only those wastes covered by the Waste Framework Directive are included in the scope of the Directive. However, assuming that this Directive will also apply to uranium mining waste, there are minimum requirements that must be respected concerning protection of soil and water, e.g. maximum permissible permeability and minimum thickness of covering layer.

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9. COSTS AND FUNDING

Scope and availability of data

Decommissioning and remediation costs may be defined in different ways. For the purpose of this report, decommissioning and remediation costs are defined as “all costs that, according to the requirements of the regulatory bodies, will be incurred to decommission and remediate uranium mining and milling facilities and land used in and/or affected by the production process”.

An in-depth analysis of decommissioning and remediation costs for different uranium mining and/or milling sites around the world would require individual costs for all items that normally would undergo decommissioning and remediation. These items include: waste rock piles, heap leach piles, ore storage and loading areas, tailing ponds, underground mines, open pit mines, buildings and infrastructure, ISL infrastructure, and contaminated groundwater and soils.

Furthermore, a complete analysis would call for a breakdown of the individual costs into their cost components, which would include research and development, planning and engineering, licensing, implementation, and monitoring.

Unfortunately information, which would allow such an analysis, is not readily available. Therefore, this report deals only with aggregate cost data, which have been reported for this study, or which are available from other published sources. To put the various decommissioning and remediation costs into perspective, unit costs are calculated and expressed in terms of uranium produced or ore processed, e.g. as cost per kilogram U or per metric ton of ore mined or processed. Although costs are calculated for a site or facility, it should be noted that no meaningful comparison of costs can be made between sites or countries without additional detail data and analysis, as these costs are very site specific. The cost data presented in this chapter are primarily to provide a global perspective and information base for policy and decision makers so that such costs can be accounted for and allocated, as with any other social costs.

The data in this chapter do not include costs for long-term care and maintenance of remediated uranium related facilities since such costs are generally not available. Costs for groundwater and mine water treatment are included, where available.

Factors influencing decommissioning and remediation costs

Cost elements

There are factors that directly affect decommissioning and remediation costs and that should be considered in any analysis. The more important factors include: ore deposit size, ore grade, mining method, climate, surrounding population density, remediation scope and objectives, technical progress in mining and milling, and funding source.

Ore deposit size

The size of the ore deposit, or rather the size of the mining operation, has a direct influence on the total remediation costs. Bigger deposits produce generally larger volumes of waste rock and larger tailing ponds, which tend to be more complex and hence more costly to deal with, than small operations.

However, the influence of the deposit size on the specific remediation costs of different sites can only be analysed, if deposits with roughly the same ore grade and with similar mining methods are compared.

Ore grade

For the same tonnage of uranium production, low-grade ores lead to more waste rock and tailings and hence higher remediation costs. On the other hand, the tailings from high-grade ores have a higher radioisotope inventory per unit volume and may require more elaborate procedures, e.g. more stringent protective cappings and radiological safety measures during handling and management.

Mining method

The decommissioning of an open pit mine is often less complicated than the decommissioning of an underground mine. An open pit mine remains accessible even if partially flooded after the restoration of the groundwater table. The expenditure for securing the slopes to make the pit safe for public access and to revegetate the embankments is relatively low. Underground mines, on the other hand, may require costly backfilling of shafts and some or all mine workings. The complexity of operation, proximity of human settlements, threat to natural resources, such as groundwater, may be in a given case the determining factor and, hence, favour one method over the other.

Both open pit and underground mines produce waste rock. The waste-to-ore ratio tends to be higher for open pit mines. Therefore, open pit mines produce larger volumes of waste rock than underground mines, but much of it may be rather “clean” overburden.

The operation of an ISL mine does not produce any waste rock or waste ore and, therefore, no waste rock piles and tailing ponds, other than water neutralisation residues. However, it requires remediation of the groundwater strata in the exhausted parts of the deposit. Remediation costs, in this case, depend on the current or future utilisation of the affected aquifer and the leaching method applied (acidic or alkaline). In general, decommissioning of ISL operations is less costly than that of conventional mining operations, especially when alkaline (carbonate) leaching can be applied.

Climate

Remediation costs are influenced by the climate of a site's geographical location. All other things being equal (ore and host rock mineralogy), the risk of acid mine drainage is higher in humid areas with high precipitation (e.g. Germany, Northern Australia), than in a dry climate. As a result, higher remediation costs are expected for waste rock piles and tailing ponds in humid areas. Furthermore, erosion and water balance considerations influence the design of waste rock and tailing pond covers. For areas with high precipitation, capping designs are more elaborate and, therefore, more expensive.

Remediation scope and objectives

The remediation scope and objectives set by corporate policy, agreement with stakeholders, and the regulatory bodies etc. in a given country constitute the most decisive factor influencing the remediation costs.

Because of the growing environmental concerns in many countries, there has been a marked increase in the stringency and scope of requirements (legal, political, socio-economic) and, hence, the overall remediation costs.

Surrounding population density

Remediation costs increase with higher population density in the vicinity of the facility. There is likely to be a higher pressure in populated areas on the facility operator to make land available to unrestricted agricultural, industrial, residential and other higher value uses, than in remote areas. In addition, long-term monitoring costs increase with higher population density.

However, the population density may also affect decommissioning and remediation costs positively. The resale value of land or buildings typically is higher in more densely populated areas.

Technological progress in mining and milling

Technical innovation can have a substantial influence on remediation costs in two ways. First, technical progress in mining and processing may lead to a less negative environmental impact, e.g. by applying *in situ* leach technologies instead of conventional mining. Secondly, new ideas and the practical experience gained from different remediation projects around the world will lead to technical progress and thus, generally, have a cost reducing effect. Moreover, newer facilities have usually been run with a higher awareness for environmental concerns and minimum use of resources, so that total remediation costs are lower in comparison.

These effects cannot always be isolated from other influencing factors. In particular, the effects of inflation run counter to the cost saving effects of technical progress. This makes it difficult to compare remediation costs at different points in time.

Sources and availability of funds

Analysis of the costs of various remediation projects indicates that the source of funding has a bearing on remediation costs. State-financed remediation projects tend to be significantly more costly than those financed and implemented by the private industry. The cost differences are not due to the quality of the remediation programme, or to the remediation philosophy since all laws and standards are applied to both cases in the same way. The natural site conditions and planning parameters are also comparable in both cases. The cost difference is, thus, due to structural, organisational and operational differences and differences in scope and objective. A particular example provides the substantial cost differences between the UMTRA Title I and Title II programmes in the United States [1]. The state-financed and managed Title I programme had a pilot function role, i.e., in the context of this programme, remediation principles and procedures were clarified and technologies developed and implemented for the first time. The experience gained here was of great value to the Title II programme, which is implemented by private companies (mining companies or contract miners), and helped reduce their costs. In addition, remediation programmes financed by governments often provide funds, as a matter of public policy, for the mitigation of the socio-economic impact of mine closures.

Table 9.1. Decommissioning and remediation costs of selected mines I

	Site	Last operator	Site characteristics		
			Type	Status	Closing date
	Czech Republic				
1	• Dylen	DIAMO	op, ug, wr	a	2002
2	• Hamr	DIAMO	ug, wr	a	2015
3	• Horni Slavkov	DIAMO	ug, wr	c	1999
4	• Krizany	DIAMO	ug, wr	a	2005
5	• Licomerice	DIAMO	ug, wr	c	2025
6	• Okrouhla Radoun	DIAMO	ug, wr	c	1998
7	• Olsi	DIAMO	ug, wr	c	1998
8	• Pribram	DIAMO	ug, wr, tp	a	2007
9	• Pucov	DIAMO	ug, wr	c	1998
10	• Vitkov II	DIAMO	ug, wr	a	2005
11	• Zadni Chodov	DIAMO	ug, wr	a	2005
	Germany				
12	• Aue	Wismut	ug, wr, tp	a	2008
13	• Gittersee	Wismut	ug, wr	a	2004
14	• Ronneburg	Wismut	op, ug, wr	a	2010
	USA				
15	• Bear Creek, WY	Rocky Mountain Energy	op,wr	c	1997
16	• Big Eagle, WY	US Energy	op,ug, wr	n	n/a
17	• Day-Loma, WY	Energy Fuels Nuclear, Inc.	op	I	n/a
18	• East Gas Hills, WY	Umetco Minerals Corp	op	i	n/a
19	• Felder, TX	Exxon Minerals Co	op	c	1983
20	• Gas Hills, WY	Power Resources	op	c	1995
21	• Highland, WY	Exxon Minerals Co	op, wr	c	1996
22	• Jackpile/Paguete, NM	Anaconda Minerals Co	op	c	1994
23	• Lucky Mc, WY	Pathfinder Mines Corp	op,wr	i	n/a
24	• Midnite, WA	Dawn Mining Co	op, wr	i	n/a
25	• Panna Maria, TX	Chevron Resources Co	op	c	1987
26	• Petrotomics Mine, WY	Petrotomics Company	op, wr	a	n/a
27	• Pitch, CO	Homestake Mining Co	op, w.r	i	n/a
28	• Rhode Ranch, TX	Chevron Resources Co	op,	c	1994
29	• Sherwood, WA	Western Nuclear Inc	op, wr	c	1993
30	• Shirley Basin, WY	Pathfinder Mines Corp	op,wr	i	n/a
31	• S. Powder River	Kerr-Mcgee Nuclear	op	c	1989
32	• St. Anthony, NM	UNC Mining & Milling	op	i	n/a
33	• Sweetwater, WY	Minerals Exploration Co	op	i	n/a

Explanations:

op: open pit mine
 ug: under ground mine
 wr: waste rock piles
 tp: tailing pond
 a: remediation in progress

c: remediation complete
 m.p.: mechanical processing.
 i: remediation incomplete.
 n: no remediation.

^a WTI: water treatment costs included
^b WTE: water treatment costs excluded
^c MLC: million local currency unit
 n/a: not available.

Table 9.1. Decommissioning and remediation costs of selected mines I (contd)

Production		Remediation costs								
Ore	Uranium	Total				Unit costs				
		1999				per t ore		per kg U		
Mt	t U	WTI ^a	WTE ^b	WTI ^a	WTE ^b	WTI ^a	WTE ^b	WTI ^a	WTE ^b	
		MLC ^c	MLC ^c	MUSD	MUSD	USD	USD	USD	USD	
Czech Republic										
1	0.8	1 100		25.8		0.7		0.93		0.68
2	9.7	13 206	13 000.0			376.1		38.77		28.48
3	1.7	2 668		120.6		3.5		2.05		1.31
4	1.1	1 108		172.4		5.0		4.53		4.50
5	0.3	383	225.4	63.4	6.5	1.8	21.73	6.11	17.02	4.79
6	1.6	1 340	56.2	44.9	1.6	1.3	1.02	0.81	1.21	0.97
7	1.9	2 922	294.4	178.1	8.5	5.2	4.48	2.71	2.91	1.76
8	35.2	48 432		876.4		25.4		0.72		0.52
9	0.2	311	91.2	30.8	2.6	0.9	13.19	4.45	8.48	2.86
10	3.2	3 970	129.3	93.6	3.7	2.7	1.17	0.85	0.94	0.68
11	2.1	4 151	295.2	220.1	8.5	6.4	4.07	3.03	2.06	1.53
	57.8	79 591	13 667.2	1 512.4	395.4	43.8	6.84	0.76	4.97	0.55
Germany										
12	22.0	81 000	1 512.0	1 303	823.5	709.7	37.43	32.26	10.17	8.76
13	3.8	3 000	150.0	136	81.7	74.1	21.50	19.49	27.23	24.69
14	130.0	110 000	3 723.0	3 413	2 027.8	1 858.9	15.60	14.30	18.43	16.90
	155.8	194 000	5 385.0	4 852	2 933.0	2 642.7	18.83	16.96	15.12	13.62
USA										
15	4.3	2 615			n/a	6.2		1.44		2.37
16	1.2	1 064			n/a	7.3		6.08		6.86
17	0.4	575			n/a	24.6		61.50		42.78
18	7.3	6 836			n/a	16.6		2.27		2.43
19	0.9	982			n/a	0.4		0.44		0.41
20	0.8	563			n/a	2.3		2.88		4.09
21	10.0	9 297			n/a	3.8		0.38		0.41
22	21.6	28 808			n/a	35.0		1.62		1.21
23	10.6	16 923			n/a	15.0		1.42		0.89
24	2.0	3 846			n/a	34.5		17.25		8.97
25	4.7	1 868			n/a	15.0		3.19		8.03
26	5.7	9 075			n/a	32.0		5.61		3.53
27	0.3	830			n/a	10.0		33.33		12.05
28	1.1	3 036			n/a	4.0		3.64		1.32
29	2.6	2 300			n/a	3.5		1.35		1.52
30	6.5	9 463			n/a	59.3		9.12		6.27
31	0.5	384			n/a	1.9		3.80		4.95
32	0.6	568			n/a	2.0		3.33		3.52
33	2.1	497			n/a	11.8		5.62		23.74
	83.2	99 530				285.2		3.43		2.87

Table 9.2. Decommissioning and remediation costs of selected mills II

	Site	Last operator	Site characteristics		
			Type	Status	Closing date
	Czech Republic				
1	MAPE Mydlovary ¹	DIAMO	acl, tp	a	2020
2	Straž p. Ralskem ²	DIAMO	Isl	a	2040
	Germany				
3	Crossen ³	Wismut	tp, wr	a	2010
4	Seelingstädt ⁴	Wismut	tp, wr	a	2015
	USA				
	Title I Sites				
5	Ambrosia Lake, NM	Phillips, UNC	all, tp	c	1995
6	Canonsburg, PA	Vitro Minerals	all, tp	c	1987
7	Durango, CO	Vanadium Corp.	acl, tp	c	1991
8	Edgemont, SD	TVA	acl, tp	c	1989
9	Falls City, TX	Susquehanna Western	acl, tp	c	1994
10	Grand Junction, CO	Climax	acl tp	c	1994
11	Green River Concentr., UT	Union Carbide	acl, tp	c	1989
12	Gunnison , CO	Gunnison Mining	acl, tp	c	1995
13	Lakeview, OR	Lakeview Mining	acl, tp	c	1989
14	Maybell, CO	Umetco Minerals Corp.	acl, tp	c	1998
15	Mexican Hat Mill, UT	Atlas Minerals	acl, tp	c	1995
16	Monticello Mill, UT	USAEC	all, tp	a	n/a
17	Monument #2 Upgrader, AZ	Vanadium Corp.	hl, tp	c	1994
18	Naturita, CO ⁵	Vanadium Corp.	tp	c	1998
19	Rifle, CO ⁵	Union Carbide	tp	c	1996
20	Riverton, WY	Susquehanna Western	acl, tp	c	1990
21	Salt Lake City, UT	Vitro Minerals	acl, tp	c	1996
22	Shiprock, NM	Footo Minerals	acl, tp	c	1986
23	Slick Rock Concentr., CO ⁶	Union Carbide	acl, tp	c	1986
24	Spook Upgrader, WY	Wyoming Mining	acl, tp	c	1989
25	Tuba City, AZ	El Paso Natural Gas	acl, tp	c	1990
	Total and averages				

Explanations:

acl: acid leach.
all: alkaline leach.
ep: evaporation pond.
hl: heap leach pile.
isl: in situ leaching.
rp: raffinate pond.
tp: tailing pond.

a: remediation in action.
c: remediation complete.
i: remediation incomplete.
n: no remediation.
n/a: not available.
^a: WTI: water treatment costs included.
^b: WTE: water treatment costs excluded.

Table 9.2. Decommissioning and remediation costs of selected mills II (contd)

	Production		Remediation costs					
	Ore	Uranium	Total		Unit costs			
			1999		t ore		kg U	
Mt	t U	WTI ^a MUSD	WTE ^b MUSD ^c	WTI ^a	WTE ^b USD	WTI ^a	WTE ^b USD	
Czech Republic								
1	16.8	28 500		87.7		5.2		3.1
2	0	15 562	1 041				66.9	
Germany								
3	74.7	77 000	473.3	368.7	6.3	4.9	6.1	4.8
4	108.8	85 500	831.7	641.6	7.6	5.9	9.7	7.5
	183.5	162 500	1 305.0	1 010.3	7.1	5.5	8.0	6.2
USA								
Title I Sites								
5	2.4	3 077	n/a	36.9		15.4		12.0
6	0.3	224	n/a	51.3		171.1		229.1
7	1.5	3 569	n/a	65.4		43.6		18.3
8	2.1	1 077	n/a	47.4		22.6		44.0
9	2.3	3 077	n/a	46.8		20.3		15.2
10	2.1	4 496	n/a	506.4		241.2		112.6
11	0.2	346	n/a	20.4		102.1		59.0
12	0.5	623	n/a	44.1		88.1		70.7
13	0.1	150	n/a	33.1		330.5		220.3
14	2.4	1 538	n/a	43.7		18.2		28.4
15	2.0	4 385	n/a	48.1		24.0		11.0
16	0.8	1 763	n/a	256.2		320.3		145.3
17	0.9	2 307	n/a	19.7		21.9		8.5
18	0.6	1 895	n/a	61.1		101.9		32.3
19	2.8	6 154	n/a	106.4		38.0		17.3
20	0.8	831	n/a	49.8		62.3		60.0
21	1.5	4 185	n/a	89.1		59.4		21.3
22	3.4	7 115	n/a	27.1		8.0		3.8
23	0.6	1 290	n/a	54.9		91.5		42.5
24	0.2	173	n/a	7.4		36.9		42.7
25	0.7	1 806	n/a	32.8		46.8		18.1
	28.2	50 081		1 648.1		58.4		32.9

Footnotes:

1. 3 030 MCZK, water treatment cost excluded [12].
2. 3 600 MCZK, water treatment cost included [12].
3. 677MDEM, water treatment cost excluded; 869 MDEM water treatment cost included [14].
4. 1 178 MDEM, water treatment cost excluded; 1 527 MDEM water treatment cost included [14].
5. Mainly vanadium processing, uranium by-product [20].
6. Includes slick rock plant of North Continental Mining [20].
7. Heap leach operation.

Table 9.2. Decommissioning and remediation costs of selected mills II (contd)

	Site	Last operator	Site characteristics		
			Type	Status	Closing date
	USA				
	Title II Sites				
26	Ambrosia Lake, NM	Rio Algom Corp.	acl, tp	i	
27	Bear Creek, WY	Rocky Mountain Energy	acl, tp	c	1997
28	Bluewater, NM	Anaconda Minerals Co.	all, tp, ep	c	1995
29	Church Rock, NM	UNC Mining & Milling	acl, tp	c	1995
30	Conquista, TX	Conoco Inc.	acl, tp	c	1993
31	East Gas Hills, WY	Umetco Minerals Corp.	acl, tp	a	n/a
32	Ford, WA	Dawn Mining Co.	acl, tp	i	n/a
33	Gas Hills, WY	Federal-American Partn.	acl, tp	i	n/a
34	Grants, NM	UNC-Homestake	all, tp	i	n/a
35	Grants NM	Quivira Mining Co.	acl, tp	n/a	n/a
36	Highland, WY	Exxon Minerals Co.	acl, tp	c	1990
37	L-Bar, NM	Sohio Western Mining Co.	acl, tp	c	1989
38	Lisbon, UT	Rio Algom Corp.	all, tp	c	1996
39	Lucky Mc, WY	Pathfinder Mines Corp.	acl, tp	c	1992
40	Maybell, CO ⁷	Umetco Minerals Corp.	tp, ep	i	n/a
41	Moab, UT	Atlas Minerals	acl, all, tp	i	n/a
42	Panna Maria, TX	Rio Grande Resources	acl, tp	c	1998
43	Ray Point, TX	Exxon Minerals Co.	all, tp	c	1994
44	Sherwood, WA	Western Nuclear Inc.	acl, tp	c	1996
45	Shirley Basin, WY	Petrotomics Company	acl, tp	c	n/a
46	Shirley Basin, WY	Pathfinder Mines Corp.	acl, tp	a	n/a
47	Split Rock, WY	Western Nuclear Inc.	acl, tp, ep	c	1997
48	Sweetwater, WY	Minerals Exploration Co.	acl, tp	i	n/a
49	Uravan, CO	Umetco Minerals Corp.	acl, tp, rp	a	n/a
50	White Mesa, UT	International Uranium	acl, tp, ep	i	n/a
	Total and averages				

Explanations:

acl:	acid leach.	a:	remediation in action.
all:	alkaline leach.	c:	remediation complete.
ep:	evaporation pond.	i:	remediation incomplete.
hl:	heap leach pile.	n:	no remediation.
isl:	in situ leaching.	n/a:	not available.
rp:	raffinate pond.	^a :	WTI: water treatment costs included.
tp:	tailing pond.	^b :	WTE: water treatment costs excluded.

Table 9.2. Decommissioning and remediation costs of selected mills II (contd)

	Production		Remediation costs					
	Ore	Uranium	Total		Unit costs			
			1999		t ore		kg U	
Mt	t U	WTI ^a MUSD	WTE ^b MUSD ^c	WTI ^a	WTE ^b USD	WTI ^a	WTE ^b USD	
USA								
Title II Sites								
26	37.9	48 360	41.2	31.4	1.1	0.8	0.9	0.6
27	4.3	2 529	n/a	4.9		1.1		1.9
28	32.8	50 000	43.0	39.5	1.3	1.2	0.9	0.8
29	3.2	3 091	16.4	14.6	5.1	4.6	5.3	4.7
30	8.0	6 154	n/a	8.0		1.0		1.3
31	7.3	6 836	45.0		6.2		6.6	
32	2.8	4 773	17.5	14.5	6.3	5.2	3.7	3.0
33	5.2	10 263	7.4		1.4	0.0	0.7	0.0
34	22.2	28 500	71.1	34.1	3.2	1.5	2.5	1.2
35	37.9	48 360	41.2		1.1		0.9	
36	10	9 297	20	17.2	2.0	1.7	2.2	1.9
37	1.5	1 736	17	15.0	11.3	10.0	9.8	8.6
38	3.5	5 712	15.5	10.0	4.4	2.9	2.7	1.8
39	14.6	21 909	9.8	7.3	0.7	0.5	0.4	0.3
40	1.8	385	n/a	3.2		1.8		8.3
41	19.5	24 769	n/a	16.0		0.8		0.6
42	5.9	5 846	21	19.3	3.6	3.3	3.6	3.3
43	0.4	292	4.1	3.6	10.3	9.0	14.0	12.3
44	2.6	2 300	n/a	8.3		3.2		3.6
45	5.7	9 075	n/a	9.9		1.7		1.1
46	6.5	9 463	n/a	6.4		1.0		0.7
47	7	7 190	25	21.4	3.6	3.1	3.5	3.0
48	2.1	497	n/a	5.4		2.6		10.9
49	9.4	16 346	96.2		10.2		5.9	
50	4	10 923	n/a	11.5		2.9		1.1
	256.1	334 606	491.4	301.5	1.9	1.2	1.5	0.9

Footnotes:

1. 3 030 MCZK, water treatment cost excluded [12].
2. 3 600 MCZK, water treatment cost included [12].
3. 677 MDEM, water treatment cost excluded; 869 MDEM water treatment cost included [14].
4. 1 178 MDEM, water treatment cost excluded; 1 527 MDEM water treatment cost included [14].
5. Mainly vanadium processing, uranium by-product [20].
6. Includes slick rock plant of North Continental Mining [20].
7. Heap leach operation.

Table 9.3. Decommissioning and remediation costs of selected integrated operations

	Site	Last operator	Site characteristics		
			Type	Status	Closing date
	Australia				
1	Mary Kathleen ^{1,5}	MKU	op, acl,	c	1985
2	Nabarlek ^{2,5}	QM	op, acl, tp, wr	c	1995
3	Rum Jungle ^{3,5}	CRA	op, acl, tp	c	1991
	Totals and averages				
4	Ranger ⁴	ERA	op, acl, tp, wr	o	
	Canada				
5	Beaverlodge ^{5,6}	Eldorado	ug, all, tp, wr	i	1985
6	Denison ^{6,7}	Denison Mines Ltd.	ug, acl, tp		1999
7	Panel ^{6,7}	Rio Algom Ltd.	ug, acl, tp	c	1999
8	Quirke ^{6,7}	Rio Algom Ltd.	ug, acl, tp	c	1999
9	Stanleigh ⁷	Rio Algom	ug, acl, tp	a	1999
10	Stanrock ^{6,7}	Denison Mines Ltd.	ug, acl, tp	c	1999
	Totals and averages				
11	Cluff Lake ⁷	COGEMA	ug, acl, tp,w.r	o	
12	Key Lake ⁷	Cameco	ug, acl, tp,w.r	o	
13	McClellan Lake ^{6,7}	COGEMA	op, acl, tp, wr	o	
14	Rabbit Lake ⁷	Cameco	ug, acl, tp,w.r	o	
	Czech Republic				
15	Rozna	DIAMO	ug, wr, tp	o	2020
	France				
16	Generic facility ⁸	COGEMA	acl, wr, tp		
	Germany				
17	Königstein	WISMUT	ug, wr	a	2015
	Hungary				
18	Mecsek ⁹	MEV	ug, wr, hl	a	2003
	Spain				
19	Elefante	Enusa	op,hl,.	a	
20	Quercus	Enusa	op, acl, tp	o	
	Totals and averages				

Explanations:

op:	open pit mine	acl:	acid leach	c:	remediation complete
ug:	under ground mine	all:	alkaline leach	i:	remediation incomplete
wr:	waste rock piles	hl:	heap leach pile	o:	operating mine
tp:	tailing pond	n/a:	not available	° MLC:	million local currency unit
		a:	remediation in action		

Table 9.3. Decommissioning and remediation costs of selected integrated operations (contd)

	Production		Remediation cost			
	Ore	Uranium	Total 1999		Unit costs	
	Mt	t U	MLC	MUSD	USD/t	USD/kgU
Australia						
1	7.0	7531	30.4	19.6	2.80	2.60
2	0.6	9228	10.5	6.8	11.33	0.74
3	2.0	5193	23.8	15.3	7.67	2.95
	9.6	21 952	64.7	41.8	4.35	1.90
4	n/a	n/a	32.0	20.6		
Canada						
5	10.0	17 530	23.9	16.1	1.61	0.92
6	63.0	56 060	39.0	26.3	0.42	0.47
7	15.0	9 160	15.0	10.1	0.67	1.10
8	43.0	43 710	25.0	16.8	0.39	0.38
9	n/a	n/a	20.0	13.5		
10	5.7	10 440	16.0	10.8	1.89	1.03
	136.7	136 900	119	80	0.59	0.58
11	n/a	n/a	33.6	22.6		
12	n/a	n/a	45.6	30.7		
13	0.78	n/a	35.0	23.6		
14	n/a	n/a	29.5	19.9		
Czech Republic						
15	12.3	15 978	6 149	177.9	14.46	11.13
France						
16	n/a	n/a	n/a	n/a	n/a	1.9
Germany						
17	27.0	17 000	1 984	1 080.6	40.02	63.57
Hungary						
18	25.7	21 251	23 129	97.5	3.79	4.59
Spain						
19	8.0	2 975	4 200	26.9	3.36	9.04
20	6.0	1 955	2 100	13.4	2.24	6.88
	14.0	4 930	6 300	40.3	2.88	8.18

Footnotes:

1. 19 MAUD in 1985 [10].
2. 10 MAUD in 1995, rehabilitation bond [9].
3. 20.6 MAUD in 1991 [10].
4. cost estimate March 2000; monies in trust fund [9].
5. 16.25 MCAD in 1985 [10].
6. All data from [10], except McClean Lake [11].
7. Remediation cost figures from [11].
8. Unit cost [13] is average figure from decommission and remediation costs of open pit and underground mines at Cellier, L'Écarpière, and Bessines [23].
9. 18 000 MHUF in 1997 [17].

Table 9.4. Decommissioning and remediation costs of selected special facilities

	Site	Last Operator	Site characteristics		
			Type	Status	Closing date
	Canada				
1	Agnew Lake ¹	ALM-Kerr Addison	ug, acl, tp	c	1986
2	Madawaska ²	Madawaska mines	op,acl,tp	c	1986
	Germany				
3	Ellweiler ³	Gewerkschaft Brunhilde	Research, tp	c	2000
4	Großschloppen ⁴	Esso/CEGB/Interuran	ug	c	1989
5	Höhenstein ⁵	Gewerkschaft Brunhilde	ug	c	1993
6	Menzenschwand ⁶	Gewerkschaft Brunhilde	ug	c	1992
	Spain				
7	Lobo-G ⁷	Enusa	op, hl	c	1997
	Sweden				
8	Ranstad ⁸	AB SVAFO	op, acl, tp, wr	c	1993
	USA				
9	Belfield Plant, ND ⁹	Union Carbide	lignite ashes	i	n/a
10	Bowman Plant, ND ⁹	Kerr-Mcgee	lignite ashes	i	n/a
11	Grand Junction Pilot Plants	USAEC	Research	i	n/a
12	Lowman, ID ¹⁰	Porter Brothers	m.p., tp	c	1992
13	Shootaring Canyon, UT	US Energy	acl, tp	i	n/a

Explanations:

op: open pit mine	m.p.: mechanical processing	n/a: not available
ug: under ground mine	acl: acid leach	c: remediation complete
wr: waste rock piles	tp: tailing pond	i: remediation incomplete

Footnotes:

- | | |
|--|-----------------------------|
| 1. 3.3 MCAD in 1986 [10]. | 6. 1.44 MDEM in 1993 [10]. |
| 2. 0.2 MCAD in 1986, only tailing pond cover [10]. | 7. 1 300 MESP in 1997 [19]. |
| 3. 43 MDEM in 1999 [16]. | 8. 140 MSEK in 1993 [10]. |
| 4. 1.7 MDEM in 1989 [10]. | 9. "ore" is coal. |
| 5. 0.93 MDEM in 1993 [10]. | 10. 11.5 MUSD in 1992 [20]. |

Table 9.4. Decommissioning and remediation costs of selected special facilities (contd)

	Production		Remediation cost		
	Ore	Uranium	Total	Unit costs	
	t	tU	1999 MUSD	t ore USD	kgU USD
Canada					
1	2 300 000	750.0	3.1	1.4	4.2
2	4 460 000	3 675.0	0.2	0.04	0.05
Germany					
3	173 000	651.1	23.4	135.4	36.0
4	18 600	30.3	1.2	62.6	38.4
5	13 900	9.1	0.6	39.9	61.0
6	98 900	584.1	0.9	9.0	1.5
Spain					
7	0.02	136	8.7	433.67	63.77
Sweden					
8	n/a	200.0	18.0		89.9
USA					
9	44 429	130.0	4.0	90.5	30.9
10	73 140	233.0	2.7	36.2	11.4
11	30 000	50.0	33.3	1 110.0	666.0
12	200 000	33.0	13.7	68.3	413.8
13	15 000	10.0	7.0	466.7	700.0

Table 9.5. Exchange rates USD vs. local currencies

Country	Currency	Exchange Rate
Australia	AUD	1.550
Canada	CAD	1.486
Czech Republic	CZK	34.569
Germany	DEM	1.836
Hungary	HUF	237.146
Spain	ESP	156.170
Sweden	SEK	8.262

The availability of funding as a function of time may also have a bearing, as extending work over time due to the lack of funding, in general, increases total costs. Reasons include *inter alia*, additional cost of intermediate safe keeping measures, prolonged hire times of equipment, and interest rates on borrowed capital.

Classification of decommissioning and remediation projects

Most available cost data provide the combined aggregate costs for (i) mine and waste rock, and (ii) mill and tailing pond decommissioning. For a few sites, only the total cost for decommissioning and remediation is available.

For this report, therefore, the remediation projects have been classified into three groups:

- Mine remediation, which includes remediation of waste rock piles.
- Mill remediation, which includes the remediation of tailing ponds.
- Remediation of integrated complexes, which includes mine, mill, waste rock, and tailing ponds.

Many countries built experimental/exploratory uranium mining and ore processing facilities in the 1960s and 1970s, sometimes using unconventional feedstock. The operations were generally small, producing only tens to several hundred tonnes of uranium. Because of their experimental character, these operations do not fit into any of the three groups. They have, therefore, been classified together in a fourth group:

- Special operations.

The cost data corresponding to these four groups are presented on Tables 9.1, 9.2, 9.3 and 9.4, respectively.

General remarks concerning the presentation of cost data in this report

The Tables 9.1 to 9.4 summarise aggregate decommissioning and remediation costs for uranium mining and milling sites in Australia, Canada, the Czech Republic, Germany, Hungary, Sweden, Spain and the USA. Where available, the compilation contains data on ore tonnage and uranium production, as well. If both cost and production data were available, unit remediation costs have been calculated.

All costs are given in local currencies and in US dollars. The exchange rates applied are given in Table 9.5. They represent the average 1999 US dollar vs. local currency exchange rates [2]. All but the historic costs figures are estimated values only.

Historic cost data for decommissioned and remediated mines in Australia, Canada, Germany, Spain, and Sweden have been converted to 1999 local currencies using the consumer price indices of the respective countries [3-7] and then converted into 1999 US dollars. Using the US consumer price index [8], the historic costs of Title I mill sites in the USA were converted into 1999 US dollars as well. Cost data of all other US sites were deemed 1999 costs. All unit costs are expressed in 1999 US dollars.

Data sources

Physical and cost data listed in Tables 9.1 to 9.4 were derived from the country reports submitted for this study by participating organisations and from other available data listed in the Reference section of this chapter. The corresponding sources for each country are as follows: Australia: [9]; Canada: [10,11]; Czech Republic: [12]; France: [13]; Germany: [10,14-16]; Hungary: [17,18]; Spain: [19]; and, USA: [1,20,21].

Analysis of decommissioning and remediation costs

A comparison of decommissioning and remediation costs based only on aggregate cost figures would not provide an objective assessment of the world situation. It is important to realise that even for similar projects, like decommissioning of an underground mine or decommissioning of an uranium mill, the scope and extend of the physical work involved may vary considerably, due to the influencing factors mentioned above. A breakdown into cost elements such as labour, capital cost, acquisition of technology and so forth, would be useful for the country comparison, but again the data are not publicly available in most cases.

A systematic analysis is further complicated by the fact that not all remediation costs presented in Tables 9.1 to 9.4 incorporate costs for dismantling and demolition, the restoration of used land, and the treatment of contaminated ground and mine water.

Nevertheless, the data listed on Tables 9.1 to 9.4 indicate some trends and broad differences between different projects in the same country and similar projects in different countries.

Decommissioning and remediation of mines

When the costs for water treatment are included, the unit costs for mine decommissioning and remediation in Germany are roughly three times the costs in the Czech Republic. The higher costs in Germany may be attributed to the extensive work required for underground decommissioning to prevent later subsidence and surface damage after flooding of the mines. In addition, the waste rock remediation plans are very elaborate because all three sites are located in densely populated areas.

It does not seem meaningful to compare the decommissioning and remediation costs of the US mines to the German and Czech costs. The sites in Czech Republic and in Germany are generally underground mines whereas the sites in the USA are all open pit mines. In addition, the published costs for the US mines do not contain costs for mine water treatment, which is a considerable cost factor in Germany and Czech Republic because of the long time foreseen for water treatment.

Decommissioning of mills

The decommissioning costs for the ore processing facilities in Germany and the Title II sites in the USA are in the same order of magnitude, i.e. between 1 and 8 USD·kg⁻¹ U. The higher costs in Germany may be explained by the fact that work at both sites entails the remediation of huge tailing ponds (56 million t residue in Crossen, 110 million t in Seelingstädt). Their supernatant water has to be removed and treated before discharge. Putting a capping on the tailings, especially on the parts containing fine-grained tailings, is a difficult task that requires expensive and innovative techniques.

The average costs for the Title I sites in the USA, though, are an order of magnitude higher than the rest in this group. The unit costs would be even higher, if costs of water treatment were included. Though water treatment costs were not available for individual sites, the Department of Energy estimates groundwater restoration costs of 215 million US dollars [20]. The explanation for the generally higher cost for Title I sites is, as mentioned above, the pilot character of these projects and, perhaps, the public sector administration of the Title I programme.

Some of the Title I sites (Table 9.2) have very specific characteristics. For example, Cononsburg, had been used intermittently as a radium extraction facility since 1911 and processed only little uranium. Parts of the tailings were reprocessed. The plant is located in a populated area, close to urban settlements. A total of 163 vicinity properties were remediated. The land for building the repository

was also purchased [10]. Similarly, more than 4 300 vicinity properties were remediated in Grand Junction. In addition, the tailings from the processing plant were transported by train and truck to the Cheney repository [10]. The remediation unit costs for the Lakeview site are abnormally high because the tailing materials were transported over 24 km to the disposal cell outside Lakeview [10]. Monticello has a very elaborate disposal cell design and also a large number of vicinity properties to clean up [22]. If these sites are excluded, the average unit cost for Title I site remediation would drop to 19.7 USD/kgU.

The abnormally high remediation costs for the Straž pod Ralskem site in Czech Republic results from the fact that the site is an ISL operation. The main costs are for groundwater clean-up [12].

Decommissioning and remediation of integrated operations

The cost differences among the sites of this group are substantial (Table 9.3). The closed commercial operations in Australia, Canada and France have average decommissioning and remediation costs in the 0.6 to 2 USD/kg⁻¹U range. At these sites remediation started right after the end of the operation and was carried out by the mining operator, using his own funds.

A second group with the Rozna complex in Czech Republic, the Mecsek mines and mill in Hungary, and the Elefante and Quercus sites in Spain, show costs in the range of 7 to 11 USD/kg⁻¹U. These sites are all located in populated areas. Site remediation is carried-out by the operator, but the funding for DIAMO and MEV is from the respective governments.

The high cost for the Königstein site in Germany is related to the fact that this mine practised underground acidic *in situ* block leaching. A major effort now goes into the clean up and protection of the overlying aquifers.

In part, the large sums required for the remediation of the sites in Germany and the Czech Republic are due to premature closure and, hence, the absence of decommissioning and remediation planning during the operational life.

No attempt has been made to calculate decommissioning and remediation cost for the uranium mining and milling facilities that are still in operation, such as Key Lake, Rabbit Lake, Cluff Lake and McClean Lake in Canada, and Ranger in Australia.

The statutory framework regulating modern uranium mining in many countries requires that uranium producers make appropriate provisions to cover decommissioning and remediation costs. In Australia, Canada and the USA, companies are complying with this requirement by placing surety bonds, irrevocable letters of credit or even outright cash deposits during the operating life of their facilities.

Therefore, there is an economic incentive to implement remediation measures, as much as possible, during the production phase. Hence, the remediation costs become part of the operating costs. The decommissioning and remediation costs for these facilities are, thus, related to the statutory financial provisions mentioned above. These funds, which are given in Table 9.3 as lump sums, cover only the remediation work that is left after the mine and mill closure. Modern uranium mining and processing facilities in Australia and Canada have estimated remediation costs of less than 1 USD/kg⁻¹U.

Decommissioning and remediation of special operations

The sites shown in Table 9.4 are all unique in one way or another. Therefore, they would skew the averages in their respective groups disproportionately.

The Agnew Lake mine, Canada, experimented with underground *in situ* block leaching and produced relatively little uranium [10].

The Belfield and Bowman plants in North Dakota, USA, extracted uranium from lignite ashes. The Shootaring Canyon plant in Utah ran only long enough for testing. The Lowman plant in Idaho processed a dredging product from a river, and the Grand Junction operation was a pilot plant with little ore throughput and uranium production, which explains the unrepresentative and high unit costs [20].

All the German sites in this group were experimental, low volume operations [10].

The Randstad mine and mill in Sweden operated only for a few years between 1965 and 1969 on a pilot plant basis. Remediation started after a hiatus of almost 20 years in 1990. Like the operation, remediation also had a pilot project character [10]. This may explain the high unit costs.

The Spanish Lobo-G plant was an experimental heap leaching plant.

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• Argentina •

Since the early 1950s, uranium ore deposits have been mined in Argentina, and yellow cake has been produced by different metallurgical processes at several sites.

At the end of the production stage, the operator began the decommissioning of the facilities, in accordance with the procedures approved by the Regulatory Authority. The tailings from processing were confined and monitored to avoid their dispersion into the environment, but without final disposal.

The present internationally accepted regulations and standards propose the suitable management of the tailings with the objective of returning the disturbed ecosystem to the community either in the same or similar conditions as it was originally.

It was realised that it was necessary to adapt international experiences to the domestic scenario. Hence, it was essential to apply an interdisciplinary analytical methodology which would allow the understanding of the relationship between the environmental systems and the distribution of the radiological and non-radiological pollutants.

For that reason, the *Comisión Nacional de Energía Atómica* – CNEA (National Atomic Energy Commission) developed the “Environmental Remediation of Uranium Tailings Sites Project”, which consists of the design and implementation of an integrated management plan.

The following sections describe the current situation in Argentina, the legal framework and the technical design developed for the closure and remediation of the Malargüe Complex.

Uranium mine and mill tailings

In Argentina there are several sites with uranium mine and mill tailings. They are still under the control of the operator, awaiting remedial action. They are: Malargüe, Huemul and San Rafael Complexes in Mendoza province; Córdoba and Los Gigantes Complexes in Córdoba province; Tonco Complex in Salta province; Pichiñán Complex in Chubut province; La Estela Complex in San Luis province; and Los Colorados in La Rioja province.

Legislative and regulatory framework

Nuclear Law

National Law No. 24.804 on Nuclear Activities (*Ley Nuclear* – Nuclear Law) of 2 April 1997 appoints the CNEA and the *Autoridad Regulatoria Nuclear* – ARN (Nuclear Regulatory Authority) as the bodies responsible for defining the policy and performing research and development, regulation and surveillance functions in the nuclear field.

The CNEA is the organisation promoting nuclear activities. It is, in particular, responsible for radioactive waste management; defining the procedures for decommissioning nuclear power plants and all other relevant radioactive installations; and performing exploration of minerals for nuclear use. The ARN is responsible for regulating and controlling nuclear activities with a view to ensuring nuclear safety and radiation protection, as well as for licensing and ensuring surveillance of nuclear facilities, through inspections.

Under the Law, a licence is required to develop any type of nuclear activity. The Law also provides for the operator's liability in the event of nuclear damage. The operators of NPPs are also required to contribute to a Fund for Decommissioning of NPPs. In this respect, implementing Decree No. 1390/98 of 27 November 1998 establishes three funds in order to guarantee the financing of the decommissioning of the Atucha I, Embalse and Atucha II plants.

Norma Básica de Seguridad Radiológica AR 10.1.1 (Basic Standard of Radiological Safety) 1995

The purpose of this standard is to achieve an appropriate level of protection for people against the risks associated with the exposure to ionising radiation. It also controls the radiological safety of facilities or practices. The scope of the standard is limited to the protection of human beings only. It is considered that standards of protection that are adequate for this purpose will also ensure that no other species is threatened as a population. The standard has requirements for practices and interventions. The competent authority in this matter is the ARN. It is a not prescriptive regulatory authority.

Requirements for uranium mine and mill tailings

Within the framework of the AR 10.1.1 Standard are the RQ 86 and the RQ 85 requirements for the uranium tailings management of the Malargüe and Córdoba Complexes. They establish that the critical group should not receive a dose higher than 0.1 mSv per year, and that long-term waste management should be performed. At present, the 0.1 mSv/year dose standard is under review.

Mining Code (MC)

Código de Minería or Mining Code (MC) No. 22.259 of August 1980 states that the mining must be done in accordance with policy, safety and preservation rules for the environment. The Mining Code establishes the environmental protection legislation framework.

The environmental and mining agencies in each province are the enforcement authorities of the code. The scope of this code is:

- Mining activities, such as prospection, exploration, development, etc.
- Milling activities, such as crushing, grinding, etc.
- Waste management.

The parties (operators) beginning an activity have to present an environmental impact assessment. An environmental impact statement must be prepared.

The purpose of the environmental assessment is to determine the potential impacts of a project on the physical, biological and socio-economic environment. This is done to determine mitigating measures for significant impacts and ultimately judging the acceptability of the project, and balancing the potential impacts against the benefits.

Radioactive Waste Management Law

Law No. 25018 on Radioactive Waste Management (*Ley de Gestión de Residuos Radiactivos*), promulgated on 19 October 1998, establishes the legal framework and technical provisions governing

radioactive waste management on Argentinean territory in order to ensure the protection of the environment and public health, and to guarantee the rights of future generations. This management extends to all activities necessary to eliminate radioactive waste generated by nuclear activities from the biosphere until its level of radioactivity no longer poses a threat to man or the environment.

The CNEA is the body responsible for the correct implementation of this Law. It ensures that the requirements concerning radiological safety and physical protection are observed while waste management activities are being carried out.

The operator of an installation which produces radioactive waste is responsible for its treatment and control until it is transferred to the Commission, which will then establish criteria concerning the acceptance of waste and conditions of its shipment. The operator may not evade his liability for potential damage to individuals or to the environment until this liability has been transferred to the Commission.

Finally, a fund is established in order to ensure the financing of the Strategic Plan for Radioactive Waste Management. This fund consists of contributions made by producers of radioactive waste, which is to be scaled according to the nature and volume of the waste produced, as well as other criteria concerning the manner in which such waste is produced.

The environmental remediation project for uranium tailings sites

The purpose of the project is the management of uranium mine and mill tailings and the remediation of the sites. The objective is to mitigate and control the environmental impacts, while taking into account the appropriate provincial, national and international regulations. The scope of the project is remediation work and investigations. This consists of the implementation of remediation works as well as environmental audits, environmental impact assessments, risk analyses, public consultation processes and preparation of engineering plans and designs for each of the sites.

Malargüe complex

The Malargüe Complex is located about 500 metres north-east of the northern edge of the town of Malargüe. The town is 420 km south of the city of Mendoza, the capital of the province. About 700 000 metric tons of uranium tailings were disposed of during 32 years of operation of the Malargüe facility. The average grade of uranium ore processed by the mill was 0.14%.

Work plan

The uranium tailings were deposited in eight piles between 1954 and 1986. They are classified as dry to semi-dry.

In the framework of the national and provincial regulations, it was necessary to develop a strategy to acquire the necessary technical knowledge to define the uranium mill tailings management technology. The context of the entire criteria of the radioactive waste management programme had to be followed. The final goal was to establish and implement the policies and procedures that would allow the management of this type of wastes within the limits imposed by the Radiological and Non-Radiological Regulatory Authorities.

A general work plan was established. It resulted from the application of a block sequence technique to the basic investigations. An overall approach was needed to understand the problem and to determine the complementary required research. It included:

- An Environmental Impact Assessment (EIA) to determine the impacts generated by the complex.
- Risk Analyses (RA) to determine the potential short-term and long-term consequences of the tailings to both humans and the natural environment.

With the EIA and the RA results, various technical options were studied to achieve the project objective. Finally, a basic and detailed engineering programme was defined to dispose of the tailings by relocating them within the facility site.

Design objectives

The plan was designed to fulfil the following design objectives:

- The dose limit specified by the Regulatory Authority should be observed.
- The annual release of radioactive and non-radioactive contaminants to the environment should be kept below the limits specified by the Provincial and Federal Authorities.
- Any exposure arising from the site must respect the ALARA principle.
- Options minimising institutional control and maintenance should be preferred.
- The use of passive barriers to confine the contaminants should be maximised.

Design requirements

It was determined that the impoundment concept was consistent with the overall Argentine strategy for radioactive waste management. This concept is considered the best and most widely used option to isolate tailings from the environment.

To ensure that risks will be adequately controlled, the design requirements for the confinement system are as follows:

- a) Dispersion and stabilisation control to ensure confinement and long-term stability of tailings.
- b) Erosion control to minimise surface water and soil contamination and to ensure the long-term integrity of the system.
- c) Control radon and radiation to reduce the dose to the population.
- d) Control surface and groundwater to prevent contamination by rain water infiltration into the tailings.

Engineering design

To achieve these requirements, the following design was developed:

1) Foundation

In order to prepare the new site for the wastes, it is necessary to perform different tasks such as the decontamination of the soil and the preparation of the foundation to homogenise the

soil base and avoid differential settlement. Considering the soil characteristics and the total amount of materials to be disposed of, the first actions to be taken on the foundation soil are: (a) to remove the first 30 cm; (b) to scarify; and (c) to compact the soil.

2) Engineering barrier

The proposed confinement system is composed of an engineered barrier of natural materials arranged in different layers. Once the soil has been compacted, the placement of the lower barrier of the system follows. This barrier consists of porous material, sandy-slimes and clay.

3) Tailings transport and disposal

The physical, chemical and mechanical characteristics of the tailings were studied. The assessment of these data enabled the selection of the best methodology to remove the material from the existing pile. Furthermore, the sequence of vertical extraction of the tailings was selected based on grain size studies and pilot assays of terraces at the working scale. The tailings will be moved to the new site by trucks controlling the moisture content to prevent contamination from dust formation. Wastes will be arranged in compacted layers. They will be neutralised with lime in order to stabilise them. Due to the fact that the materials are heterogeneous, they will be located according to their characteristics. Those of higher strength will be located in the lower part of the system and those of lower strength in the upper part.

4) Cover

The tailings will be covered with a natural multilayer barrier. The objectives of the multilayer barrier are: to reduce the radon release and gamma radiation, to minimise the rainwater infiltration, to prevent dehydration of the clay layer and to provide a long-term barrier against the erosion. The multilayer barrier is composed of a compacted clay layer, a compacted sandy-slimy soil layer and finally, a rock layer.

Conclusions

In Argentina, parallel with the continuing reduction of the mining of uranium ores, the remediation and decommissioning activities are becoming the main programme of CNEA. As many of these mines were started before environmental impact assessments were made, plans must now be developed to remediate these situations.

The new regulations in the safety field as well as the new environmental protection legislation in Argentina give the framework for the technological decisions in the uranium mine and mill activities. Thus, in the future, it will be possible to avoid the very costly environmental restoration that is being carried out at some sites today where practically no precautions were taken during the planning or operational stages.

• Australia •

Government policies and regulations

Uranium mining and milling have been carried out in Australia since the 1950s. The main historical centre is the Pine Creek geosyncline region of the Northern Territory where there were mines at Rum Jungle and the South Alligator Valley in the 1950s and 1960s, and Nabarlek in the 1980s; there were also mines at Radium Hill in South Australia and Mary Kathleen in Queensland. Radium Hill was first worked intermittently for radium during 1906 to 1931, and for uranium during 1954 to 1962. Mary Kathleen operated in two stages during 1958 to 1963 and 1976 to 1982. The rehabilitation status of each of these former operations is described in a later section of this document.

Currently, there is uranium mining at Ranger in the Northern Territory (uranium only-open cut) and Olympic Dam in South Australia (copper-gold-uranium mixed ores-underground). At Beverley in South Australia, an *in situ* leach operation began operation in November 2000. In the Northern Territory, developmental work has begun on the Jabiluka underground mine, but completion of this work is subject to negotiation with the traditional landowners. Milling of uranium in Australia is generally done adjacent to the mine in a dedicated plant. However, ore from numerous small mines in the South Alligator valley was treated in a small central mill in the area. Some ore was also trucked 50 km to Moline for treatment in a modified base metal processing plant. Concentrates from Radium Hill were sent 280 km by rail to Port Pirie for treatment.

Commonwealth legislation

Within Australia, the mining of uranium and the rehabilitation of associated milling facilities is governed by legislation at both federal (Commonwealth) and state levels. The *Atomic Energy Act 1953* gives effect to the Commonwealth's retention of ownership rights to uranium in Australian territories and also provides the mechanism whereby the operation of the Ranger uranium mine in the Northern Territory is authorised. Uranium exports are controlled under the Customs (Prohibited Exports) Regulations under the *Customs Act 1901*. These Regulations forbid the export of uranium and other source material, including thorium-bearing ores such as monazite, except with a permit from the Minister for Resources and Energy. There are, however, no specific Commonwealth laws dealing with mine site rehabilitation as this is usually the concern of the relevant state or territory government, which has day to day responsibility for regulation of all mining operations. It should be noted that within Australia there is little uniformity in the detail of legislation between states and territories over the mine site rehabilitation issue, although the general principles and objectives are similar.

The Commonwealth's recently enacted Environment Protection and Biodiversity Conservation Act 1999 does list the decommissioning or rehabilitation of an uranium ore mining and milling facility as a "nuclear action". Such nuclear actions require approval from the Federal Minister of the Environment and Heritage before they may be allowed to proceed. Such approval may require assessment through an *environmental impact assessment process*.

Although the federal government has no specific laws relating to the day to day control of uranium mining, the Commonwealth's *Environment Protection (Nuclear Codes) Act 1978* provides for the Commonwealth to prepare, in consultation with the states and territories, codes of practice relating

to nuclear activities (including uranium mining and milling). Three national codes of practice have been developed under this Act:

- Code of Practice for the Safe Transport of Radioactive Substances 1990 (transport code).
- Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores 1987 (health code).
- Code of Practice on the Management of Radioactive wastes from the Mining and Milling of Radioactive Ores 1982 (waste code).

The codes are reviewed and updated periodically. Each has an associated set of guidelines in the current editions. However, the health and transport codes are currently being updated and the most relevant code here, the waste code, is not proposed to have any update at the present time.

The present waste code guidelines set out overall objectives for the rehabilitation of sites where mining and milling of radioactive ores, primarily uranium, have taken place. The revised code will be dealing with the management of radioactive wastes from the mining and processing of any minerals, including uranium. The general principles of rehabilitation requirements are set out in a generic form in the waste code. The prime objective of the waste code is “*to provide, both in the short and long terms, for the protection of people and the environment from harmful effects due to radioactive contaminants in waste*”.

The introductory notes go on to state that the code shall apply to all stages of mining and mineral processing, including decommissioning and rehabilitation.

The implementation and enforcement of the codes is the responsibility of the states and territories and, whilst not formally adopted by any state or territory, they are frequently referred to in appropriate legislation. There are no national standards for the management of radioactive waste from mining but the approach taken by the individual states is broadly similar. The introduction of the codes has been successful in so far as they are called up by legislation and the standards within the codes may be enforced by state regulations.

State/territory level legislation

The following sections describe the current legislation relevant to rehabilitating uranium production facilities in the states and territories where uranium mining is presently taking place or expected.

Requirements for rehabilitation of uranium mining sites in the Northern Territory

The Northern Territory is not a state but a self-governing territory with certain powers retained by the Commonwealth, including ownership and mining of uranium. The Commonwealth Government’s unique position in the Northern Territory is reflected in the provisions of the *Environment Protection (Alligator Rivers Region) Act (1978)*. The Commonwealth Office of the Supervising Scientist was established under this Act with the express responsibility for oversight of all environmental aspects of uranium mining within the Alligator Rivers Region. In particular, the Supervising Scientist reports and provides advice to the Commonwealth Minister for the Environment on the environmental effects of uranium mining in the region, and is responsible for ensuring that the operations are carried out in accordance with the Commonwealth’s Environmental Requirements. The Commonwealth has a

particular interest by virtue of the Region's mines being on Aboriginal land and with three identified uranium deposits (Ranger, Jabiluka and Koongarra) surrounded by the World Heritage Kakadu National Park which is managed by the Commonwealth in association with the Aboriginal Traditional Owners.

The Northern Territory Department of Mines and Energy (NTDME) is responsible for the day-to-day regulation of uranium mining. Most general mining issues are regulated through the *Northern Territory Mining Act 1980* and *Mine Management Act 1990*, which establish a system of licences and leases for mineral exploration and mining, "minerals" being defined broadly enough to include uranium. Licence applications must include proposals for rehabilitation of the area affected by the activities concerned. Mine leases and exploration licences may also have conditions attached to them, which mention rehabilitation of disturbed ground. Furthermore, in the Northern Territory, there is specific legislation relating to the protection of the environment in relation to uranium mining. The Uranium Mining (Environment Control) Act 1979 (UMEC) sets out the specific conditions for uranium mining, including provision for the relevant Minister (currently the Minister for Resources Development) being able to require any mine or area disturbed by mining activity to be rehabilitated, including revegetation. The specific conditions for the environmental management of the mine sites at Ranger and Nabarlek (including rehabilitation) are set down in the Commonwealth Government Environmental Requirements, which are copied as Schedules to UMEC. These requirements include specific clauses on rehabilitation and call for a certificate of revegetation to be issued only after the Supervising Authority is satisfied that all the conditions of the Environmental Requirements have been met. The site-specific goals and objectives for rehabilitation of the sites have been agreed after negotiations between the mining companies, the representatives of the Traditional Owners and the Commonwealth and Northern Territory Governments.

When a uranium mining company in the region wishes to change any significant aspect of operation, it is required to make an application to NTDME for permission to implement the proposal. This application is copied to the Supervising Scientist. The Northern Territory Minister, through the NTDME, is obliged to seek the opinion of the Supervising Scientist before making the final decision. However, the Minister is not obliged to give effect to any advice given by the Supervising Scientist. This approval process is also applied to rehabilitation of the uranium mining and milling facilities in the Region. In all instances, the Northern Land Council, representing the Traditional Owners of the land, is also consulted.

The detailed administrative arrangements being applied to the rehabilitation of uranium mines of the Alligator Rivers Region are described in a later section of this document. If there were to be other uranium mines developed in the Northern Territory, but outside the Alligator Rivers Region, under the present arrangements the Supervising Scientist would not be involved.

Requirements for rehabilitation of uranium mining sites in South Australia

Government policy in South Australia is that all sites affected by mining or mineral processing, including those concerned with uranium production, should be rehabilitated. A number of legislations implement this policy, as described below. In addition, the Government has a policy of rehabilitating old abandoned uranium sites in the State and has carried out work at Radium Hill (stabilisation of mine wastes) and Port Pirie (capping of uranium mill tailings). These projects are described in a later section of this document.

Overall requirements for rehabilitation of mine sites (and environmental protection in mining generally) are administered by the South Australian Department of Primary Industries and Resources,

under the *Mining Act 1971* and the *Mines and Works Inspection Act 1921*. These requirements do not differentiate between uranium mining and other types of mining; that is, there are no specific requirements for rehabilitation of uranium mining or milling sites under this Act.

Under the *Mining Act*, when a mining lease is granted, conditions can be set on the lease to safeguard the environment. These could include conditions arising from a project's environmental assessment that are designed to ensure that rehabilitation could be effectively achieved. Prior to operations, a mining and rehabilitation programme must be prepared and approved by the Department. The programme must include a description of works proposed and wastes generated that will require rehabilitation, and the measures proposed and the rehabilitation schedule. Failure to implement the rehabilitation measures as required can lead to penalties including the loss of the mining lease. There are provisions for holding funds in bond, against proper completion of rehabilitation measures.

The other main legislation dealing with uranium mining is the *Radiation Protection and Control Act 1982*. This Act requires that a licence must be held in order to mine or mill uranium ore. Requirements can be placed on the operation in the form of conditions on the licence. The principal condition, as far as rehabilitation is concerned, is compliance with the *Commonwealth Code of Practice on Management of Radioactive Waste from the Mining and Milling of Radioactive Ore 1982* (the waste code), which is applied routinely to all operations. The Code requires that a waste management plan, which includes plans for rehabilitation, be prepared, submitted for approval, and implemented. Failure to rehabilitate would be a breach of a condition on the licence, and an offence, subject to penalty.

The only commercially operating uranium mine in the State at present is the Olympic Dam project, which is subject to an indenture between the State and the operator, given effect to by the *Roxby Downs (Indenture Ratification) Act 1982* (the Indenture). The Indenture includes a requirement that the operator complies with the Commonwealth's waste code, transport code and health code, and also a requirement that a "*programme for the protection, management and rehabilitation (if appropriate in the opinion of the supervising authority) of the environment...*" be prepared, approved, and implemented. If the Indenture is terminated and the project closed, then rehabilitation must be carried out. Failure to comply with these requirements would be a breach of the Indenture agreement, and there are procedures for settling such breaches, including recovery of costs. Before the project was established, an environmental impact statement (EIS) was approved (in 1983) under Commonwealth legislation. This was triggered by the potential environmental impacts of the Commonwealth's actions in relation to granting export licences for uranium; i.e. issuing such licences would facilitate the development of the mine. More recently, a joint Commonwealth and South Australia EIS assessment process was completed in 1997 in relation to a substantial expansion of the project that was completed in first half of 1999.

None of the legislative requirements above include specific technical requirements for rehabilitation in the form of, for example, thickness of soil cover over tailings dams etc., or soil contamination limits. Although the *Radiation Protection and Control Act 1982* imposes an annual radiation dose limit to members of the public, the measures that must be undertaken to achieve this are not specified, but must be proposed by the operator and approved by the regulatory authority. Similarly, the requirements for "non-radiological" rehabilitation, for example, revegetation of disturbed sites, are not specified, but must be developed by the operator having regard to site and operation specific conditions.

The Beverley uranium *in situ* leaching project, Australia's first mine to use this method of mining, was also subject to an intensive EIS assessment process, run jointly by the South Australian and Commonwealth Governments. The rehabilitation of the site has the primary objective of restoring

the natural vegetation community after removal of all infrastructure. Where possible, rehabilitation will be progressive through the life of the project. The well-head sites will be rehabilitated with the bores cut off at least 500mm below ground level and plugged from bottom to near surface with locatable markers inserted; and any process residues or evaporites from the plant and ponds will be buried at an approved location on site. Liquid wastes will be injected into the northern component of the Beverley aquifer which is effectively sealed from surrounding groundwater. This aquifer is unsuitable for domestic or animal use as it is highly saline and already highly contaminated with radionuclides. Plant and facilities will either be demolished and disposed of in approved repositories or decontaminated and sold. Whilst the mining company's agreed plan calls for all facilities to be removed, some infrastructure, e.g., drinking water bores and some roads etc. may be handed over to local Traditional Owners together with the Aboriginal Heritage Centre. The final details will be resolved in consultation with the regulatory authorities and the direct stakeholders.

Legislative framework for rehabilitation of uranium mines in Western Australia

There are a number of uranium deposits in Western Australia but none has yet been mined on a commercial basis. There are nevertheless various State legislative mechanisms that are applicable to the design, operation and decommissioning, including rehabilitation, of uranium mines. The current application of this legislation requires a potential project to incorporate the concept and feasibility of decommissioning and rehabilitation, of any new uranium mine into the initial design parameters for that mine. The entire life of the potential project is then assessed at the time of initiation of the proposal.

Listed below are the agencies within the Western Australian State Government with responsibilities for rehabilitation of uranium production facilities and their main legislation applicable to this situation. These agencies generally work in partnership, avoiding overlap of responsibility as far as possible:

- Department of Minerals and Energy
Mining Act 1978 and Mining Regulations 1981.
Mines Safety and Inspection Act 1994 and Mines Safety and Inspection Regulations 1995.
- Radiological Council
Radiation Safety Act 1975 and Radiation Safety (General) Regulations 1983.
- Department of Environmental Protection
Environmental Protection Act 1986.

In addition, there is some other legislation that might be applicable, depending on the specifics of the project. For instance, for a mine incorporating *in situ* leaching techniques, particular aspects of the *Rights in Water and Irrigation Act 1914* could be applicable. Any rehabilitation of that sort of ore-body would be commensurate with that legislation as well as the others. Western Australia would also, as necessary, promulgate Agreement Acts for specific projects. These Agreement Acts may include specific requirements on that project.

The specific requirements for the rehabilitation of a uranium mine would be covered by the *Mining Act 1978* and associated Regulations and the *Mines Safety and Inspection Act 1994* and associated Regulations. The legislation dealing with the radioactive aspects of the rehabilitation of the mine are included in the *Mine Safety and Inspection Regulations 1995*. These regulations include specific provision for long-term radioactive waste management and radioactive discharges from a mine site, as well as, provision to recall the main employer of a mine if rehabilitation is, or is likely to become, unacceptable after some time has elapsed.

The main management tool covering radioactive rehabilitation that is applicable within the Mine Safety and Inspection Regulations is the requirement of a waste management plan for the mine to be included in the approved Radiation Management Plan for that mine. This waste management plan must include, amongst other requirements, an outline of the proposal for the eventual decommissioning and rehabilitation of the mine. The waste management system used at a mine is also required to utilise the best practicable technology and is designed to minimise the release of radioactivity. Compliance with the requirements of the waste management plan will determine the effectiveness of a mine's rehabilitation.

The Mining Regulations include requirements for posting bonds to cover environmental rehabilitation and these are applicable to all mines in Western Australia. The *Environmental Protection Act 1986* (EP Act), administered by the Department of Environment Protection (DEP) could also be applied in situations where the *Mining Act 1978* is not wholly applicable. Under the EP Act a works approval and licence to operate will be issued if there is a discharge of waste or water from a facility, or a waste disposal system on site e.g. a tailings dam. Once the facility is decommissioned, the involvement of the DEP is limited to the life of the licence; implementation, long-term monitoring and management of rehabilitation is covered by the DME legislation. If the original development has been subject to an environmental impact assessment process under DEP legislation, the Minister can set rehabilitation conditions in the EIA approval which may be enforced by DEP. If pollution is caused by a facility after decommissioning, then the EP Act can be used to track down the party responsible and require them to stop the pollution and remediate any damage as well as provide a long-term management solution.

There is also Contaminated Sites legislation that is currently in draft form and elements may become applicable to Western Australian uranium mine sites if they are developed.

Information on Australia's restoration activities

Historical restoration activities

In the early days of uranium processing, during the early 1950s, tailings were not considered to be a particularly problematical waste. In Australia, for example, at the South Alligator mill in the Northern Territory, the tailings were deposited on a flat area immediately downhill of the mill which in turn was immediately adjacent to the South Alligator River. There was no serious attempt to retain tailings and observers from that time comment that tailings often went into the river as a consequence of flooding during the wet season. The tailings were relocated by truck some 37 km to Moline in 1986 where they were reprocessed for their gold content. The tailings were then incorporated into a redesigned tailings impoundment built under the supervision of the NTDME.

The mines were not rehabilitated but abandoned in accordance with the regulatory regime of the 1960s. Little further action was taken until the early 1990s when the Commonwealth Government funded a programme of hazard reduction works. This had the objective of making the sites safe with respect to physical and radiological hazards to visitors to the park. Work included collection and burial of contaminated infrastructure remains and process residues, including small quantities of tailings. Open cuts were fenced and adits and tunnels were collapsed wherever possible. The Office of the Supervising Scientist was responsible for radiological oversight of the works programme and the subsequent monitoring programme for the integrity of the containment for both radiological and erosional stability. Details of the works undertaken appear in a later section of this document.

At Moline, the tailings are derived from a series of base metal and gold mining operations near Moline and from the uranium mines of the South Alligator area approximately 37 km to the east. In addition, approximately 6 000 tonnes of uranium tailings relocated from the South Alligator mill were reprocessed for gold in 1987. About 246 000 tonnes of tailings had accumulated at the Moline site by 1972, which included a small proportion of uranium mill tailings. These tailings were deposited unneutralised behind bunds adjacent to the mill area. Subsequent erosion at the site resulted in tailings being distributed down the local creek and rivers system so that only 174 000 tonnes remained in 1983. The radioactivity of the tailings ranged from $6 \text{ Bq m}^{-2} \text{ s}^{-1}$ to $2 \text{ Bq m}^{-2} \text{ s}^{-1}$. These differences were a function of the different ore grades and mineral processing streams. The tailings repository was capped by contractors under the supervision of the NTDME later in the 1991/92 period and covered with a rock mulch as erosion protection.

In the case of Rum Jungle, which operated from 1954 to 1971, this was the site of uranium, copper, nickel and lead mining. At the end of operations, the mining company, which had been authorised to undertake uranium mining on behalf of the Commonwealth, had no obligation to rehabilitate the site. Tailings were deposited unneutralised into a series of small impoundments behind a dam wall. The total amount of tailings deposited was 600 000 tonnes spread over an area of about 31 ha. Supernatant liquid, which also contained some suspended tailings, was allowed to drain over a spillway whence it flowed into the Finnis River. There was also some wind dispersal of tailings from the dry surfaces behind the dam. From time to time, there were breaches of the dam, which resulted in considerable volumes of tailings being released to the river system.

From 1977 to 1978 a “clean-up” programme was organised with the intention of restoring the site to natural bushland but the works did little to relieve the impact of discharges from the site into the Finnis River. The impact on the river was severe with the waterway being declared “dead” for 8.5 km downstream of the mine site to a major confluence and severely impacted for a further 15 km downstream of that point. As a consequence of increasing public concern, the Commonwealth announced in 1980 that funding for a rehabilitation programme would be made available. The programme was managed by the Northern Territory Government and ran from 1982 to 1986. In the rehabilitation programme, tailings and contaminated underlying soil materials were placed in the Dysons Open Cut. This was covered with a 1 metre thick rock blanket and then alternating layers of contaminated subsoil and copper heap leach pile material, from the copper leach pad site. The pit was then sealed and vegetated. The tailings dam site was covered with topsoil, surface drainage was installed and the whole area revegetated. Overburden heaps were re-shaped and sealed with clay covers and erosion protection layers to prevent development of acid rock drainage conditions.

The ore and waste rocks at Rum Jungle contained sulphides in such quantities that their hydrolysis and oxidation during weathering produced sufficient sulphuric acid for heavy metals, particularly copper, and low levels of radioactivity to be leached from waste rock and tailings. The dominant metal was copper which is a very toxic material. The tailings also contributed to this contamination but have been estimated to have contributed only 5% of the copper load which was so destructive to the aquatic ecosystem of the Finnis River. It has also been suggested that sulphuric acid residues in the tailings contributed to the contamination of the river.

After completion of the rehabilitation works, a comprehensive environmental monitoring programme was put in place, undertaken by the Northern Territory agencies responsible for erosion control and water quality maintenance. The programme continues to the present time, as well as research programmes carried out by a Commonwealth agency, the Australian Nuclear Science and Technology Organisation. The site required considerable maintenance and management in the early stages of post-rehabilitation. This was mainly due to the choice of non-native grasses and concerns about tree roots possibly breaking through the clay capping layers. Maintenance has now been reduced and trees are allowed to grow unhindered, as the original fear is now considered unfounded.

The evidence from the monitoring programme is that the remediation of the Finnis River has been successful with aquatic life returning to the reaches downstream of the site. The groundwater monitoring programme results indicate that it is likely to be another 15 years or so before there is a noticeable drop in contaminant concentrations in waters leaving the waste heaps. Monitoring continues to the present time with no firm date set for the end of the programme.

Rum Jungle Creek South was an open cut mine located about 3 km from the main Rum Jungle mine. The mine operated between 1961 and 1963 and approximately 665 000 tonnes of ore were extracted to be milled at the main site. The pit was allowed to flood after mining ceased and the location became a popular picnic and recreation area. An assessment of radiation risk to members of the public was undertaken by the NTDME for a number of abandoned uranium mine sites in the Northern Territory, including Rum Jungle Creek South. A proposal for rehabilitation was drawn up and submitted to the Commonwealth Government for funding. A budget of approximately AUD 2 million was allocated for the work, which was carried out by local contractors under NTDME supervision between October 1990 and January 1991. The main objective of the works was to reduce the radiation dose to the public to less than 1mSv per year. After reshaping of the waste rock dump and removal of contaminated surface soil layers, the final landform was covered with suitable soil materials sourced from local areas. The recreation function of the site was retained through use of the water filled pit as a lake and the creation of a sports field by levelling part of the site. Suitable management and monitoring programmes for the site were introduced and the recreation area was opened to the public at the end of January 1991. A number of other uranium related sites, small mines and ore dumps, within the Northern Territory were also rehabilitated between 1990 and 1992 as part of this same programme at a total budgeted cost of AUD 4 million.

Uranium mining at Radium Hill in South Australia began in 1954, at a site approximately 120 km south-west of Broken Hill. The ore was concentrated by floatation and railed 280 km further south-west to Port Pirie, on the Spencer Gulf, where yellowcake was produced by an acid leach and ion exchange process. The operation ceased in 1962. There were two tailings dams at the mine site, covering an area of about 40 ha. By 1981, one of the tailings heaps had suffered considerable erosion with considerable gulying and wind blown tailings were dispersed over an extensive area. A second tailings heap had been partially covered with waste rock prior to the site being abandoned and was in considerably better condition. Concerns about the spread of radioactive dust from the tailings heap led to a rehabilitation programme being undertaken in 1981. The tailings surfaces were sealed with a compacted clay layer 1 metre thick and the old dams structures surrounded by compacted clay walls 9 metres thick at the base thinning to 3 metres at the top. Rock armouring of the structures was not carried out because it was considered to be too expensive. At the time construction was finished, a twenty year maintenance period was considered necessary. Monitoring of the site by the supervising authority continues to the present time and no major maintenance works have been required to date. Emissions from the site are reported by the Supervising Authorities as being below any possible intervention level.

The other processing residues, at Port Pirie, were also a cause of concern due to dusting and frequent public ingress to the site. Relocation of these materials to Radium Hill was discounted on the grounds of cost, as was the possibility of importing suitable fill materials to construct an *in situ* cover. However, a local zinc smelting plant in Port Pirie offered to supply free slag from the smelter in exchange for the rights to dump material on the land occupied by the processing wastes. Slag was placed over the pile to a final depth of 1.5 metre, which prevented dusting and reduced radon emanation levels to below the US Environment Protection Agency recommended limit for rehabilitated uranium tailings piles.

Another rehabilitated Australian uranium mine and milling complex is the Mary Kathleen site located about 60 km east of Mount Isa in Queensland. This facility mined ore from 1958 to 1963 and again from 1976 to 1982. Unlike the other Australian uranium mines described previously in this section, Mary Kathleen was rehabilitated at a time when public awareness of environmental issues had grown and the need for proper rehabilitation planning was seen as being paramount. The rehabilitation here included not only the mine, the tailings dam, evaporation ponds and the process plant but also the township. The overall objective of the plan was to leave the site in a safe and stable state consistent with the proposed future land use, grazing and with no restrictions on public access due to radiation levels.

Within the overall rehabilitation plan, the tailings area became the repository for all the contaminated wastes and liquids. There were about 7 million tonnes of tailings covering an area of approximately 28 ha. The tailings surfaces were graded to slopes of 0.5% leading into perimeter drains and the initial intention was then to place 1 metre of waste rock on this surface to provide erosion protection, radiation shielding and reduce radon emanations. This procedure was carried out over about 60% of the tailings dam. At this stage of the work, it was established that improved control of radon could be achieved using a 500 mm layer of clay and soil. As a consequence, the waste rock was removed and replaced by a compacted 500 mm layer of clay and soil taken from the uncontaminated portion of the evaporation dam wall; the waste rock layer, 1 metre thick, was then replaced. The remaining 40% of the area was covered with a 500 mm layer of contaminated clay, soil and evaporites from the floors of the evaporation ponds, followed by 500 mm of clean soil and clay and, finally, 1 metre of waste rock.

Radionuclides and salts were precipitated from the residual liquid using lime. After a period of drying, the area was covered with 500 mm of soil/clay and 1 metre of waste rock.

During production, the coarse tailings had been deposited on the downstream side of the main tailings dam wall. During rehabilitation, these were levelled out and waste rock was placed on the top of the tailings. The surface provided a minimum cover of 2 metres on a batter slope of 2.5:1; rock cover on the level portion was 1 metre, graded at a slope of 0.55 to direct runoff. A final layer of large garnetite boulders was placed over the waste rock as additional erosion protection. At the end of the work, a filter zone to trap fine particles washed from the tailings was built beyond the toe of the wall; this filter was covered by a 2 metre layer of compacted waste rock topped with large boulders.

Current restoration activities

At the Nabarlek mine site, the ore body was mined out in 143 days during the 1979 dry season. The ore was stockpiled under a concrete cover on a specially built clay-lined pad pending completion of mill construction. In a situation that is probably still unique, the tailings were deposited into the pit from which the ore was extracted, although there are examples of old mine pits being used as tailings repositories (e.g. Elliot Lake, Canada; Falls City, Texas, USA). The Nabarlek pit was essentially dry with no significant groundwater ingress, hence the placing of tailings was not seen as being likely to lead to contamination of ground water resources in the region. Tailings were initially deposited sub-aqueously after being neutralised to pH 9. In 1985, the deposition method was changed to sub-aerial, with discharge points being moved to alternate sides of the pit throughout the following years. The milling operation ended in 1989. In 1990, after the tailings surface had been allowed to dry out and form a crust, geotextile was laid over the tailings and then covered with 1-2 metres of graded waste rock to provide a working platform for the installation of vertical drainage wicks. The wicks were installed on a 3m x 3m grid to a maximum depth of approximately 33 metres. The wicks drained water as the tailings began to consolidate under their own weight, the weight of the rock blanket and the vibration of the installation machinery. The wicks were still operational in early 1993 after further materials had been deposited in the pit.

After a period of mothballing, the Supervising Authorities determined that rehabilitation had to be completed by 31 December 1995. In the dry season of 1994, a contractor was engaged to decommission and dismantle the mill. The work continued through the wet season and, by April 1995, all dismantled and decontaminated equipment was certified and ready to be removed from the site. Any remaining equipment and parts that could not be cleaned either sufficiently or economically, were placed in the pit. The pit was filled with a layer of waste rock about 15 metres thick. The evaporation ponds were filled in by having their embankment walls bulldozed in and the whole area was landscaped to a close approximation of the pre-mining landform. The complete site was ripped and all earthworks were completed before the end of the dry season. In December 1995 and January 1996, seeding was undertaken to take advantage of the early wet season rains. The seed mix was a combination of an exotic but non-persistent grass to provide surface stability and initial erosion protection and a comprehensive mix of native plants. This was to ensure the best opportunity to meet the rehabilitation objective set by the traditional land owners who required the area to be returned to a vegetative cover that would match the surrounding countryside and permit traditional hunting and gathering activities with occasional overnight camping. Radioactivity on the remediated site was surveyed and found to meet the requirements when the agreed occupancy factor of 10% was employed in the calculations. The final handover of the site has still not been made as the final decision on the acceptability of the vegetation is yet to be made. Parts of the site are well covered in trees and shrubs whereas other parts are almost bare. Investigations are underway to assess the prognosis for achievement of the rehabilitation requirements within the next few years. The mining company is currently considering introducing an active environmental management programme on a full-time basis rather than the part-time effort, which has been in place since December 1995.

From 1956 to 1964, the upper South Alligator valley, an area about 200 km south east of Darwin, was the location for 13 operating uranium mines and a number of prospects. In each case, the exploration involved drilling, costeaning and development of adits and shafts. The sites had all been abandoned by 1964, together with a small mill and solvent extraction plant and a gravity battery plant. There were no rehabilitation requirements under the regulations in force at that time.

In 1986, a survey of abandoned mines was undertaken by the Commonwealth Government to establish the size and scope of a possible rehabilitation project. The area lay within the boundaries of Kakadu National Park and visitor numbers were increasing annually. The funds available from the Commonwealth rehabilitation fund were insufficient to permit a major rehabilitation programme. In 1988, after discussions between the various agencies involved, it was agreed that a hazard reduction programme would be undertaken. This was to include reductions in physical, as well as radiological, hazards for visitors to the area. The programme required old mine workings to be fenced and rendered inaccessible where possible. The radiological study was to ensure that all potentially troublesome radioactive waste materials were dealt with in satisfactory manner.

The work was undertaken in two programmes starting in December 1990 and finishing in July 1992. The phasing of earthworks in particular had to coincide with the dry season. At the end of this programme, the initial objectives of hazard reduction were considered to have been achieved. In 1996, the former Gimbat pastoral lease, which included the area in which these former mines are located, was granted to the Traditional Owners, the Jawoyn people. The Jawoyn Association immediately leased the area back to the Commonwealth to be incorporated as Stage 3 of the World Heritage-listed Kakadu National Park. One clause of the lease requires that all former evidence of mining within the leased area be rehabilitated. As a consequence, negotiations began between the Traditional Owners and the Commonwealth and other stakeholders (Northern Territory Government, Northern Land Council) to establish goals and objectives for the rehabilitation programme. Following formation of a steering committee in March 1999, meetings for the preparation of the rehabilitation have been held. Currently, the rehabilitation plan is in preparation and this has to be agreed between

all parties by December 2000. This programme will require all remedial works to be completed by December 2015, the agreed date from the 1996 lease. The expectation is that the sites will be rehabilitated to a point where they will not require management significantly different from the remainder of the National Park, traditional hunting and food gathering activities can be carried out without serious limitations and the area will be safe for short-term camping.

Future restoration activities

At the Ranger Uranium mine in the Northern Territory, the planning of final restoration is well established. Each year, the mine operator, Energy Resources of Australia (ERA), is required to prepare a plan of rehabilitation assuming that operations were stopped on 1 April of that year. The plan, which is fully costed, has to meet the goal and objectives agreed for the site. The broad goal is:

“Rehabilitation of the Ranger Project Area should aim to establish an environment in the Area that reflects to the maximum extent that can reasonably be achieved the environment existing in the adjacent areas of Kakadu National park, such that the rehabilitated Area could be incorporated into Kakadu National Park without detracting from park values of adjacent areas.”

The main objectives of the rehabilitation programme are :

- To revegetate the disturbed sites of the Ranger Project Area with local native plant species similar in density and abundance to that existing in adjacent areas of Kakadu National Park, in order to form an ecosystem the long-term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the Park.
- To establish stable radiological conditions on disturbed sites of the Ranger Project Area so that, with a minimum of restrictions on use of the area, the public dose limit will not be exceeded and the health risk to members of the public, including Traditional Owners, will be as low as reasonably achievable.
- To limit erosion in rehabilitated areas, as far as can reasonably be achieved, to that characteristic of similar landforms in surrounding undisturbed areas.

The plan is assessed annually by the major stakeholders (Commonwealth and Northern Territory Governments, and Northern Land Council on behalf of the Traditional Owners) and, after discussions, a final version is agreed. Finally, the plan, including the cost, is checked by an independent assessor appointed by the Federal Minister (currently the Minister for Industry, Science and Resources) responsible for administering the *Atomic Energy Act 1953* (the Act under which the authority to mine uranium is granted). The assessor’s estimate of the cost of implementing the agreed rehabilitation plan is used to determine the amount which ERA must pay into a Commonwealth-administered trust fund, thereby securing the cost of rehabilitation. The assessor’s latest estimate of the cost of rehabilitating the Ranger Project area is AUD 29.8 million.

Adjacent to the Ranger Project Area is the Jabiluka Mineral lease, where ERA is currently developing the Jabiluka #2 uranium deposit as an underground mine. This mine project has been the centre of much controversy and international debate. As a consequence the rehabilitation requirements for the site have been made even more stringent than at Ranger. This is evidence that increasing levels of public concern are leading to rehabilitation standards being raised higher and higher.

In the case of Jabiluka, there are currently two alternative development plans approved by the Commonwealth Government. ERA's preferred option is the Ranger Mill Alternative (RMA), under which ore would be transported by road some 22 km to be milled at the existing Ranger mill and tailings deposited in the existing, mined-out, Ranger pits. At Jabiluka, stopes would be backfilled using low-grade (sub-economic) ore materials from the Ranger site, thus reducing the amount of mineralised material to be incorporated into the final rehabilitated landform at the Ranger site.

The second option is known as the Jabiluka Mill Alternative (JMA). This would require the construction of a mill at Jabiluka and the disposal of tailings within the Jabiluka lease. The Environmental Requirements set down by the Commonwealth Minister for the Environment call for all tailings to be disposed of underground. The current proposal from ERA is that as much tailings as possible would be used as backfill in stopes, possibly up to 60%. The remaining tailings would be placed in underground silos specially excavated in the sandstone rock overlying the rocks hosting the ore-body. ERA is investigating the possible of new technology such as paste technology (with or without cement) for the silo filling operation. A final decision on the development option is likely to be made by 2002.

Facilities with ongoing or future plans for restoration activities

Australian uranium production facilities

Ranger uranium mine

Characterisation	Name	Ranger Uranium Mine, Jabiru, Northern Territory. Operated by Energy Resources of Australia (ERA).
	History	Discovered in 1969. Reserves of 60 500 tonnes U ₃ O ₈ in two ore bodies. Mining began in orebody 1 from 1981 to 1995 and second orebody (# 3) from 1997 to present. Milling began in 1982 and is currently ongoing; lease area is 7 860 ha, mine site covers approximately 500 ha.
	Activity type	Open cut mining and milling to produce circa 4 000 tpa of U ₃ O ₈ (maximum capacity 6 000 tpa).
	Current status	Operational; second orebody (#3) due to be mined out and operations ended by 2006; 5-year rehabilitation period planned; mill may continue with ore from nearby Jabiluka deposit depending on outcome of negotiations with Traditional land owners.
Contamination	Radiological	Gamma dose rates in air from stockpiles and in pits; no public exposure. Radionuclides in water leaving site are negligible; some mine waste waters are irrigated within the site but areas will be cleaned where necessary before final close out. Radon dose rates in air from pits, tailings dam and stockpiles; public dose rate at nearest town (7 km) is 50µSv per year. Dust in air is very low; tailings are all below water or moist beaches hence minimal dust.
	Chemical	Sulphur, Sulphuric Acid, Mn, SO ₄ , U, other metals, oils and assorted hydrocarbons e.g. process kerosene and amines. Other process chemicals. Possible water pathways controlled by restricted release zone system.

Ranger uranium mine (contd)

Monitoring	Long term	ERA is required to monitor radiation, soil, air and water (ground and surface) under a programme agreed by the stakeholder, Commonwealth and Northern Territory Governments and Northern Land Council on behalf of Traditional Owners. The Regulator [Northern Territory Department of Mines and Energy (DME), State Government] operates check monitoring programmes. DME / Commonwealth long-term stewardship.
Rock dumps	Waste (<0.02%U)	15 247 936 tonnes.
	Very low grade/ low grade (0.02%-0.12%)	26 451 574 tonnes. some very low/low grade ore being buried in final landform beneath a minimum of 1 m of clean waste rock placed and rolled in two 500 mm lifts.
	Millable ore (>0.12%)	6 204 869 tonnes.
Tailings	Tailings dam	100 hectares surface area, 1 km ² plan and containing 10 M m ³ of tailings. This facility is no longer used for active tailings deposition but is an evaporation pond and still holds tailing. All tailings will eventually be transferred to pits #1 and #3.
	#1 pit	Pit is approximately 700 m x 750 m and 160 m deep. Available volume for tailings (to reference level 0.0) 15 M m ³ . 5.05 M cu metre tailings at present; this is the active repository.
	#3 pit	Pit being mined at present. Anticipated volume for tailings (to reference level 0.0) 34 M m ³ .
Costs		Amended plan of rehabilitation #24 costed at AUD 29.8 million by independent assessor. All monies held in trust fund, plan updated and fund re-assessed annually.
	(Government and owner/ operator, cost/ benefit analysis)	No data or cost benefit analysis available.

Olympic Dam

Characterisation	Name	Olympic Dam (copper and uranium mine), Roxby Downs, South Australia.
	History	Discovered in 1975. Proven reserves of 630 000 tonnes U ₃ O ₈ . Mineable reserves of 569 M tonnes containing 2.0% copper, 0.6 kg U ₃ O ₈ /t, 0.7 g/t gold and 4.9 g/t silver. Construction began in 1985. Lease area of 12 000 ha, mine etc. cover about 600 ha. Mining began in 1985 and milling in 1988: operation has recently expanded production to 4 300 tpa U ₃ O ₈ .

Olympic Dam (contd)

Characterisation	Activity type	Underground mining and milling to produce 4 300 tpa of U ₃ O ₈ .
	Current status	Recently expanded, mining could continue for at least 60 years at current rates.
Contamination Risk	Radiological	Gamma dose rates – underground so public exposure negligible. Radon dose rates – associated with discharge from ventilation raises, stockpiles, processing plant and tailings, but negligible risk to community. Dust – underground mine; dust managed; tailings facilities offer little dust risk.
	Chemical	Acid plant, process chemicals, U ₃ O ₈ , other metals, hydrocarbons, saline waters. Workplace safety to a high standard; negligible risk to the community.
Monitoring	Long term	Quarterly environmental report to Regulatory Authorities; Annual report to the public; comprehensive routine company programme of environmental monitoring. South Australia/Commonwealth long-term stewardship post mining has been discussed; to be finalised nearer the time of decommissioning.
Rock dumps	Waste	Waste rock and coarse tailings (20% of tailings) are used as backfill in the mine, no waste dump at surface; backfill rock produced by a quarry approximately 2 km from the mine.
	Very low grade	Minimal ore stockpiles at surface. All primary crushing underground. Cut off grade 0.06%.
Tailings	Tailings dam	Coarse fraction used in backfilling underground. Fine fraction tailings in 4 paddocks covering about 360 ha. Currently holding approx. 21 M tonnes tailings. Annual production deposited in tailings facility is 2.7 Mt. Expansion of production to about 8.5 M tpa by October 1999.
	Evaporation ponds	4 ponds, with a combined total area of 110 ha for evaporation of tailings liquor.
	Water disposal pond	30 ha, excess mine ground water disposal only.
Costs	Plan for rehabilitation	Rehabilitation fund exists; currently AUD 6.22 M. Assessment of total rehabilitation costs is revised six monthly. Current estimate of overall cost is AUD 60 million but there is also a commitment to use best practice at the time of decommissioning and rehabilitation.
	(Government and owner/ operator, cost/ benefit analysis)	No data available.

• Brazil •

Government policies and regulations

In Brazil, a uranium mining and milling project requires the environmental licensing of the Brazilian Institute of the Environment (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* – IBAMA) and the nuclear licensing of the Brazilian Nuclear Energy Commission (*Comissão Nacional de Energia Nuclear* – CNEN). The decommissioning of a mining facility is treated as abandonment of the installation and requires the following actions:

- Backfilling with mine debris and sealing of all wells, holes, galleries or any other excavation for research or ore removal, in the surface or sub-surface, to prevent the occurrence of accidents.
- Actions to limit the potential risks to human health and safety.
- Classification of areas in the mine to avoid the release of toxic substances to the environment.
- Execution of an abandonment and area restoration plan, to be approved by the regulatory authority (CNEN), where possible future uses are predicted.

These criteria are expressed in Standard CNEN-NE-1.13 (1989) that regulates the licensing of uranium and thorium mining and milling facilities. Numerical standards, however, are not provided but it is implicit that the releases into the environment shall not exceed those authorised for the operation of the installation.

Specific regulations are also available for waste dam systems containing radionuclides-Standard CNEN-NE-1.10 (1980). It is required that the wastes shall be stabilised physically and chemically in order to assure that effluents leaving the system comply with the acceptable regulatory levels. Stabilisation shall begin immediately after the termination of waste deposition. The systems shall be provided with means to seal or eliminate contaminated drainage sources in order to avoid, as much as possible, the collection and treatment of the drainage. The system shall also be protected against the natural drainage by means of engineering works like dykes and embankments. It shall also be controlled and signs posted in order to restrict the invasion of members of the public and to prevent non-authorised use of the wastes. The stabilisation, control and maintenance of the system in the long-term shall be documented and this document must be part of any commercial transaction involving the area. CNEN shall also be informed promptly about any new landowner.

Uranium mining and milling facilities are also regulated by the federal environmental organisation IBAMA. In this sense and to comply with the Brazilian Constitution (article 225 paragraph 2), decree No. 97623 of April 10, 1989, required that every existing project involving mineral extraction in the country should make available a degraded area recuperation plan in no more than 180 days after the promulgation of the decree. The decree has also established that in the case of a new project the plan must be presented during the environmental licensing of the project. Economical aspects of environmental restoration are also taken into account and costs related to this activity must be part of the overall project cash flow.

Historical information on country's restoration activities

The only uranium production facility that operated on a regular basis in Brazil is the uranium mining and milling facility of Poços de Caldas (CIPC). The facility ceased operations (uranium production) in 1997. However, a well-defined plan of action aimed at restoring the site has not yet been implemented. The mining company still has plans for processing other materials at the site, i.e., by-products of a monazite plant located at Rio de Janeiro State. There is also the possibility of uranium being extracted from tantalite/columbite ores from a tin mining site located in the north region of the country.

Complexo Minerio Industrial de Poços de Caldas–Brief History

The uranium mining and milling facility of Poços de Caldas was developed to provide uranium for the internal market consumption in the scope of the Brazilian Nuclear Programme. The project was intended to produce 500 t U₃O₈/year and 275 t/year of calcium molybdate as a by-product.

- 1974: Building of the pilot plant, development of wells and galleries.
- 1977: Beginning of earth moving activities.
- 1979: Beginning of development of the milling plant.
- January 1981: Beginning of the tailings dam construction.
- November 1981: Beginning of the experimental uranium concentrate production.
- 1982: Beginning of the commercial uranium production.
- 1990: Due to investment restrictions the uranium production had to be suspended.
- 1993: Restart of uranium production.
- 1997: End of uranium mining and milling.

Type of radiological and chemical contamination

The main sources of contamination to the environment are the tailings dam, where the industrial effluents used to be released, and the waste rock dumps, where the oxidation of pyritic material leads to the generation of acid drainage with low pH values and significant amounts of pollutants.

The liquid effluent leaving the waste dam is treated with BaCl₂ in order to reduce the concentration of radium isotopes (226 and 228). Lime also needs to be added in the flooded area of the tailings in order to keep the pH high (about 10). Residual pyrite oxidation is also observed in the tailings. Mn and sulphates are the pollutants of main concern among the non-radioactive ones [1]. Average concentration of Mn in the effluent of the tailings dam is 56 mg/l (0.70-750 mg/l) and that of sulfate is 1 612 mg/l (560 - 4 600). With respect to the radioactive pollutants, the average concentrations are: ²²⁶Ra - 0.161 (0.002-1.09 Bq/l); ²³⁸U - 0.038 (0.15-2.81 Bq/l).

In terms of the groundwater, sulfate concentrations (185-347 mg/l) higher than the background levels (<10mg/l) of the area have already been registered.

In terms of future impacts, in case of the interruption of the chemical treatment of the effluents (which is not an option) doses of 8.0 mSv/year (conservative estimate) or doses in the range 0.48 - 0.62 mSv/year (non-conservative estimate) would be predicted to the critical group. Among the studied radionuclides, ²¹⁰Pb and ²¹⁰Po were the radionuclides of concern.

It is important to mention that the tailings dam received (and continues to receive) the product of the chemical treatment of the acid rock drainage.

Table 1 shows the average concentrations of some pollutants in the acid drainage of one of the waste rock piles existing at the site.

Table 1. Average concentrations of pollutants in the acid drainage from WRP-4 [3]

Chemical Species	Average	Minimum	Maximum
²²⁶ Ra (Bq/l)	0.29	0.14	0.58
²³⁸ U (Bq/l)	175	71	315
Al (mg/l)	96	61	161
F (mg/l)	99	5.1	167
Mn (mg/l)	75	6.6	105
pH	3.30	2.9	3.7

The acid drainage from the two waste rock piles existing at the site are collected in holding ponds, pumped to the mine pit and treated with CaCO₃ and Ca(OH)₂. The solid material is deposited in the tailings pond and the overflow is released into the environment. The effluent released into the environment has to comply, in terms of radionuclide activity concentrations, with the authorised levels established by the regulatory authority.

Type of long-term monitoring and surveillance

With respect to the industry operation, a comprehensive monitoring programme is carried out. The collection of air samples, soil, surface water, groundwater, vegetables, animal products (milk), is carried out as part of a regular programme. In addition to this, measurements of external gamma exposure are made by means of thermo-luminescent detectors. Effluent monitoring is also carried out. Monitored radionuclides are the long-lived ones from the ²³⁶U and ²³²Th series (²³⁸U, ²²³Ra, ²¹⁰Pb, ²³²Th and ²²⁸Ra). Non-radioactive pollutants like Al, Mn sulfate, Fe and fluoride are also determined in the effluent and water samples. This programme will have to continue, with some adaptations, after the mine closure.

Waste rock dumps, sub-grade and ore stockpiles

The operations developed by CIPC gave rise to the waste-rock piles as described in Table 2.

Table 2. Volume, mass and areas of the waste-rock piles at the CIPC [4]

Waste-rock pile	Volume (10 ⁶ m ³)	Mass (10 ⁶ t)	Area (10 ⁶ m ²)
WRP-1	4.4	10.6	2.5
WRP-3	9.8	23.5	2.0
WRP-4	12.4	29.8	5.7
WRP-7	2.4	5.8	5.3
WRP-8	14.8	35.5	6.4
Total	43.8	105.2	21.9

The most important ones, in terms of environmental aspects, are the waste rock piles 4 and 8. The amount of (acid) water pumped from the holding pond of WRP-4 is $8.9 \times 10^5 \text{ m}^3$. Average rainfall at the location is 1.7 m/a. Table 3 summarises the costs with the treatment of the acid drainage at CIPC.

Table 3. **Consumption and costs associated to acid drainage treatment [4]**

Period	Amount Ca(OH)_2 (t/a)	Cost (USD/a)
1982-1988	1 620	137 700
1989-1992	2 246	190 910
Total	17 084	1 442 140

It is recognised that the collection and treatment option shall not be seen as a permanent solution to the problem and that permanent solutions need to be sought.

Tailings

There is only one tailings dam at CIPC. The small basin where it is located presents a bedrock geology that consists essentially of cretaceous alkaline volcanic rock cut by fault joints and fluorite veins. The foundations of the dam have been initially homogenised by injection of cement grout to reduce permeability and to prevent possible fracture widening. Table 4 shows other characteristics of the tailings dam. Presently the tailings dam comprises an area covered with water (the tailings dam lake) and another uncovered (dry area).

Table 4. **General characteristics of the tailings dam [2]**

Drainage Area	0.86 km^2
Average Waste Discharge	$0.15 \text{ m}^3 \cdot \text{s}^{-1}$
Volume	$2.17 \times 10^6 \text{ m}^3$
Maximum volume of waste disposal	$1.97 \times 10^6 \text{ m}^3$
Average outflow rate	$0.05 \text{ m}^3 \cdot \text{s}^{-1}$

Table 5 shows the total inventory of the tailings dam.

Table 5. **Inventories of metals and radionuclides at the waste dam [2]**

Element	Total Inventory (t)
Al	2.5×10^5
Fe	5.6×10^4
Mn	4.1×10^2
Ca	1.8×10^2
Zn	3.5×10^3
U	3.70×10^2
Th	8.20×10^1
^{226}Ra	$5.1 \times 10^{12} \text{ (Bq)}$
^{228}Ra	$2.9 \times 10^{12} \text{ (Bq)}$
^{210}Pb	$6.9 \times 10^{12} \text{ (Bq)}$

It has been estimated that 66×10^3 t of precipitate resulting from the neutralisation of acid mine drainage have been deposited in the waste dam

Costs

The mining operator has not provided yet a solid budget for the mine area restoration. The specified data are derived from an independent work [3] and are focused on the remediation of the tailings dam and waste rock piles.

In the case of the waste rock piles, studies have focused on the WRP-4. The studies were aimed at providing permanent remedial solutions. The driving force in the process of pyrite oxidation was assessed as being the diffusion of air oxygen into the dump.

An Intrinsic Oxidation Rate (IOR) of 10^{-9} kg (O₂).m⁻³.s⁻¹ was estimated for the deposited material. It has also been estimated that more than 500 years will be necessary for the total consumption of the pyritic material embodied in the dump. These results were produced by means of mass balance calculations, column leaching experiments and geochemical modelling. By means of mathematical simulations, it has been observed that a cover layer 0.5 m thick with an oxygen diffusion coefficient of 1×10^{-9} m².s⁻¹ (compacted clay) would be an effective strategy of remediation (cost and benefit analysis being taken into account). The total costs involved in the covering of the waste dump (three layer system-gravel/clay/sand) would amount to USD 10 million. Engineering work (reshaping) will also need to be performed. These costs relate only to one of the waste rock piles. As a rough estimate, it can be anticipated that similar costs will be experienced in relation to WRP-8. Costs associated with returning back the material to the open pit were also assessed to USD 70 million.

In terms of the tailings pond, it has been assessed in the above study that the contamination of groundwater by radionuclides will only be observed after 4 000 years (peak concentrations being observed after 7 000 years). The remediation scheme considered the reduction of Rn exhalation (doses due to Rn inhalation were estimated as being equal to 40 mSv/year in the first year in case of intrusion – house construction over the tailings) and the reduction of external gamma exposure (doses around 8.0 mSv/year were also estimated).

The proposed scheme consisted of covering the tailings with a three layered system. The total cost of the adoption of this scheme would be USD 3.7 million.

The above costs are based on standard market prices. Obviously, they can be reduced if, for example, clay material is obtained at the site from neighbouring areas.

Other uranium production facilities

The Lagoa Real Project started operations in 2000. The uranium extraction is performed by heap leaching and a total production of about 300 t U₃O₈ per year is expected to be achieved.

The remediation plan includes the flooding of the open pit. The waste rock piles will be covered with clay and soil and revegetation will be undertaken with local species. The leaching areas will be monitored in order to assess possible soil contamination. In this case, the soil will be covered with waste rock, soil and vegetation. The waste ponds will be drained and covered with impermeable material (PVC, clay or asphalt), and subsequently with waste rock material, soil and revegetation.

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• Canada •

Government policies and regulations

The federal government is responsible for all nuclear activities in Canada, including uranium mining and milling. Provincial and territorial governments within Canada also have jurisdiction over mining activities, including uranium, as outlined in a later section of this document.

Federal policy

The federal government announced the Radioactive Waste Policy Framework in 1996. The Framework emphasises the Government of Canada's commitment to the principles of sustainable development and guides Canada's approach to the disposal of nuclear fuel waste, low-level radioactive waste and uranium mine and mill waste. It sets out the principles governing institutional and financial arrangements for disposal of all radioactive waste. It also clearly delineates the responsibilities of the federal government and the waste producers/owners. The responsibilities of the Government of Canada include:

- Policy development.

- Regulation of producers and owners of radioactive waste.
- Oversight to ensure producers and owners comply with legal requirements, funding and operational obligations.

Waste producers and operators are responsible, in accordance with the principle of “the polluter pays” for:

- Operation, closure and decommissioning of disposal and other waste management facilities.
- Funding, organisation and management required for their wastes.

Federal acts and regulations

The federal government has responsibility for the regulation of matters relating to atomic energy, including uranium mines and mills, under the Nuclear Safety and Control Act (NSCA).¹ Under this act, the Canadian Nuclear Safety Commission (CNSC) is responsible for the administration and licensing of uranium mining facilities. The relevant regulations under this act include:

- General Nuclear Safety and Control Regulations.
- Uranium Mines and Mills Regulations.

Environmental restoration and decommissioning of uranium production facilities are governed by *Uranium Mines and Mills Regulations*. These regulations stipulate that a uranium mining facility be decommissioned in accordance with a CNSC licence. Licence applications must be accompanied by a detailed decommissioning plan; information on the land, buildings, equipment, nuclear and hazardous substances that will be affected by the decommissioning; and a description of the planned state of the site upon completion of the decommissioning work.

Companies annually accrue accounting provisions to finance future costs for decommissioning and reclamation. In addition, formal financial assurance, usually in the form of irrevocable letters of credit, for decommissioning and waste management costs associated with the licensed uranium mine or mill, is required to be submitted to the regulatory authorities prior to mine commissioning.

Under the *Canadian Environmental Assessment Act (CEAA)*,² in force since 1995, an environmental assessment must be conducted by the proponent(s) prior to the construction, operation, modification, decommissioning or abandonment of uranium mining and milling facilities.

In addition to the Federal Radioactive Waste Policy Framework and the regulations and acts listed above, the following regulatory documents are applicable to uranium mining facility decommissioning:

- *Policy on the Decommissioning of Nuclear Facilities*, Regulatory Document R-90, August 1988. Describes CNSC policy for the decommissioning of nuclear facilities including uranium mines and mills.

1. The NSCA was promulgated on May 31, 2000, replacing the Atomic Energy Control Act which was in force since 1946.

2. The CEAA was proclaimed on January 19, 1995.

- *Regulatory Objectives, Requirements and Guidelines for the Disposal of Radioactive Wastes, Long-term Aspects*, Regulatory Document R-104, June 1987. Outlines the regulatory basis for judging the long-term acceptability of radioactive waste disposal.
- *Decommissioning Planning for Licensed Activities*, Consultative Document G-219, June 2000. Provides guidance for the preparation of decommissioning plans.
- *Financial Guarantees for the Decommissioning of Licensed Activities*, Consultative Document C-206, June 2000. Provides a regulatory guide for the establishment and maintenance of measures to fund the decommissioning activities.

Provincial/territorial acts and regulations

Depending on the location of a uranium mining facility within Canada, certain provincial or territorial acts or regulations may also apply to decommissioning.

The Government of Saskatchewan's *Environmental Assessment Act* requires the proponent(s) of all developments in the province, including uranium mines and mills, to conduct an environmental assessment and to complete an environmental impact statement describing the assessment. On November 30, 1999 the governments of Canada and Saskatchewan signed an agreement to improve federal-provincial co-operation in the environmental assessment of projects subject to both the *Environmental Assessment Act* and the *Canadian Environmental Assessment Act*. A conceptual decommissioning plan is a component of the initial mining project assessment, and a final decommissioning plan will be subjected to an assessment prior to project closure.

Saskatchewan Environment and Resource Management (SERM) requires; among other things, approval of a decommissioning and reclamation plan during the development phase of uranium mines and mills, pursuant to the *Environment Management and Protection Act*. During operations, SERM also requires annual approvals pursuant to the *Air Pollution Regulations*, the *Hazardous Substances and Waste Dangerous Goods Regulations* and the *Mineral Industry Environmental Protection Regulations*. If a company wishes to permanently close a mining site, it must seek approval from SERM to implement a decommissioning and regulation plan following the *Guidelines for Decommissioning and Reclamation of Northern Minesites*.

In the Province of Ontario, the *Environmental Protection Act*, the *Environmental Assessment Act*, and the *Mining Act* are the main pieces of legislation pertinent to the decommissioning of uranium mines and mills. In 2000, the *Mining Act* was amended to include the *Mine Rehabilitation Code*. The *Mine Rehabilitation Code* includes requirements of other Ontario departments (such as the Ministry of Environment, the Ministry of Labour and the Ministry of Natural Resources) to assist proponents in satisfying the requirements of the *Mining Act* when preparing decommissioning plans.

In the Northwest Territories (NWT), the *Territorial Lands Act*, under the jurisdiction of Indian and Northern Affairs Canada (INAC), is the enabling legislation for several key regulations including: *Canada Mining Regulations*, *Territorial Land Use Regulations*, *Territorial Lands Regulations* and *Territorial Quarrying Regulations*. The NWT *Waters Act* is regulated by INAC and the NWT Water Board governs water use and disposal. The federal *Fisheries Act*, administered by the Fisheries and Oceans Canada, contains provisions to control the release of deleterious substances into fish habitat, and includes the *Metal Mining Liquid Effluent Regulations* administered by Environment Canada. Future projects are reviewed by the Mackenzie Valley Environmental Impact Review Board or the Nunavut Impact Review Board.

Background and overview of Canadian sites

The first uranium mine in Canada began at Port Radium in the Northwest Territories in 1933, and was owned by a private company, Eldorado Gold Mines. Concentrate that had uranium associated with it was sent to Port Hope, Ontario, where radium was extracted. At that time, uranium had little or no commercial value. The Port Radium Mine produced ore for radium until 1940 and reopened in 1942 to supply the demand for uranium from the British and U.S. defence programmes.

In 1943, the governments of Canada, the United Kingdom and the United States instituted a ban on private exploration and development of radioactive materials. Also in 1943, the Government of Canada nationalised Eldorado Gold Mines and established the federal Crown Corporation, Eldorado Mining and Refining, with a monopoly on all uranium prospecting and development. Canada lifted the ban on private exploration in 1948.

In 1949, Eldorado Mining and Refining began development of a uranium mine in the Beaverlodge area of northern Saskatchewan and, in 1953, commenced milling the ore onsite. The Gunnar and Lorado uranium mines and mills began operating in the same area in 1955 and 1957, respectively. Several other small satellite mines also opened in the area in the 1950s, sending ore for processing to either the Eldorado or the Lorado mills.

In the Province of Ontario, fifteen uranium mines began production between 1955 and 1960 in the Elliot Lake and Bancroft areas (twelve in Elliot Lake: Pronto, Buckles, Lacnor, Nordic, Quirke, Panel, Milliken, Spanish American, Stanleigh, Stanrock, Can-Met and Denison; and three in Bancroft: Madawaska/Faraday, Bicroft, and Dyno). Ten of these production centers in the Elliot Lake produced tailings, as did three in the Bancroft area.

Production of uranium in Canada peaked in 1959 at 12 200 tU. However, the demand for uranium to meet defence requirements dropped dramatically in 1959, and Canadian uranium mining entered a period of decline. Production dropped to less than 3 000 tU by 1966. Commercial sales of uranium to electrical utilities then began to revive the industry. With the Government of Saskatchewan offering incentives for exploration, uranium deposits were discovered at Rabbit Lake, Cluff Lake and Key Lake in 1968, 1969 and 1975, respectively. By the late 1970s these three sites were under development and production began at Rabbit Lake in 1975, Cluff Lake in 1980 and Key Lake in 1983. Although most of the mines and mills in Ontario had closed by the late 1960s, electrical utility demand stimulated renewed operations in the 1970s, particularly in the Elliot Lake area, including the development of a new uranium production facility at Agnew Lake, some 90 km west of Elliot Lake. The last of the Elliot Lake region mines, Stanleigh, closed in June 1996.

At present, all active uranium mines are located in the province of Saskatchewan. Mining is ongoing at Cluff Lake, McClean Lake and McArthur River. Uranium mills and tailings exist at Cluff Lake and McClean Lake, as well as at Rabbit Lake, where mining operations were suspended in April 1999, and at Key Lake, where deposits were mined-out in 1997. Tailings deposition continues at Key Lake however, as all McArthur River ore is being processed at the Key Lake mill.

In addition to the active sites in Saskatchewan, uranium tailings exist at the inactive and decommissioned sites in Saskatchewan, Ontario and the North West Territories (Table 1).

There are also two other sites in Saskatchewan (Midwest and Cigar Lake) that are planned for production. Operations are expected to commence in 2003 and 2005, respectively, subject to market conditions and regulatory approvals. At present, ore from Midwest is expected to be milled at McClean Lake and ore from Cigar Lake is expected to be milled at both McClean Lake and Rabbit Lake.

Review of Canadian remediation activities

In addition to the four active tailings facilities at the operating Saskatchewan sites and the two inactive tailings sites at the Key Lake and Rabbit Lake operating mine/mills, there are 20 inactive sites at various stages of decommissioning and environmental remediation. Figure 1 shows the locations of uranium mines and tailings sites in Canada.

Historical remediation activities

Saskatchewan

There are three inactive uranium sites in the Province of Saskatchewan. The Beaverlodge operation was shut down in 1982 and decommissioned in 1985. Cameco Corporation is currently conducting post decommissioning monitoring and site evaluation of the Beaverlodge facilities under CNSC licence.

The Lorado and Gunnar sites have been closed since 1960 and 1964 respectively, and have not been adequately decommissioned. Some decommissioning activities were conducted at the Gunnar site in the early 1990s.

Northwest Territories

There are two inactive uranium sites in the Northwest Territories. Mining at the Port Radium site occurred from 1933 to 1940 and from 1942 to 1960 to recover radium and uranium respectively, and finally from 1964 to 1982 to recover silver. The site was partially decommissioned in 1984. In 2000, the federal government signed a partnership agreement with the local community to discuss measures to be taken at this site.

Uranium mining and milling occurred at the Rayrock site from 1957 until 1959 when it was abandoned. Indian and Northern Affairs Canada began decommissioning and rehabilitation of the Rayrock site including capping of the tailings in 1996. Performance monitoring of the Rayrock site began in 1996.

Table 1. Summary of uranium mines and tailings sites

Mine/mill name	Operator/ responsible party	Location	Tailings site	Operating history	Decommissioning status	Current CNSC licence
Operating sites						
Cluff Lake	Cogéma Resources Inc.	Northern Saskatchewan	Tailings Management Area (TMA) in Mill Creek Valley	Site operating since 1980 Tailings disposal since 1983 Mining and milling expected to be suspended in 2001 and 2002, respectively.	To be completed in future	MFOL
Key Lake	Cameco Corporation	Northern Saskatchewan	Deilmann Tailings Management Facility (TMF)	Site operating since 1983 Tailings disposal since 1995 Mining suspended; milling continues with stockpiled ores and ores from McArthur River	To be completed in future	MFOL
Rabbit Lake	Cameco Corporation	Northern Saskatchewan	Rabbit Lake Pit	Mining and milling since 1975 Tailings disposal since 1985 Mining suspended in 1999; milling expected to be suspended in June 2001	To be completed in future	MFOL
McClellan Lake	Cogéma Resources Inc.	Northern Saskatchewan	JEB Pit	Mining and milling began in July 1999 Tailings disposal since 1999	To be completed in future	MFOL
McArthur River	Cameco Corporation	Northern Saskatchewan	None - Ore milled at Key Lake	Mining began in December 1999 No milling on site	To be completed in future	MFOL
Inactive or decommissioned sites						
Key Lake	Cameco Corporation	Northern Saskatchewan	Surface Tailings	Site operating since 1983 Tailings disposal 1983-1996	To be completed in future Ongoing monitoring	MFOL
Rabbit Lake	Cameco Corporation	Northern Saskatchewan	Surface Tailings	Site operating since 1975 Tailings disposal 1975-1985	To be completed in future Ongoing monitoring	MFOL
Beaverlodge	Cameco Corporation	Northern Saskatchewan	Surface Tailings & Underground/Mine Backfill	Site operated 1953-1982	Majority completed in 1985 Monitoring ongoing	MFDL

Table 1. Summary of uranium mines and tailings sites (contd)

Mine/mill name	Operator/ responsible party	Location	Tailings site	Operating history	Decommissioning status	Current CNSC licence
Inactive or decommissioned sites (contd.)						
Gunnar	Saskatchewan Government	Northern Saskatchewan	Surface Tailings	Site operated 1955-1964	Not completed	Unlicensed
Lorado	Saskatchewan Government	Northern Saskatchewan	Surface Tailings	Site operated 1957-1960	Not completed	Unlicensed
Port Radium	Indian & Northern Affairs Canada	Northwest Territories	Surface Tailings – Four Areas	Site operated 1942-1960 and 1964-1982 ²	Partially completed by 1984	Unlicensed
Rayrock	Indian & Northern Affairs Canada	Northwest Territories	North & South Tailings Piles	Site operated 1957-1959	Under way. Ongoing monitoring	PSL
Denison	Denison Mines Ltd.	Elliot Lake, Ontario	Denison TMA	Site operated 1957-1992	Completed 1999 Tailings flooded Ongoing monitoring	MFDL
Stanrock/Can-Met	Denison Mines Ltd.	Elliot Lake, Ontario	Stanrock TMA	Site operated 1957-1964	Completed 1999 Tailings covered/vegetated Ongoing monitoring	MFDL
Quirke 1 & 2	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Quirke Mine Waste Management Area (WMA)	Site operated 1956-1961 and 1968-1992	Completed 1999 Tailings flooded Ongoing monitoring	MFDL
Mine/Mill Name	Operator/ Responsible Party	Location	Tailings Site	Operating History	Decommissioning Status	Current CNSC Licence
Panel	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Panel Mine WMA, Main Basin (North) & South Basin	Site operated 1958-1961 and 1979-1990	Completed 1999 Tailings flooded Ongoing monitoring	MFDL
Stanleigh	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Stanleigh WMA	Site operated 1958-1961 and 1983-1996	Completed 1999 Tailings flooding Ongoing monitoring	MFDL
Spanish American	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Spanish American WMA	Site operated 1958-1959	Completed 1999 Tailings flooded Ongoing monitoring	Unlicensed ¹
Milliken	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Stanleigh WMA and Sheriff Creek Park	Site operated 1958-1965	Completed 1999. Ongoing monitoring	Unlicensed ¹

Table 1. Summary of uranium mines and tailings sites (contd)

Mine/mill name	Operator/ responsible party	Location	Tailings site	Operating history	Decommissioning status	Current CNSC licence
Inactive or decommissioned sites (contd.)						
Lacnor	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Lacnor WMA	Site operated 1957-1960	Completed 1999 Tailings partially flooded and partially vegetated Ongoing monitoring	Unlicensed ¹
Nordic	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Nordic WMA	Site operated 1957-1990 ³	Completed 1999 Tailings covered/vegetated Ongoing monitoring	Unlicensed ¹
Buckles	Rio Algom Ltd. ⁵	Elliot Lake, Ontario	Spanish American and Lacnor WMAs	Site operated 1957-1958	Completed 1999 Ongoing monitoring	Unlicensed ¹
Pronto	Rio Algom Ltd. ⁵	Blind River, Ontario	Pronto WMA	Site operated 1958-1960 and 1961-1970 ⁴	Partially completed 1999 Tailings partially covered Ongoing monitoring	Unlicensed ¹
Agnew Lake	Ontario Government	Espanola, Ontario	Surface Tailings	Site operated 1977-1983	Completed 1990 Tailings covered/vegetated No Further Action	Unlicensed ¹
Dyno	AEC West Ltd.	Bancroft, Ontario	Surface Tailings	Site operated 1958-1960	Completed 1990s Tailings covered/vegetated Ongoing monitoring	Unlicensed
Bicroft	Barrick Properties	Bancroft, Ontario	Surface Tailings – Two Areas	Site operated 1958-1963	Completed 1990. Tailings covered/vegetated Ongoing monitoring	Unlicensed
Madawaska/ Faraday	AEC West Ltd.	Bancroft, Ontario	Surface Tailings – Two Areas	Site operated 1957-1964 and 1976-1983	Completed 1994. Tailings covered/vegetated Ongoing monitoring	DA

CNSC: Canadian Nuclear Safety Commission. MFOL: Mining Facility Operating Licence. PSL: Prescribed Substance Licence. DA: Decommissioning Approval.
MFDL: Mining Facility Decommissioning Licence.

1. Currently Unlicensed, Prescribed Substance Licence pending.
2. Mining and milling of silver ore from 1964 to 1982.
3. Uranium mining/milling ceased in 1968; drying and packing.
4. Uranium mining/milling ceased in 1960; mill processed copper from Pater Mine and deposited tailings in WMA until 1970.
5. Rio Algom was purchased by Billiton Base Metals in November 2000.

Ontario

Elliot Lake Area

There are 12 inactive uranium mines and 10 inactive uranium tailings sites in and around Elliot Lake, Ontario (some of the mines utilised other mills and/or tailings disposal areas). The tailings disposal areas are referred to as waste management areas (WMAs) by Rio Algom Ltd. and tailings management areas (TMAs) by Denison Mines Ltd.

Rio Algom Ltd. is responsible for the Quirke, Panel, Spanish American, Stanleigh, Lacnor, Nordic, Buckles, Pronto and Milliken mines, whereas Denison Mines Ltd. is responsible for the Denison and Stanrock/Can-Met mines.

Decommissioning of the Stanleigh, Quirke and Panel and the Stanrock/Can-Met and Denison uranium mining facilities was essentially completed by the end of 1999. Site decommissioning is governed by the *Uranium Mines and Mills Regulations* under the *Nuclear Safety and Control Act*. All five sites have CNSC Mine Facility Decommissioning Licences (MFDLs). Most, if not all, of the major site decommissioning and reclamation has been completed at all of these sites. The WMAs/TMAs have been stabilised and contained and most have been flooded. Tailings at the Stanrock TMA have been saturated to reduce acid generation but have a dry cover. These areas will continue under interim monitoring and active management until effluent meets discharge criteria without treatment. Long-term monitoring with care and maintenance will follow. The companies predict that discharges will stabilise at the flooded WMAs/TMAs and that treatment can be discontinued within five years, whereas it is predicted that treatment will be required at the Stanrock TMA for at least 50 years.

By the end of 1999, Denison Mines and Rio Algom had spent over CAD 75 million on the decommissioning of the Quirke, Panel, Stanleigh, Denison and Stanrock/Can-Met mines. With the bulk of the remedial work completed, capital decommissioning costs by both companies at these sites were projected to be less than CAD 1 million in 2000.

Financial assurances or guarantees are in place for all of these sites. Decommissioning costs at the Stanleigh site were paid by the electrical utility, Ontario Power Generation (formerly Ontario Hydro). A letter of credit for CAD 9.2 million has been posted by Rio Algom to cover transition period and long term care and maintenance costs. Sufficient capital for six years of operation, maintenance and monitoring is to be maintained in this fund.

Rio Algom's six other Elliot Lake mine facilities (Spanish American, Lacnor, Nordic, Buckles, Pronto and Milliken) had been reclaimed some 30 years ago prior to the establishment of the current legal framework for mine closure and decommissioning. Since nuclear substances are present at these sites, Rio Algom began the process of obtaining a CNSC licence in 1995 to meet the regulator's mandate to control radioactive materials. In support of its application for a Prescribed Substance Licence at these sites, Rio Algom recently submitted a screening environmental assessment. Licensing of these sites is anticipated in 2001.

Between 1992 and 1997, Rio Algom upgraded these facilities to meet current requirements. Upgrading was completed at all sites except Pronto, where re-vegetation of the waste management area continues. The Spanish American waste management area has been flooded, whereas tailings at Nordic and Pronto are contained in dry, vegetated waste management areas and Lacnor tailings have

been partially flooded. Financial assurances for the care and maintenance of these sites will be required before the Prescribed Substance Licence is issued to Rio Algom.

All of the Elliot Lake tailings sites have effluent water treatment plants which generally employ barium chloride and lime to remove radium and neutralise pH. Discharges to the environment are monitored on a continuous basis and meet Provincial Water Quality Objectives.

Rio Algom and Denison are also conducting the Serpent River Watershed Monitoring Programme to assess environmental impacts to the entire Serpent River watershed which encompasses the majority of the Elliot Lake tailings. The programme includes periodic monitoring of background and receiving waters as well as studies of the biota in the watershed and in the man-made tailings environments every five years. Fieldwork for the first of the five-year biota assessments was completed in the fall of 1999 and a report is expected in 2000. Water quality monitoring is ongoing.

The Agnew Lake Mine near Espanola, Ontario, ceased operation in 1983. The site was decommissioned and monitored by Kerr Addison Mines from 1983 until 1988. The site was turned over to the Province of Ontario in the early 1990s.

Bancroft area

Inactive uranium tailings sites also exist in the Bancroft, Ontario area at the Madawaska/Faraday, Dyno and Bicroft Mines. The Madawaska Mine has been inactive since 1983, while operations at the Dyno and Bicroft sites ceased in the early 1960s. AEC West Ltd. has completed decommissioning activities at the Madawaska and Dyno mine sites. Barrick Properties have completed decommissioning activities at the Bicroft Mine.

The Madawaska site has a decommissioning license from the CNSC. The site has been decommissioned and is managed and monitored by AEC West. The Dyno and Bicroft sites do not have CNSC licences. Effluent discharges from the tailings areas at the three Bancroft sites meet Provincial Water Quality Objectives and there is no active water treatment. There are no financial assurances in place for the three Bancroft area mines.

In January 1996, the Government of Canada and the Government of Ontario signed an agreement specifying financial and long term management responsibilities for abandoned uranium mine and mill tailings in Ontario. At present, there are no abandoned uranium mines in Ontario. This agreement is in essence a "safety-net" in the event that the owner responsible for decommissioning costs becomes incapable of providing the necessary funds to do so. A similar agreement between the Government of Canada and the Government of Saskatchewan is currently under consideration.

Ongoing and future remediation activities

With respect to the Lorado and Gunnar sites in northern Saskatchewan, the Saskatchewan government is working with the federal government through Natural Resources Canada (NRCan) to facilitate the decommissioning of both of these sites. Some decommissioning work was done at the Lorado site in the early 1990s while little or no work has been done at the Gunnar site. Preliminary work plans and estimated costs have recently been developed.

The federal government has entered into a joint process with the Deline Dene Band (local aboriginal people) to discuss and decide measures to be taken to address the community of Deline's concern about the Port Radium mine site in the Northwest Territories. An official announcement of this joint process was made on January 20, 2000 and a forum known as the

Canada/Deline Uranium Table (CDUT) was established. The CDUT is currently developing an action plan which will recommend studies and investigations as appropriate.

Some decommissioning and rehabilitation was completed at the Rayrock site in the Northwest Territories in 1996. Decommissioning included capping of the tailings and sealing of mine openings. Performance monitoring of the Rayrock site began in 1998. The federal government is responsible for decommissioning and monitoring of the site through Indian and Northern Affairs Canada.

Decommissioning and site remediation will be required at all five of the current operating sites in Saskatchewan. Conceptual or detailed decommissioning plans as well as financial assurances in the form of letters of credit from the operators are in place for all of these sites.

The first of these sites likely to undergo full decommissioning is Cluff Lake which is scheduled to cease operation by the end of 2002. Cogéma Resources Inc. submitted a detailed decommissioning plan for Cluff Lake in June 1999 and will be required to complete a comprehensive study environmental assessment of the proposed decommissioning under the *Canadian Environmental Assessment Act*. As the responsible authority for this assessment, the CNSC outlined the scope of the required study in October 1999.

At most of these sites rehabilitation for eventual decommissioning is an ongoing process as remediation is conducted on facilities or areas which are no longer used. For example, decommissioning research and activities are being conducted at the inactive tailings management areas, waste rock piles and mined-out pits at the Key Lake and Rabbit Lake operating sites.

Sites planned for future production in Saskatchewan (Midwest and Cigar Lake) will also require decommissioning. Test mining has taken place at both sites, and production is expected in 2003 and 2005, respectively, depending on market conditions and regulatory approvals. Conceptual decommissioning plans have been developed for both sites as part of their pre-operational environmental assessments.

Facilities with ongoing or future plans for restoration activities

Gunnar

Site characterisation	Name	Gunnar mine. Beaverlodge area, province of Saskatchewan. Operated by Gunnar Mines Ltd.
	History	Began production in 1955. Closed in 1964. Site was never licensed by the CNSC.
	Activity type	Former mine and mill.
	Current status	Inactive; site has not been decommissioned. Site is not licensed by the CNSC. Saskatchewan and federal governments are currently reviewing decommissioning and restoration of site.
Contamination	Radiological	Studies by Environment Canada in 1980s indicated elevated radionuclide levels in local fish, surface water and sediment. Surface waters in Langley Bay exceeded Saskatchewan water quality objectives for ²²⁶ Ra.
Environmental monitoring	Ongoing	None.
	Long-term	To be determined.

Gunnar (contd)

Rock dumps	Waste rock	Unknown.
	Special waste	
	Ore	
Tailings – surface tailings	Description	Tailings placement from approximately 1955 to 1964. Tailings dam failed in 1960, released tailings into Lake Athabasca and created Langley Bay tailings delta. Some revegetation studies conducted by Environment Canada in early 1980s.
	Size (volume, area)	Approximately 4.4 M tonnes.
	Water treatment	None.
Site characterisation	Name	Gunnar mine. Beaverlodge area, province of Saskatchewan. Operated by Gunnar Mines Ltd.
Restoration costs	To date	CAD 0.
	Future	Unknown.
	Guarantees/surety	None.
	Cost/benefit analysis	Not completed.

Lorado

Site characterisation	Name	Lorado Mine. Beaverlodge area, province of Saskatchewan. Operated by Lorado Uranium Mines Ltd.
	History	Began production in 1957. Closed in 1960. Site was never licensed by the CNSC. Site was partially decommissioned by Conwest in the early 1990s including dismantling of mill and flattening of site. Restoration of a portion of tailings on private land. Approximately CAD 1 million spent. Saskatchewan government accepted decommissioning work.
	Activity type	Former mine and mill.
	Current status	Site is not licensed by the CNSC. Saskatchewan and federal governments are currently reviewing additional decommissioning and restoration requirements for site.
Contamination		Studies by Environment Canada in late 1970s/early 1980s found low pH and elevated ²²⁶ Ra in Nero Lake, a small local pond. ²²⁶ Ra exceeded Saskatchewan water quality objective.
Environmental monitoring	Ongoing	None.
	Long-term	To be determined.
Rock dumps	Waste rock	Unknown.
	Special waste	
	Ore	

Lorado (contd)

Tailings – surface tailings	Description	Tailings placement from approximately 1957 to 1960. A portion of tailings located on government land still requires some restoration work.
	Size (volume, area)	Approximately 360 000 tonnes.
	Water treatment	None.
Restoration costs	To date	CAD 1 000 000.
	Future	Unknown.
	guarantees/surety	None.
	Cost/benefit analysis	Not completed.

Port Radium

Site characterisation	Name	Port Radium. Great Bear Lake, Northwest Territories. Operated by Eldorado Mining and Refining Ltd. (for uranium) and Echo Bay Mines Ltd. (for silver).
	History	Discovered in 1930. Extraction of radium from 1933-1940. Uranium extraction from 1942, uranium milling onsite from 1952-1960 when ore was depleted. Silver mining/milling was also conducted on site from 1964-1982.
	Activity type	Former mine and mill. Pitchblende deposit.
	Current status	Inactive. Restoration of some of the tailings areas completed by Echo Bay Mines following closure in 1982. Site is not licensed by the CNSC. Federal government through Indian and Northern Affairs Canada is lead agency currently reviewing requirements for site. Joint federal/provincial process announced on 20 January, 2000 to develop plan, investigate site and recommend appropriate action.
Contamination		Assessments of tailings areas and receiving waters have not detected any significant environment problems.
Environmental monitoring	Ongoing	To be determined.
	Long-term	To be determined and will be completed as part of the future decommissioning work.
Rock dumps	Waste rock	Yes.
	Special waste	Unknown.
	Ore	No.

Port Radium (contd)

Tailings – surface tailings	Description	Uranium tailings placement from approximately 1952-1960. Uranium tailings in four areas including small lake basins. Some tailings also deposited into deeper waters of Great Bear Lake. Silver tailings placement from 1964-1982.
	Size (volume, area)	Approximately 907 000 tonnes of uranium tailings and approximately 500 000 tonnes of silver tailings.
	Water treatment	Between 1975 and 1982 tailings water and mine waste water were treated with barium chloride and ferric sulphate to precipitate radium and arsenic respectively. Water was then discharged to Garbage Lake.

Rayrock

Site characterisation	Name	Rayrock mine. Marian River/Sherman Lake, Northwest Territories. Operated by Rayrock Mines Ltd.
	History	Mining and milling of uranium from 1957-1959.
	Activity type	Former mine and mill.
	Current status	Site has a CNSC Prescribed substance licence for decommissioning activities. The Indian and Northern Affairs Canada (INAC) is lead agency currently reviewing additional decommissioning and restoration requirements for site.
Contamination	Radiological	Waters directly in contact with tailings have elevated levels of ²²⁶ Ra and copper. ²²⁶ Ra and ²¹⁰ Pb levels are high compared to other abandoned or inactive uranium tailings areas in Canada. ²²⁶ Ra ranged from 350-3 300 pCi/g. ²¹⁰ Pb ranged from 350-3 000 pCi/g.
	Chemical	
Environmental monitoring	Ongoing	DIAND began monitoring the site in 1998. Radiological survey and pathways analysis completed.
	Long-term	Final monitoring plan to be approved by the CNSC.
Rock dumps	Waste rock	Unknown.
	Special waste	
	Ore	
Tailings – surface tailings	Description	Tailings placement from approximately 1957-1959.
	Size (volume, area)	Approximately 71 000 tonnes. Situated in two piles south of mine site. Piles cover areas of 6 and 8 ha.
	Water treatment	None. Tailings are weakly acid-generating but pH in small water bodies in contact with tailings has not been affected.

Rayrock (contd)

Restoration costs	To date	CAD 2.5 million to date, CAD 100 000 for monitoring to date.
	Future	Initial estimates for annual maintenance to multi-year monitoring events are CAD 60 000 per event.
	Guarantees/surety	None.
	Cost/benefit analysis	Not completed.

Cluff Lake

Site characterisation	Name	Cluff Lake operation. Province of Saskatchewan. Owned and operated by Cogéma Resources Inc.
	History	Deposits discovered and explored in 1969 through 1986. Production began early in 1980, with approximately 22 700 tonnes of concentrate (U ₃ O ₈) produced as of August 1999. Project includes four mined-out open pits and two operating underground mines.
	Activity type	Open pit and underground mines and mill.
	Current status	Licensed for 2 020 tonnes/year uranium. Production in 1998 was 1 040 tU. Site has a CNSC Mining Facility Operating Licence. Currently mining two underground ore bodies. Cogéma announced in August 1998 that it would suspend operations indefinitely by end of 2000. Provided detailed decommissioning plan to the CNSC in June 1999. Plan is now subject of ongoing environmental assessment. Cogéma will be submitting an environmental assessment report (called Comprehensive Study report) under the Canadian Environmental Assessment Act. A document outlining the scope of the project and assessment was prepared by the CNSC in October 1999.
Contamination	Radiological	Workplace area and personnel dose monitoring meet acceptable targets.
	Chemical	

Cluff Lake (contd)

Environmental monitoring	Ongoing	Radiation protection monitoring including measurement of gamma radiation and radon progeny conducted in work areas throughout site. Personnel dosimetry monitoring also conducted. Monitoring of water quality in water treatment plant discharges and surface water sites for general parameters, radionuclides and metals.
	Long-term	Monitoring after closure would continue until no longer required by regulatory agencies. Monitoring would include any water treatment systems, surface water and assessment of revegetation. Extensive post-closure monitoring programme for surface water, groundwater, sediment, fish and air is outlined in decommissioning plan.
Rock dumps	Waste rock	Waste rock from open pit and underground mines stockpiled at surface. Waste rock research project being conducted on Claude Pit pile in support of decommissioning plans. Hauling and disposal of OP/DP waste rock pile, and industrial waste buried within OP/DP waste, to flooded Claude Pit under way since 1997. The Claude and DJN waste rock piles will receive engineered covers.
	Special waste	Mineralised special waste (0.03 to 0.10% U or acid generating) is also disposed in Claude Pit.
	Ore	Hauled from mine to mill.
Tailings – surface tailings	Description	Between 1980 and 1983 tailings were placed in temporary lined containment near the mill. These tailings were reprocessed and deposited in Surface Tailings Management Area (TMA) located in Mill Creek sub-basin. Tailings placement in TMA began in March 1983.
	Size (volume, area)	Capacity of TMA is 2.67 M m ³ . Approx. 2.3 M m ³ (2.7 M tonnes) placed to end of 1998.
	Water treatment	Two water treatment plants at TMA discharging to settling ponds prior to discharge to environment. Plants remove radium and suspended solids and control pH. Water from mines is pumped to mill for use, then to TMA for treatment.
Restoration costs	To date	Unknown.
	Future	Decommissioning costs developed by Cogéma for 1999 detailed decommissioning plan.
	Guarantees/surety	Irrevocable letter of credit in place for CAD 33.6 million.
	Cost/benefit analysis	Yes

Key Lake

Site characterisation	Name	Key Lake Operation; Province of Saskatchewan. Operated by Cameco Corporation. Ownership: Cameco 83%, Cogéma 17%.
	History	Mining of Gaertner Pit began in 1982. Open pit mining of ore from Gaertner and Deilmann Pits completed in 1987 and 1997 respectively. Ore milled onsite and tailings deposited initially to surface tailings area and then to Deilmann Pit.
	Activity type	Open pit mine and mill.
	Current status	Licensed for 5 700 tonnes/year uranium. Production in 1998 was 5 400 tU. Deposits mined-out in 1997. Milling of stockpiled ore from Deilmann Pit ongoing. McArthur River ore will be milled at Key Lake beginning in December 1999. High grade McArthur River ore will be blended with lower grade Key Lake ore. Milling of McArthur River ore projected to continue until 2025. Site has a CNSC Mining Facility Operating Licence.
Contamination	Radiological	Workplace radon progeny and gamma monitoring indicates acceptable levels. Personal gamma dosimetry also acceptable. Radionuclides in surface water leaving site are negligible. Airborne particulate occasionally exceeds the acceptable level; however, metals and radionuclide concentrations are low.
	Chemical	Surface water quality meets provincial objectives except for nickel.
Environmental monitoring	Ongoing	Aquatic, air and terrestrial monitoring is conducted by Cameco under guidelines set by the federal and provincial agencies in the site operating licences. Surface water, fish and sediments in local creeks impacted by mill effluent and dewatering. Air sampling for heavy metals, radionuclides, radon and SO ₂ . Routine monitoring of groundwater quality.
	Long-term	Monitoring after closure would continue until no longer required by regulatory agencies. Monitoring would include any water treatment systems, surface water and assessment of revegetation.

Key Lake (contd)

Rock dumps	Waste rock	Waste rock piles (40 M m ³) will be decommissioned <i>in situ</i> . Nickel-rich waste rock placed in Gaertner Pit in 1998.
	Special waste	Gaertner and Deilmann special waste piles. Storage capacity of each is 600 000 m ³ . Special waste will be blended with McArthur River ore. Approval also granted to dispose of mineralised waste rock from McArthur River at Key Lake site.
	Ore	Deilmann Pit ore stockpile was 501 000 tonnes (5 622 000 kg U ₃ O ₈) at end of 1998. Will be blended with McArthur River ore.
Tailings – in-pit TMF	Description	Tailings deposition switched to Deilmann TMF pit in 1995/96. Pit has a pervious surround to minimise mixing of groundwater with tailings. Approval received from the CNSC in November 1999 to place tailings subaqueously. Pit to be decommissioned by covering tailings with sand and till and flooding.
	Size (volume, area)	Estimated final volume 4.5 M m ³ , 12 ha, contained 1 015 M tonnes at end of 1998.
	Water treatment	All contaminated water from dewatering is treated at reverse osmosis plant prior to discharge.
Tailings – surface tailings	Description	Operational from 1983-1996. Decommissioning options include relocating tailings to Deilmann Pit or capping and decommissioning <i>in situ</i> .
	Size (volume, area)	3.8 M tonnes, 52 ha, contained 3 586 M tonnes at end of 1998.
	Water treatment	All discharged water is pumped to reservoir for re-use or treatment prior to disposal.
Restoration costs	To date	Unknown.
	Future	CAD 45.6 M based on current decommissioning plan.
	Guarantees/surety	Irrevocable letters of credit in place for CAD 45.6 M to Saskatchewan government.
	Cost/benefit analysis	Under development.

Rabbit Lake

Site characterisation	Name	Rabbit Lake Operation; Province of Saskatchewan Owned and operated by Cameco Corporation.
	History	Discovered in 1968. Construction and mining began in 1972/74. Milling began in 1975. Purchased by Eldorado in 1982. Mining of open pits known as Rabbit Lake and A, B and D Zones has been completed.
	Activity type	Open pits and underground mine with mill.
	Current status	Licensed for 6 500 tonnes/year uranium. Production in 1998 was 4 500 tU. Mining from Eagle Point underground mine was suspended in March 1999. Milling of stockpiled ore continues at a reduced rate. Approvals currently being sought to process 57% of Cigar Lake Phase 1 ore at Rabbit Lake mill, which would extend mill life by est. 12 years. Site has a CNSC Mining Facility Operating Licence.
Contamination	Radiological/chemical	Workplace radon progeny and gamma monitoring indicates acceptable levels. Personal gamma dosimetry also acceptable. Monitoring conducted at surface facilities, mill and underground. A, B and D Zone pits have been reflooded and water quality is being monitored for radionuclides and heavy metals. Water quality in A and D Zones generally meets provincial guidelines. Water in B Zone Pit exceeds provincial guidelines for Ni and As. Effluent treatment plant at mill. Water is treated with acid, lime, barium chloride and ferric sulphate to remove contaminants such as As, Ni and ²²⁶ Ra. Water also passes through two settling ponds and sand filters prior to discharge.
Environmental monitoring	Ongoing	Composite samples of treated effluent water are collected weekly. Routine monitoring of surface water and groundwater in pits and onsite for general parameters, radionuclides and heavy metals. Air sampling for heavy metals, radionuclides, radon and SO ₂ .
Environmental monitoring	Long-term	Monitoring after closure would continue until no longer required by regulatory agencies. Monitoring would include any water treatment systems, surface water and assessment of revegetation.

Rabbit Lake (contd)

Rock dumps	Waste Rock	Waste is located at the Eagle Point waste pad, the B-Zone waste stockpile area and the east, west and north stockpile areas around the tailings pit. 1 073 M tonnes of waste were generated to the end of 1998. Waste from the waste pad and tailings pit waste areas is used for backfill in the Eagle Point underground mine. Waste rock has also been used to construct the pervious surround in the tailings pit.
	Special waste	Mineralised special waste is stored at the B-Zone special waste area. 223 000 tonnes were generated to the end of 1998.
	Ore	394 000 tonnes of ore from A, B and D Zones and Eagle Point Mine onsite at end of 1998.
Tailings – in-pit TMF	Description	Mined-out Rabbit Lake Pit with pervious surround. Demonstration tailings placement Nov 1984-March 85. Full operation since Nov 85. Expected to receive tailings from milling of Cigar Lake ore. Pit to be decommissioned by covering tailings and flooding.
	Size (volume, area)	Estimated final volume 6.2 M m ³ , approximately 20 ha, contained 4.53 M tonnes at end of 1998.
	Water Treatment	Water from dewatering is pumped to mill for re-use.
Tailings – surface tailings	Description	Above-ground tailings management facility. Tailings placement from 1975 until 1985. Decommissioning will include placement of fill on the surface and consolidation. Fill placement is scheduled for 2001-2004 with final grading and cover beyond 2004.
	Size (volume, area)	53 ha, contained 6.5 M tonnes at end of 1998.
	Water treatment	Seepage directed to effluent treatment plant at mill.
Restoration costs	To date	Ongoing decommissioning and reclamation of areas where operations have ceased. One-year and five-year plans in place. Costs to date: unknown.
	Future	Cost estimates developed by Cameco in 1996.
	Guarantees/surety	Irrevocable letter of credit in place for CAD 29.5 million. Likely to be reviewed within two years.
	Cost/benefit analysis	Under development.

McClellan Lake

Site characterisation	Name	McClellan Lake project; Province of Saskatchewan Operated by Cogéma Resources Inc. Ownership: 70% Cogéma, 22.5% Denison Mines Ltd., 7.5% OURD (Canada) Co. Ltd.
	History	Discovery and exploration from 1980-1990. Mining of waste rock and ore from JEB Pit completed in July 1997. Mining of waste rock from Sue C Pit commenced in July 1997, completed late in 1998. Construction of mill completed in September 1997. Construction problems in 1998 resulted in delays in converting JEB Pit to tailings management facility (TMF). CNSC issued operating licence in June 1999 to permit operation of mill and JEB TMF and processing of stockpiled ore. Milling began shortly thereafter. CNSC approved mining of Sue A, B and C open pits in November 1999.
	Activity type	Open pit mine and mill. Potential underground mine.
	Current status	Licensed for 2 300 tonnes/year uranium. Milling of stockpiled ore from JEB Pit began in June 1999. Mining of ore from Sue C Pit began in 1999. Ore reserves from JEB and Sue Pits expected to feed mill for five years. Sue deposits contain approximately 12 000 tonnes of uranium at average grade of 2%. The McClellan Lake ore body will be mined last by underground methods. Ore from Midwest Project and Cigar Lake planned for future mill feed. Site has a CNSC Mining Facility Operating Licence. Expected life of the combined McClellan Lake/Cigar Lake Project is 40 years.
Contamination	Radiological/ chemical	Workplace radon progeny and gamma monitoring indicates acceptable levels. Monitoring conducted throughout site. Monitoring of sump waters from JEB and Sue C Pits indicates that water requires treatment prior to discharge to the environment.
Environmental monitoring	Ongoing	Radiation protection monitoring including measurement of gamma radiation and radon progeny conducted in work areas throughout site. Personnel dosimetry monitoring also conducted. All predicted doses <60% of permitted annual dose of 20 mSv. Monitoring of water quality in pit sumps, water treatment plant discharges and surface water sites for general parameters, radionuclides and metals.
Site characterisation	Name	McClellan Lake project; Province of Saskatchewan Operated by Cogéma Resources Inc. Ownership: 70% Cogéma, 22.5% Denison Mines Ltd., 7.5% OURD (Canada) Co. Ltd.

McClellan Lake (contd)

Environmental monitoring	Long-term	Monitoring after closure would continue until no longer required by regulatory agencies. Monitoring would include any water treatment systems, surface water and assessment of revegetation.
Rock dumps	Waste rock	10 M tonnes of waste rock removed from JEB Pit and stockpiled. Waste rock piles will be contoured and covered. 24 M tonnes of waste rock from Sue C Pit to be stockpiled at surface, covered and vegetated (600 m x 1 000 m x 35 m high). Waste rock from the Sue A and B Pits (6.2 M tonnes) to be placed in the deeper Sue C Pit. Waste rock will be covered with 2 m of local till and flooded. All three pits will be flooded to become lakes.
	Special waste	67 000 tonnes of mineralised special waste removed from JEB Pit. Stockpiled on site. Mineralised special waste from JEB and Sue A, B and C Pits (208 000 tonnes) will be placed back in mined out Sue C Pit. Total estimated volume of waste and special waste to be placed in Sue C Pit is 3.5 M m ³ .
	Ore	206 000 tonnes of ore removed from JEB Pit. Estimated 578 000 tonnes of ore to be removed from Sue A, B and C Pits. All ore transferred to JEB mill for processing.
Tailings – in-pit TMF	Description	All tailings to be placed in JEB Tailings Management Facility (TMF). The TMF will operate as a partially flooded pit with subaqueous tailings deposition. The TMF will not require a pervious surround. When tailings placement is complete, tailings will be covered and the pit will be backfilled with waste rock and revegetated.
	Volume/area	4.7 M m ³ of material removed to construct JEB Pit. Approx. 12 ha.
	Water treatment	Yes, all sump water from JEB Pit is pumped to JEB treatment plant. Sump water from Sue Pit is pumped to Sue treatment plant. Treated effluent from both plants and uncontaminated water from JEB dewatering wells is transferred to Sink/Vulture Treated Effluent Management System prior to discharge to surface water.
Site characterisation	Name	McClellan Lake project; Province of Saskatchewan Operated by Cogéma Resources Inc. Ownership: 70% Cogéma, 22.5% Denison Mines Ltd., 7.5% OURD (Canada) Co. Ltd.

McClellan Lake (contd)

Restoration costs	To date	N/A.
	Future	Estimates developed by Cogéma and approved by the CNSC and Saskatchewan Environment (SERM) based on conceptual decommissioning plan. Plan does not include undeveloped components including: Sue A and B Pits, McClellan underground mine, future Midwest and Cigar Lake ore processing at JEB mill. Plan includes numerical modelling to predict performance of flooded pits.
	Guarantees/ surety	Irrevocable letters of credit in place for CAD 35 million to the Province of Saskatchewan.
	Cost/benefit analysis	Yes.

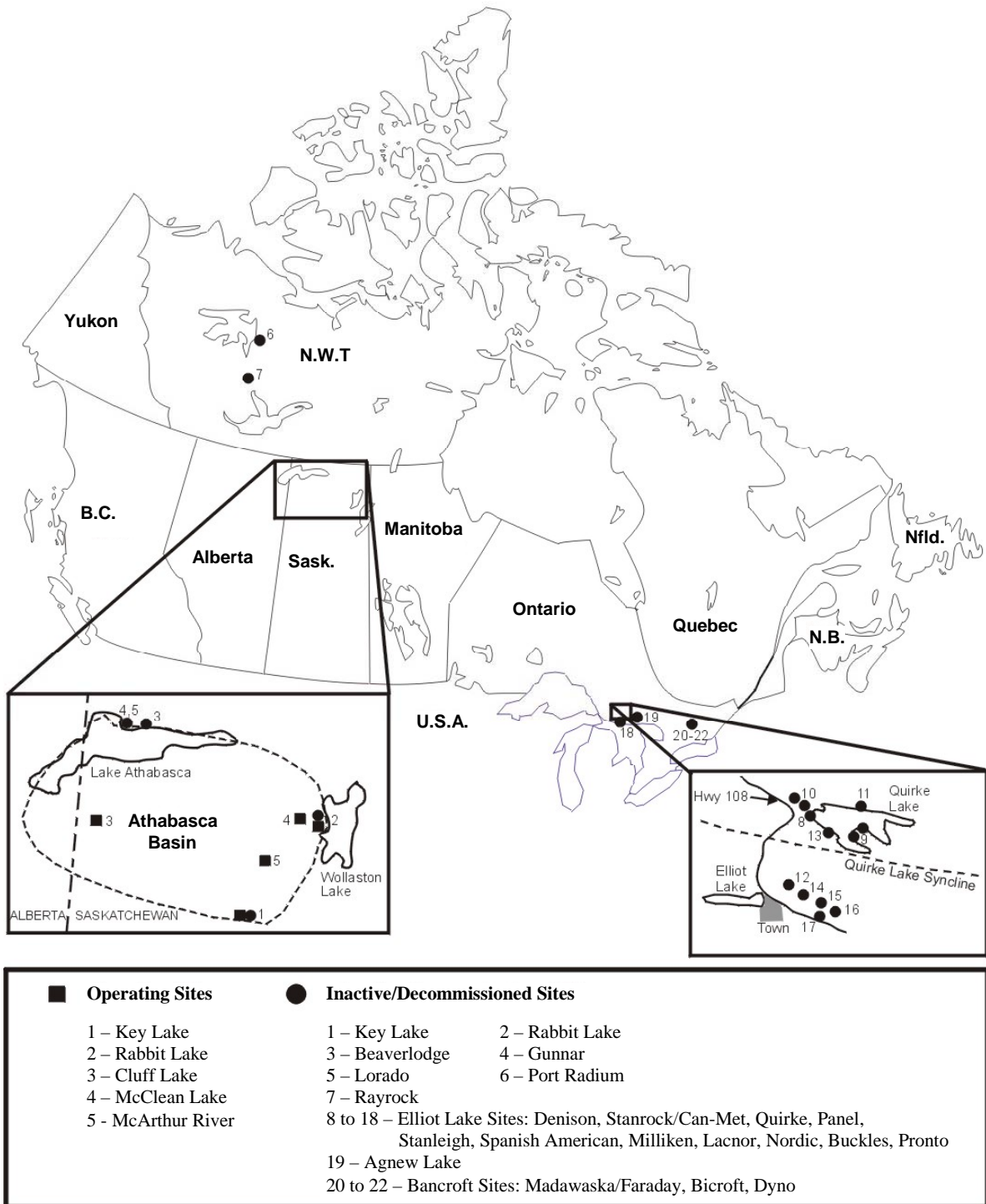
McArthur River

Site characterisation	Name	McArthur River Project; Province of Saskatchewan Operated by Cameco Corp. Ownership: 70% Cameco, 30% Cogéma.
	History	Discovered in 1988. World's largest high-grade uranium mine. Operating licence approved in October 1999.
	Activity type	Underground mine and ore processing facility.
	Current status	Hauling of ore to Key Lake site for milling began in December 1999. Licensed for 7 200 tonnes/year uranium. Site has a CNSC mining facility operating licence.
Contamination	Radiological	Predictions of radiation dose to nearest critical group from both aqueous and air emissions are well below allowable limits. Main radiological concern is control of radon progeny released from groundwater during underground activities. Control measures developed.
	Chemical	Some exceedences of metals and ammonia in water and/or sediment predicted in lakes near site. Far field effects predicted to be negligible.
Site characterisation	Name	McArthur River Project; Province of Saskatchewan Operated by Cameco Corp. Ownership: 70% Cameco, 30% Cogéma.

McArthur River (contd)

Environmental monitoring	Ongoing	Radiation protection monitoring including measurement of gamma radiation and radon progeny conducted in work areas throughout site. Personnel dosimetry monitoring also conducted. Monitoring of water quality at water treatment plant discharges and surface water sites for general parameters, radionuclides and metals. Air and terrestrial monitoring programme in place.
	Long-term	Monitoring after closure would continue until no longer required by regulatory agencies. Monitoring would include any water treatment systems, surface water and assessment of revegetation.
Rock dumps	Waste rock	Waste rock placed in storage area. 128 000 m ³ stockpiled at present. Estimated 900 000 m ³ to be stockpiled. Approximately 104 500 m ³ was used for site development.
	Special waste	Mineralised waste (>0.3% U) and acid-generating waste placed on lined storage pads. 25 000 m ³ and 74 000 m ³ respectively have been stockpiled to end of 1998. Mineralised special waste to be transferred to Key Lake for disposal.
	Ore	Ore is mined by raise boring. Ore cuttings ground and thickened underground. Ore slurry pumped to surface, loaded into containers and transported to Key Lake for milling.
Tailings – surface tailings	Description	No milling on site. Milling at Key Lake with tailings deposited to Deilmann Pit TMF.
	Size (volume, area)	N/A.
	Water treatment	All contaminated water from underground operations, dewatering, surface runoff and mineralised waste stockpiled is treated at Primary and Secondary Water Treatment Plants. Treated water discharged to monitoring ponds and released to lake if it meets effluent discharge limits.
Restoration costs	To date	Unknown.
	Future	Cost estimates developed by Cameco to support letters of credit.
	Guarantees/surety	Irrevocable letter of credit with sliding scale in place with current value of CAD 8.6 million.
	Cost/benefit analysis	Unknown.

Figure 1. Uranium mines and tailings sites in Canada



• Czech Republic •

Government policies and regulations

Government policy in uranium production

Exploration, production and processing of uranium ores are controlled by the state in the Czech Republic. Given the changes in domestic nuclear power plant needs, the negative developments on uranium production costs and the continuous declining tendency on uranium prices worldwide, the government decided to implement a stage by stage contraction of the uranium industry. A large-scale contraction programme was worked out that solves technical, social and environmental aspects of such production contraction and it is fully covered by the state.

The contraction programme started at the end of the 1980s and production was adapted to the Czech Republic reactor-related uranium requirements. The stage by stage reduction on uranium production solves mainly the social impacts in mining areas. Part of uranium concentrate production has been stored in the state material reserves. In accordance with an understanding between the Czech Republic and the European Union, the government decided to protect the domestic uranium market until 2001 to finish the production of selected deposits. Before 2001, licence measures prohibit any import of nuclear fuel that has not been derived from uranium mined in the country.

In accordance with the state policy of continuous improvement of the environment, the state is responsible for financing the remediation of effects from uranium exploration, mining and processing at old operations sites also called the “old reminders”.

Environmental laws and regulations applied to mining, decommissioning and remediation

General obligatory regulations

Acts

- Act No. 17/1992 Coll. (Collection of Laws), on the Environment.
- Act of CNR (Czech National Council – a part of the Parliament) No. 388/1991 Coll., on the State Fund for the Environment, in Act of CNR No. 334/1992 Coll.
- Act of CNR No. 282/1991 Coll., on the Czech Environmental Inspection and Its Activity in Forest Protection.
- Act of CNR No. 244/1991 Coll., on Environmental Impact Assessment (EIA).
- Act No. 123/1998 Coll., on Rights on Information about Environmental.
- Act No. 157/1998 Coll., Act on Chemical Agents and Chemical Products and on Changes of Same Act.

Regulation

- Regulation of MZP (Ministry of Environment) No. 499/1992 Coll., on Expert Qualification for EIA and on Method and Course of Public Hearings of Expert Opinions.

Air protection

Acts

- Act No. 309/1991 Coll., on Air Protection against Pollutants (Act on Air), in Act No. 218/1992 Coll. and in Act No. 158/1994 Coll., (full text Act No. 211/1994 Coll.).
- Act of CNR No. 389/1991 Coll., on State Administration of Air Protection and Charges for Its Pollution (full text in Act No. 212/1994 Coll.), in Act No. 86/1995 Coll.
- Act No. 38/1995 Coll., on Technical Conditions for Road Vehicle Traffic on Ground Thoroughfares.
- Act No. 86/1995 Coll., on Protection of the Earth Ozone Layer.

Regulations

- Regulation of MZP No. 41/1992 Coll., which Defines Areas of Special Air Protection and Sets Principles of Creation and Operation of Regulation Systems and Some Other Measures to Air Protection in MZP No. 279/1993 Coll.
- Regulation of MZP No. 117/1997 Coll., which Sets Emission Limits and Other Conditions for Operation of Stationary Pollution Sources and Air Protection.

Measure

- Measure of the Federal Committee for the Environment from October 1, 1991 to the Act No. 309 from July 9, 1991, on Air Protection against Pollutants (Act on Air), in Measure of the Federal Committee for the Environment from June 23, 1992 published in part 84/1992 Coll., in Regulation of MZP No. 122/1995 Coll. and Regulation of MZP No. 17/1997 Coll.

Water protection (water management)

Acts

- Act No. 138/1973 Coll., on Waters (Water Act), in Act CNR No. 425/1990 Coll., Act No. 114/1995 Coll., Act No. 14/1998 Coll. and Act No. 58/1998 Coll.
- Act of CNR No. 130/1974 Coll., on State Administration in Water Management, in Act of CNR No. 49/1982 Coll., Act of CNR No. 425/1990 Coll. and Act of CNR No. 23/1992 Coll., (full text Act of CNR No. 458/1992 Coll.), in Act of CNR No. 114/1995 Coll.
- Act No. 58/1998 Coll., on Charges for Discharge of Waste Waters to Surface Waters.

Directives of the government

- Directive of the government of the CR No. 100/1999 Coll., on Protection against Floods.
- Directive of the government of the CSR (Czech Socialist Republic) No. 35/1979 Coll., on Payments in Water Management, in Directive of the Government of the CSSR (Czechoslovak Socialist Republic) No. 91/1988 Coll., (full text Directive of the Government No. 2/1989 Coll.), in Act CNR No. 281/1992 Coll. and Act No. 58/1998 Coll.
- Directive of the Government of the CSR No. 85/1981 Coll., on Protected Areas on Natural Accumulations of Waters Cheb Basin and Slavkov Forest, Northbohemian Creataceous, Eastbohemian Creataceous, Police Basin, Trebon Basin and Quarternary of the Morava River.
- Directive of the Government of the CR No. 82/1999 Coll., which Sets Indices and Values of Admissible Level of Water Pollution.

Regulations

- Regulation of MLVH (Ministry of Forestry and Water) CSR No. 28/1975 Coll., which Sets Waterworks Streams and Their Catchment Areas and Sets a List of Waterworks Important Streams.
- Regulation of MLVH CSR No. 62/1975 Coll., on Expert Technical-Safety Advising on Some Waterworks and on Technical-Safety Advising of National Committees (Local Governments).
- Regulation of MLVH CSR No. 63/1975 Coll., on Duties of Organisations to Report on Groundwater Discoveries and to Report the Data on Their Use.
- Regulation of MLVH CSR No. 42/1976 Coll., on Managers of Water Supplies.
- Regulation of MLVH CSR No. 126/1976 Coll., on Water Management and Complete Water Mangement Recordkeeping.
- Regulation of MLVH CSR No. 6/1977 Coll., on Protection of Surface Waters and Ground Waters Quality.
- Regulation of MZP No. 47/1999 Coll., which provides application of the Act No. 58/1998 Coll., on Charges for Discharge of Waste Waters to Surface Waters.
- Regulation of MLVH CSR No. 19/1978 Coll., which Sets Duties of Waterstreams Administrators and Some Tasks Concerning Waterstreams.
- Regulation of MLVH CSR No. 144/1978 Coll., on Public Water Supply Systems and Public Sewerages, in Regulation of MLVH DP CSR No. 185/1988 Coll.

Waste management

Act

- Act No. 125/1997 Coll., on Wastes.

Regulations

- Regulation of MZP No. 337/1997, which Publishes a Catalogue of Wastes and Sets Other Lists of Wastes (Catalogue of Wastes).
- Regulation of MZP No. 338/1997, on Details in Waste Management.
- Regulation of MZP No. 339/1997, on Assessment of Dangerous Features of Wastes.
- Regulation of MZP No. 340/1997, which Sets Amounts of Financial Reserves for Recultivation, Waste Dump Care Assurance and Remediation after Its Operation and Details of Its Development and Use.
- Regulation of CBU (Czech Bureau of Mines) No. 99/1992 Coll., on Establishing, Operation, Assurance and Decommissioning of Operations for Deposition of Wastes in the Underground.

Nature and land protection

Act

- Act of CNR No. 114/1992 Coll., on Nature and Land Protection in Act Measure of CNR Presidium No. 347/1992 Coll., Act No. 289/1995 Coll., Finding of the Constitutional Court of the CR No. 3/1997 Coll., Act No. 16/1997 Coll., Act No. 123/1998 Coll., and Act No. 161/1999 Coll.

Regulation

- Regulation of MZP No. 395/1992 Coll., in Regulation of MZP No. 105/1997 Coll., which provides application of Some Provisions of the Act of the CNR No. 114/1992 Coll., on Nature and Landscape Protection.

Protection of agricultural land

Act

- Act of CNR No. 334/1992 Coll., on Protection of Agricultural Land, as results from changes and additions to the Act CNR No. 10/1993 Coll. and the Act No. 98/1999 Coll.

Regulation

- Regulation of MZP No. 13/1994 Coll., which Sets Some Details of Protection of Agricultural Land.

Forestry

Acts

- Act No. 289/1995 Coll., on Forests and on Changes and Additions to Some Acts (Forestry Act).
- Act of CNR No. 282/1991 Coll., on the Czech Environmental Inspection and Its Activity in Forest Protection.

Regulations

- Regulation of MZe (Ministry of Agriculture) No. 82/1996 Coll., on Genetic Classification, Forest Renovation, Forestry and on Recording of Forest Wood Species Seed and Seedling Treatment.
- Regulation of MZe No. 77/1996 Coll., on Requirements on Application for Taking off or Restriction and on Details of Protection of Land Appointed to Forestry.

Rock environment protection

Acts

- Act No. 44/1988 Coll., on Protection and Use of Raw Materials (Mining Act), in Act of CNR No. 541/1991 Coll. (full text in No. 439/1992 Coll. in application for the CR) and Changes Resulting from the Act of CNR No. 10/1993 Coll. and the Act No. 168/1993 Coll.
- Act of CNR No. 61/1988 Coll., on Mining Activities, Explosives and State Mining Administration, in Act of CNR No. 425/1990 Coll. and Act CNR No. 542/1991 Coll. (full text for the CR Regulation in Act No. 440/1992 Coll.) and Act No. 169/1993 Coll.
- Act of CNR No. 62/1988 Coll., on Geological Works and on the Czech Geological Office, in Act of CNR No. 543/1991 Coll. a No. 369/1992 Coll.

Regulations

- Regulation of CBU No. 104/1988 Coll., on Rational Use of Deposits of Prescribed Minerals, on Licensing and Registration of Mining Activities and Registration of Activities Done by Mining Way, in Regulation of CBU No. 242/1993 Coll.
- Regulation of CBU No. 172/1992 Coll., on Mining Claims.
- Regulation of MZP CR No. 364/1992 Coll., on Protected Area of Raw Material Deposits.
- Regulation of CBU No. 15/1995 Coll., on Mining Licences.
- Regulation of CBU No. 52/1997 Coll., which Sets Requirements to Assure Safety and Health Protection at Work and Work Safety during Decommissioning of Main Mine Workings.
- Regulation of CBU No. 158/1997 Coll., which Changes and Adds Regulation CBU No. 435/1992 Coll., on Mine Survey Documentation (Recordkeeping) during Mining Activities and Some Activities Done by Mining Way.

Ionising radiation

Act

- Act No. 18/1997 Coll., on Peaceful Use of Nuclear Energy and Ionising Radiation (Atomic Act) and on Changes and Additions to Some Acts.

Regulations

- Regulation of SUJB (State Office for Nuclear Safety) No. 146/1997 Coll., which Sets Activities Having Direct Influence on Nuclear Safety and Activities Especially Important for Radiation Protection, Request on Qualification and Professional Preparation, Ways to Evaluate Expert Qualification and Giving Permits to Selected Workers and Way of Carrying Out of Approved Documentation for Permits to Preparation of Selected Workers.
- Regulation of SUJB No. 184/1997 Coll., on Requirement for Assurance of Radiation Protection.
- Regulation of SUJB No. 214/1997 Coll., on Quality Assurance during Activities Associated with Use of Nuclear Energy and Activities Resulting in Irradiation and on Setting of Criteria for Classification and Sorting of Selected Equipment into Safety Classes.
- Regulation of SUJB No. 196/1999 Coll., on Decommissioning of Nuclear Installations or Workplaces with Significant or Very Significant Ionising Radiation Sources.

Others

Acts

- Act No. 13/1997 Coll., on Ground Thoroughfares in Act No. 259/1998 Coll.
- Act No. 77/1997 Coll., on State-Owned Enterprise.
- Act No. 19/1997 Coll., on Some Measures Associated with Prohibition of Chemical Weapons and on Change and Addition to Act No. 50/1976 Coll., on Territorial Planning and Building Order (Building Act), in later versions, Act No. 455/1991 Coll., on Business Activities (Business Act), in later versions and Act No. 140/1961 Coll., Criminal Act, in later versions.
- Act No. 197/1998 Coll., on Territorial Planning and Building Order (full text in Act No. 50/1976 Coll. with its changes and additions).

Hygiene

Act

- Act No. 20/1966 Coll., on Healthcare of People in changes and additions of Acts No. 60/1995 Coll., No. 14/1997 Coll., No. 206/1996 Coll., No. 79/1997 Coll., No. 110/1997 Coll., No. 83/1998 Coll. No. 167/1998 Coll. (full text Act No. 20/1966 Coll. – Act No. 86/1992 Coll.).

Regulations

- Regulation of MZd (Ministry of Health) No. 45/1966 Coll., on Creation and Protection of Healthy Living Conditions in changes and additions of Acts No. 146/1971 Coll., No. 185/1990 Coll., No. 14/1998 Coll., No. 292/1998 Coll.
- Regulation of MZd No. 13/1977 Coll., on Protection of Health Against Unfavourable Influence of Noise and Vibrations.

Explanatory notes on State Institutions and State Administrative Bodies active in Decommissioning and Remediation:

1. Ministry of Industry and Trade of the Czech Republic (CR) – founder of DIAMO, state-owned enterprise, superior authority, which sets tasks arising from government decrees, approves concepts, projects, realisation conditions and financing.
2. Ministry of Environment of the CR, Regional Offices (Departments) – execution of state administration and supervision in the area of environment.
3. Czech Environmental Inspection – checks adherence to regulations and decisions of administration bodies for the environment. It sets conditions and deadlines for tasks and gives penalties.
4. Office for Environment in County Authority – sets conditions for activities in environment, checks adherence to regulations and issued decisions, sets measures and deadlines for improvement of the status.
5. Czech Bureau of Mines / Regional Bureau of Mines – state administration and supervision in organisations with mining activities.
6. State Office for Nuclear Safety – state administration and supervision for use of nuclear energy, activities resulting in irradiation and nuclear items.
7. Regional and County Hygienic Stations – hygienic supervision for Ministry of Health.
8. Ministry of Industry and Trade, Building Bureau for Uranium Industry – administrative direction for building in uranium industry in areas appointed for these purposes.

Historical overview of decommissioning and remediation activities

The first important decommissioning and remediation works after uranium mining were performed in the 1950s. These works were usually performed after depletion of the deposit or after finishing of exploration, production and processing activities. Uranium mines Jachymov, Horni Slavkov, Open Cast Hajek, processing plant Nejdek and others are examples. Because these remediation works were not always sufficient, they were marked as “Old Reminders”. During 1993 and 1997, an inventory of these Old Reminders was carried out. Since 1998, the Remediation Project for Old Reminders of the Uranium Industry has been implemented. This project is planned to end by 2007 and should cost about 232.3 million CZK (6.6 million USD).

The biggest volume of decommissioning and remediation works corresponds to the contraction programme of Czecho-Slovak uranium industry. Works will continue approximately until 2040 and should cost more than 60 billion CZK (1.7 billion USD).

The first production contraction programme was approved by the former Czechoslovak Federal Government in 1989. The main reasons for implementing a contraction programme were high costs of low-grade deposits, complicated mining-geological and hydrogeological conditions and unfavourable conditions on the uranium market. The contraction programme consists of:

- Finishing uranium exploration in Czechoslovakia.
- Continuous decrease of mining volumes and uranium concentrate production.
- Financing this programme by the state without further contribution to production.
- Deposition of uranium concentrate overproduction to state reserves.
- Starting the time schedule of close out for mines and mills.

- Restructuring of uranium industry.
- Decreasing the number of employees and developing replacement activities for free employees at the same time.

Given the changes in domestic nuclear energy needs, long-term unfavourable development of production costs and continuous decrease of uranium market prices, the government has issued other decrees deepening and speeding up the contraction programme. Production decreased step by step to 23% of 1989 production, to about 600 tU a year in 1999. Almost 90% of employees were discharged to the 1999 level of 3779. In 1992, the state stopped financing of uranium production. The state covers only costs of decommissioning and remediation activities, costs related to the Old Reminders from the past and costs of the social part of the contraction programme.

Overview of the government decrees to uranium production contraction programme in the Czech Republic

1. *Decree of the Presidium of the Government of the Czechoslovak Socialist Republic (from October 19, 1989 No. 94)* – on the concept for a decrease in uranium production profitability in the USSR in 1990, during the 9th and the 10th five-year plan of the production contraction programme.
2. *Decree of the Government of the Czech and Slovak Federal Republic (from December 17, 1990 No. 894)* – on the change in concept of the production contraction programme in the CSFR in consequence with nuclear power production needs and the report on the checking of conditions for implementation of the contraction programme in 1990 and 2000.
3. *Decree of the Government of the Czech Republic (from December 20, 1991 No. 533)* – on realisation of changes in the concept of uranium production in consequence with the Czechoslovak nuclear power production needs in 1992 and following years.
4. *Decree of the Government of the Czech Republic (from May 20, 1992 No. 366)* – in relation to results of a complex evaluation of uranium ISL in Ceska Lipa region and following course of work to set the way of production and remediation of the deposit.
5. *Decree of the Government of the Czech Republic (from August 11, 1993 No. 429)* – on change of the production contraction programme concept and mothballing of the Hamr I Mine.
6. *Decree of the Government of the Czech Republic (from April 26, 1995 No. 244)* – on the realisation of uranium production and processing contraction programme in the Czech Republic.
7. *Decree of the Government of the Czech Republic (from March 6, 1996 No. 170)* – on reporting the course of uranium ISL remediation in Straz pod Ralskem.
8. *Decree of the Government of the Czech Republic (from July 16, 1997 No. 427)* – on reporting the evaluation of uranium mining and processing in the area of Dolni Rozinka and following course in this case.
9. *Decree of the Government of the Czech Republic (from July 21, 1999 No. 750)* – on reporting the prolongation of uranium production contraction for 4 years with possibility of production from easily mineable reserves on the presently closed-down mines.

**Time overview of the special regime beginning
for production, mothballing and close-out of mines and mills**

Area	Starting date		
	Mine/Mill	Special regime	Mothballing
Uranium mines Western Bohemia			
Okrouhla Radoun Mine	–	–	April 1, 1990
Dylen Mine	–	–	January 1, 1991
Vitkov II Mine	–	–	January 1, 1991
Zadni Chodov Mine	–	–	January 1, 1993
Uranium mines Pribram			
Mine III	–	–	July 1, 1990
Mine IV	–	–	October 1, 1991
Uranium mines Dolni Rozinka			
Olsi Mine	–	–	January 1, 1989
RI, RII Mines	–	–	January 1, 2002*
Uranium mines Hamr			
Krizany Mine	–	–	May 1, 1990
Hamr I Mine	–	July 1, 1993	May 1, 1995
ISL Mine Straž pod Ralskem	July 1, 1992	–	March 1, 1996
Mills			
MAPE Mydlovary	–	–	November 1, 1991
CHU Straž pod Ralskem	–	July 1, 1993	May 1, 1995
CHU Dolni Rozinka	–	–	January 1, 2002*
Uranium Exploration			
Exploration Mine Licomerice	–	–	January 1, 1986
Exploration Mine Brzkov	–	–	July 1, 1990
Exploration Mine Pucov	–	–	July 1, 1990
Exploration Mine Novoveska Huta**	–	–	January 1, 1991

* Dates given by the decree of the Government of CR from July 16, 1997 No. 427.

** Uranium mine facilities in Slovakia.

Facilities with on-going or future plans for restoration activities

Okrouhla Radoun mine

Facility characterisation

- Short history: Production between 1972 and 1990. 2 mining shafts, 3 prospecting shafts and 41.6 km horizontal mine workings. Mining claim 1.4 km². Depth of mining 600 m under the surface. 1 339.5 tU produced. Ore was processed in MAPE Mydlovary mill.
- Type of activity: Uranium deep mining. Method – overhand stopping with backfill and underhand stopping. Soda leaching of low grade ores on the surface.
- Present status: Mine decommissioned, underground flooded, surface decontaminated and reclaimed. Usable buildings sold.

Environmental problems and their solutions

Mine waters: discharge of contaminated mine water after mine flooding. Direct pumping and treatment of discharging water.

Type of water	Amount	Main and secondary contaminants	
Neutral waters pumped from mine	71 000 m ³ /year ⁻¹	pH = 6.8 – 7.0 U = 1.3-11.3 g.m ⁻³ ²²⁶ Ra = 600 – 1 450 Bq.m ⁻³ TDS = 0.8-1.1 kg.m ⁻³	SO ₄ ²⁻ , Cl ⁻ , Fe

Tailings impoundments

None.

Waste rock dumps

Type: waste rock only; volume of deposited material: 700 000 m³; area: 45 000 m²; status: reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. The main monitored items are:

- Mine waters: U, Ra, TSS, TDS, BCO₅.
- Air: falling dust – U, Ra and volume activity of Rn.

Costs

Decommissioning and remediation (1990-1998)	44.9 million CZK (1.3 million USD)
Pumping and treatment of water, monitoring maintenance (1999-2006)	11.3 million CZK (0.3 million USD)
Total (1990-2006)	56.2 million CZK (1.6 million USD)

Dylen mine

Facility characterisation

- Short history: Production between 1965 and 1991. At the beginning – open pit, then 2 shafts and 28.2 km of horizontal mine workings. Area of mining claim was 0.539 km². Depth of mining was 1 200 m under the surface. Total production: 1 100.5 tU. Ore was processed in MAPE Mydlovary mill.
- Type of activity: Uranium open pit and deep mining. Method – open room, overhand stopping on ore and overhand stopping with delayed backfill.
- Present status: Mine decommissioned, underground flooded, surface decontaminated and partly reclaimed.

Environmental problems and their solutions

Mine waters: Flooded mine. No discharge to the surface.

Waste rock dumps

Type: waste rock only; volume of deposited material: 218 000m³; area: 20 000 m²; status: partly processed to crushed stone, partly reclaimed.

Tailings impoundments

None.

Costs

Decommissioning and remediation (1991-1998)	22.8 million CZK (0.7 mil. USD)
End of area remediation (1999-2002)	3.0 million CZK (0.1 mil. USD)
Total (1993-2002)	25.8 million CZK (0.8 mil. USD)

Vítkov II mine

Facility characterisation

- Short history: Mining between 1961 and 1991. 2 shafts, 2 prospecting shafts and 83.0 km of horizontal mine workings. Area of mining claim was 0.990 km². Depth of mining was 1 050 m under the surface. Total production: 3 972.6 tU. Ore was processed in MAPE Mydlovary mill.
- Type of activity: Uranium deep mining. Method – overhand stopping with backfill and underhand stopping. Partly also open pit.
- Present status: Mine decommissioned, underground flooded, surface decontaminated and reclaimed. Useful buildings prepared to sale or dismantling.

Environmental problems and their solutions

Mine waters: seepage of contaminated mine water to the surface after mine flooding. Corrective action performed (cementing of drillholes). Monitoring.

Type of water	Amount	Main and secondary contaminants	
Neutral mine waters	0 m ³ /year ⁻¹	PH = 6.8-7.0 U = 0.02-0.74 g/m ⁻³ ²²⁶ Ra = 40-3 490 Bq/m ⁻³ TDS = 0.7-1.0 kg/m ⁻³	SO ₄ ²⁻ , Cl ⁻ , Fe

Tailings impoundments

None.

Waste rock dumps

Removed (crushed stone). Area reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: U, Ra, TSS, TDS, BCO₅.
- Air: falling dust – U, Ra.

Costs

Decommissioning and remediation (1991-1998)	39.3 million CZK (1.1 mil. USD)
Close out and remediation (1999-2005)	54.3 million CZK (1.6 mil. USD)
Pumping and treatment of water, monitoring, maintenance (1999-2015)	35.7 million CZK (1.0 mil. USD)
Total (1991-2015)	129.3 million CZK (3.7 mil. USD)

Zadni Chodov mine

Facility characterisation

- Short history: Mining between 1953 and 1993. 5 shafts and 167.4 km of horizontal mine workings. Area of mining claim was 7.2 km². Depth of mining was 1 200 m under the surface. Total production: 4 150.7 tU. Ore was processed in MAPE Mydlovary mill.
- Type of activity: Uranium deep mining. Method – overhand stopping with backfill and underhand stopping without backfill (caving-in under artificial roof).
- Present status: Mine decommissioned, underground flooded, surface decontaminated and partly reclaimed. Waste rock dumps are processed into crushed stone. Usable buildings are prepared for sale or dismantling.

Environmental problems and their solutions

Mine waters: seepage of contaminated mine water to the surface after mine flooding. Pumping and treatment of water.

Type of water	Amount	Main and secondary contaminants	
neutral waters pumped from mine workings	314 200 m ³ /year ⁻¹	pH = 6.8-7.3 U = 2.8-9.3 g.m ⁻³ ²²⁶ Ra = 3 120-6 225 Bq.m ⁻³ TDS = 1.35-1.45 kg.m ⁻³	SO ₄ ²⁻ , Cl ⁻ , Fe

Tailings impoundments

None.

Waste rock dumps

- Type: waste rock dumps.
- Volume of deposited material: 2 581 900 m³.
- Area: 227 270 m².
- Status: being removed (being processed to crushed stone), not reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: U, Ra, TDS, pH.
- Air: falling dust - U, Ra.

Costs

Decommissioning and remediation (1993-1998)	76.8 million CZK (2.2 mil. USD)
Close out and remediation (1999-2005)	143.3 million CZK (4.1 mil. USD)
Pumping and treatment of water, monitoring, maintenance (1999-2015)	75.1 million CZK (2.2 mil. USD)
Total (1993-2015)	295.2 million CZK (8.5 mil. USD)

Horni Slavkov mine

Facility characterisation

- Short history: Mining between 1948 and 1962. 26 shafts and 30 adits. Area of mining claim was 21.7 km². Total production: 2 668.3 tU. Ore was processed in gravity processing plant Elias, Bratrstvi and in chemical processing plant Nejdek.
- Type of activity: Uranium deep mining. Method – overhand stopping with backfill.
- Present status: Mine decommissioned, underground flooded, surface decontaminated and reclaimed. Old reminder.

Environmental problems and their solutions

Mine waters: continuous discharge of contaminated mine water from flooded non uranium and uranium mines in the area. New drainage system and treatment plant was built.

Type of water	Amount	Main and secondary contaminants	
neutral water pumped from mine workings	6 401 800 m ³ /year ⁻¹	pH = 6.0 - 6.3 U = 3.0 - 5.9 g.m ⁻³ ²²⁶ Ra = 300 – 600 Bq.m ⁻³ TDS = 0.49 - 0.52 kg.m ⁻³	SO ₄ ²⁻ , Fe, Mn

Tailings impoundments

None.

Waste rock dumps

- Type: Waste rock dumps.
- Volume of deposited material: 4 382 968 m³.
- Area: 645 900 m².
- Status: naturally forested.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: U, Ra, TSS, TDS, SO₄, Fe, Mn.
- Air: volume activity of Rn.

Costs

New remediation measure – construction of drainage adit and water treatment plant (1994-1999)	120.6 million CZK (3.5 million USD)
Continuous water treatment, monitoring, maintenance	7.5 million CZK/year (0.2 million USD/year)

Nejdek Tailings impoundment

Facility characterisation

- Short history: tailings impoundments of former chemical processing plant in Nejdek. In operation between 1952 and 1959. Acid leach process. Capacity 270 t/day.
- Type of activity: chemical processing plant tailings deposition.
- Present status: processing plant is decommissioned. Tailings impoundment covered by inert material and forested. Old Reminder.

Environmental problems and their solutions

Mine waters: discharge of approximately 10 l.s⁻¹ of contaminated water from tailings impoundment (content of U = 0.3-1.6 mg.l⁻¹, ²²⁶Ra = 478 mBq.l⁻¹).

Tailings impoundment

- Volume of deposited material: 852 000 m³.
- Area: 135 000 m².
- Status: Inflow of surface and ground water into tailings impoundment. Influence on Rolava River. Inconvenient drainage and capture system. Danger of instability of dams. Reconstruction of drainage system.

Waste rock dumps

None.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Drainage waters: U, Ra, TSS, TDS.
- Air: volume activity of Rn.

Costs

New remediation measures – reconstruction of drainage system	7.5 million CZK (0.2 million USD)
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Elias tailings impoundment

Facility characterisation

- Short history: Tailings impoundment of former physical processing plant Elias in the area of Jachymov. In operation between 1949 and 1962.
- Type of activity: Gravity processing plant tailings deposition.
- Present status: Processing plant is decommissioned. Tailings impoundment is closed-out. Partly forested. Old reminder.

Environmental problems and their solutions

Mine waters: discharge of contaminated water from tailings impoundment (content of U = 0.3-1.6 mg.l⁻¹, ²²⁶Ra = 475 mBq.l⁻¹).

Tailings impoundments

- Volume of deposited material: 1 467 000 m³.
- Area: 105 000 m².
- Status: Inflow of surface and ground water into tailings impoundment. Influenced by Eliassky creek. Inconvenient drainage and capture system. Danger of instability of dams. Reconstruction of drainage system.

Waste rock dumps

None.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Drainage waters: U, Ra, TSS, TDS.
- Air: volume activity of Rn.

Costs

New remediation measures – reconstruction of drainage system	7.5 million CZK (0.2 million USD)
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Hajek open pit

Facility characterisation

- Short history: Uranium open pit between 1965 and 1966 and 1968 and 1971. Total production 202.7 tU and basalt (846 458 m³), kaolin (243 617 m³) and bentonite (5 325 m³). Depth of open pit was 85 m. Mining claim 0.73 km². Between 1966 and 1968, 5 000 t of ballast isomers and chlorinebenzen from chemical production of HCH (hexachlorine-cyklohexane) of SPOLANA Neratovice was deposited on the dump.
- Type of activity: Deposition of waste rocks from uranium open pit mining on the dump.
- Present status: Open pit decommissioned. Surface decontaminated and reclaimed. Old Reminder.

Environmental problems and their solutions

Mine waters: discharge of contaminated water from the dump. New remediation measures:

- 1st stage – insulation, drainage, efficiency evaluation.
- 2nd stage – new drainage and capture system for water.

Tailings impoundments

None.

Waste rock dumps

- Type: waste rock dump.
- Volume of deposited material: 7 000 000 m³.
- Area: 120 000 m².
- Status: reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Waste rock dump drainage water: HCH (hexachlorinecyklohexane), CB (chlorinebenzen), isomers.

Costs

Monitoring, risk analysis (1993-1998)	3.1 million CZK (0.1 million USD)
New remediation measures	
I. Stage (1999-2000)	63.0 million CZK (1.8 million USD)
II. Stage (up to 2002)	Not specified yet
Total (1993-2000)	66.1 million CZK (1.9 million USD)

Příbram Mines

Facility characterisation

- Short history: Production between 1950 and 1991. 41 shafts (14 winzes), 42 exploration small shafts, 4 adits and 2 188.3 kms of horizontal mine workings. Area of mining claim was 57.6 km². Depth of mining was approximately 1 400 m under the surface (deposit extent to the depth of 1 750 m). Total production: 48 432.2 tU. Ore was processed in physical processing plant on site and from 1962 in MAPE Mydlovary mill.

- After production ended (1992-1998) underground of one of mines (Mine IV, shaft No. 16) was used for cavern gas storage development (capacity of 620 000 m³).
- Type of activity: Uranium deep mining. Method – overhand stopping with backfill and selective mining. Physical processing of ore.
- Present status: Mines decommissioned, underground is being flooded (until 2007), surface partly reclaimed. Waste rock dumps are processed into crushed stone. Usable buildings are prepared for sale or dismantling.

Environmental problems and their solutions

Mine waters: seepage of mine waters after mine flooding. Pumping and water treatment of seeping water (from mines, waste rock dumps, tailings impoundments). Loss of water in local waterstreams (Pribram brook, K Sazkam brook etc.) due to mining activities. Remediation measures.

Type of water	Amount	Main and secondary contaminants	
neutral waters pumped from mine workings	698 600 m ³ /year ⁻¹	pH = 6.9 - 7.1 U = 2.1 - 4.9 g.m ⁻³ ²²⁶ Ra = 1 355-1 620 Bq.m ⁻³ TDS = 0.8-1.2 kg.m ⁻³	SO ₄ ²⁻ , HCO ₃ ⁻ , Fe, Mn

Tailings impoundments

Name	Area m ²	Deposited volume m ³	Status
KI	330 000	98 800	partly reclaimed
KII	111 000	152 500	not reclaimed

Waste rock dumps

- Type: Waste rock dumps.
- Area: 1 457 700 m².
- Volume of deposited material: 30 071 800 m³.
- Status: being removed (processed to crushed stone), not reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published.

Main monitored items:

- Mine waters: U, Ra, TSS, TDS.
- Surface waters: U, Ra, TSS, TDS, CHCO, BCO₅, heavy metals.
- Waste rock dumps seepage waters: U, Ra, TDS, TSS, pH, SO₄, heavy metals.
- Air: falling dust - U, Ra, volume activity of Rn, and equivalent volume activity of Rn.

Costs

Decommissioning and remediation (1990 - 1998)	324.7 million CZK (9.3 million USD)
Close out and remediation (1999-2007)	551.7 million CZK (15.8 million USD)
Water treatment, monitoring, maintenance (after 2007)	Not specified yet
Total (1990-2007)	876.4 million CZK (25.0 million USD)

Olsi mine

Facility characterisation

- Short history: Mining between 1959 and 1989. 5 shafts (3 winzes), 2 adits, 3 exploration shafts and 141.4 km horizontal mine workings. Area of mining claim was 6.29 km². Total production: 2 922.2 tU. Depth of mining was 900 m under the surface.
- Type of activity: Uranium deep mining. Method – underhand stopping with caving-in under artificial roof and selective mining.
- Present status: Mine decommissioned, underground flooded, surface decontaminated and partly reclaimed. Usable buildings sold.

Environmental problems and their solutions

Mine waters: seepage of contaminated mine waters after mine flooding. Pumping and treatment of seeping waters.

Type of water	Amount	Main and secondary contaminants	
Neutral waters pumped from mine workings	234 100 m ³ /year ⁻¹	PH = 7.0-8.3 U = 1.4-4.0 g/m ⁻³ ²²⁶ Ra = 80-160 Bq/m ⁻³ TDS = 1.0-2.15 kg/m ⁻³	SO ₄ ²⁻ , NO ₃ ⁻ , NO ₂ ⁻ Fe, Mn, NH ₄ ⁺

Tailings impoundments

None.

Waste rock dumps

- Type: waste rock dumps.
- Area: 125 000 m².
- Volume of deposited material: 800 000 m³.
- Status: partly reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Surface waters (Haduvka river): U, Ra, NH₄, pH, SO₄, TDS, NO₃, NO₂, Fe, Mn.
- Groundwater: U, Ra, NH₄.
- Drainage water from dumps: U, Ra, SO₄, TDS.
- Air: falling dust – U, Ra.
- Volume activity of Rn.

Costs

Decommissioning and remediation (1989-1998)	178.1 million CZK (5.1 million USD)
Remediation finish, water treatment, monitoring, maintenance (1999-2015)	116.3 million CZK (3.3 million USD)
Total (1989-2015)	294.4 million CZK (8.4 million USD)

Rozna mines

Facility characterisation

- Short history: Production started in 1958 and still continues. Since 1968 chemical processing plant and two tailings impoundments have been in operation. 15 978 tU were produced as of 1 January 2000 at the deposit. Deposit is opened with 11 shafts and there are 493.4 km of mine workings. Depth of mining is 1 200 m under the surface. Mining claim has 12 km².
- Type of activity: Uranium deep mining. Method – underhand stopping with caving-in under artificial roof, overhand stopping with backfill and selective mining. Chemical processing plant and tailings impoundments. Alkaline leaching process.
- Present status: In depleted parts of the deposit, decommissioning and remediation are being performed (mine workings, waste rock dumps, tailings impoundments, not usable buildings). Production is planned until 2001 (The Government of the CR decree No. 427/1997).

Environmental problems and their solutions

Mine waters: seepage of contaminated waters. Pumping and water treatment due to mining activities.

Type of water	Amount	Main and secondary contaminants	
neutral waters pumped from mine workings	1 972 500 m ³ .year ⁻¹	pH = 6.8-8.8 U = 2.3-6.8 g/m ⁻³ ²²⁶ Ra = 60-610 Bq/m ⁻³ TDS = 1.1-2.05 kg/m ⁻³	SO ₄ ²⁻ , Cl ⁻ , NO ₃ ⁻ , Fe

Tailings impoundments

Name	Area m ²	Deposited volume m ³	Status
Rozna KI	627 500	9 211 115	in operation
Zlatkov KII	274 400	851 195	in operation

Waste rock dumps

Name and type	Area m ²	Deposited volume m ³	Status
Rozna 1 (waste rock)	85 000	600 000	partly reclaimed
"	28 000	200 000	partly reclaimed
"	8 200	20 000	partly reclaimed
"	10 000	0	reclaimed

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: U, Ra, TSS, pH, TDS, SO₄, NO₃, Cl, BCO₅, Fe, Mn.
- Groundwater: U, Ra, pH, SO₄, TDS, heavy metals, PCB.
- Air: falling dust – U, Ra, volume activity of Rn, equivalent volume activity of Rn, NH₃ and H₂S – technological emissions from uranium mill.
- Contamination of soils: heavy metals (Cu, Zn, Ni, Cr, Cd, Pb), gamma dose input.
- Contamination of agricultural products: U, Ra, Zn, Cu, Ni.

Costs

Decommissioning and remediation (1993-1998)	213.9 million CZK	(6.1 million USD)
Decommissioning and remediation (1999-2020)	5 847.8 million CZK	(167.1 million USD)
Water treatment, monitoring, maintenance (2002-2030)	87.2 million CZK	(2.5 million USD)
Total (1993-2030)	6 148.9 million CZK	(175.7 million USD)

Brzkov mine

Facility characterisation

- Short history: Production during detailed exploration programme between 1988 and 1990. 1 shaft, small open cast and 6.6 kms of horizontal mine workings. Area of mining was 6.29 km². Total production: 65.3 tU. Depth of mining was 300 m under the surface.
- Type of activity: Deposit exploration. Mining method – overhand stopping. Open cast.
- Present status: Exploration ended. Deposit mothballed until 2001. Mine partly reclaimed, partly decommissioned, underground flooded, surface decontaminated and partly reclaimed.

Environmental problems and their solutions

Mine waters: flooded mine. No seepage to the surface.

Tailings impoundments

None.

Waste rock dumps

- Type: ore dump.
- Area: 24 800 m².
- Volume of deposited material: 80 000 m³ (taken into account for U reserves on the deposit).
- Status: not reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: U, Ra, pH, TSS, Fe, Mn, SO₄.
- Drainage water from dumps: U, Ra, pH, TSS, Fe, Mn, SO₄.
- Groundwater: U, Ra, pH, TSS, Fe, Mn, TDS.

Costs

End of decommissioning and remediation after 2001: 25 million CZK (0.7 million USD).

Pucov mine

Facility characterisation

- Short history: Production in the frame of exploration in 1963-1967 and 1974-1991. 1 shaft, 3 exploration small shafts, 2 adits, open cast and 15.4 kms of horizontal mine workings. Area of mining claim was 0.278 km². Total production 311.2 tU. Depth of mining was 400 m under the surface.
- Type of activity: Deposit exploration. Mining method – underhand stopping with caving-in, locally overhand stopping. Open cast.
- Present status: Exploration and production ended. Mine partly decommissioned, underground flooded, surface decontaminated and partly reclaimed.

Environmental problems and their solutions

Mine waters. Seepage of contaminated mine water after mine flooding. Pumping and water treatment.

Type of water	Amount	Main and secondary contaminants	
Neutral waters pumped from mine workings	151 800 m ³ /year ⁻¹	PH = 6.75 U = 0.18 g/m ⁻³ ²²⁶ Ra = 500 Bq/m ⁻³ TDS = 1.0 kg/m ⁻³	SO ₄ ²⁻ , Fe, Mn

Tailings impoundments

None.

Waste rock dumps

- Type: waste rock dump.
- Area: 48 000 m².
- Volume of deposited material: 150 000 m³.
- Status: reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: U, Ra, pH, TSS, TDS, Fe, Mn.
- Surface waters: U, Ra, pH, TSS, TDS, Fe, Mn.
- Groundwater: U, Ra, pH, TSS, TDS, SO₄, Fe, Mn.

Costs

Decommissioning and remediation(1992-1998)	30.8 million CZK (0.9 million USD)
End of decommissioning and remediation, water treatment, monitoring, maintenance (1999-2014)	60.4 million CZK (1.7 million USD)
Total (1992-2014)	91.2 million CZK (2.6 million USD)

Licomerice mine

Facility characterisation

- Short history: Production between 1968 and 1982. Between 1977 and 1985 biological leaching in the underground and on the surface with use of mine water was performed (pH=3-4 with free H₂SO₄) and aerobic bacteria (thiobacillus ferrooxidalis). 2 shafts (1 winze), 1 adit and 9 km of horizontal mine workings. Area of mining claim was 0.348 km². Total production: 383.3 tU.
- Type of activity: Uranium deep mining. Method – underhand stopping with caving-in and overhand stopping with backfill. Biological leaching on the surface and in the underground.
- Present status: Mine decommissioned, underground flooded, surface partly reclaimed.
- Old Reminder.

Environmental problems and their solutions

Mine waters. Seepage of contaminated mine waters after mine flooding. Pumping and water treatment.

Type of water	Amount	Main and secondary contaminants	
neutral mine waters pumped from mine workings	76 200 m ³ /year ⁻¹	pH = 5.5 U = 0.2 g/m ⁻³ ²²⁶ Ra = 810 Bq/m ⁻³ TDS = 4.15 kg/m ⁻³	SO ₄ ²⁻ , Fe, Mn

Tailings impoundments

None.

Waste rock dumps

- Type: waste rock dump.
- Area: 47 000 m².
- Volume of deposited material: 120 000 m³.
- Status: partly reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA.

The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: pH, U, Ra, Fe, Mn, TSS, TDS.
- Surface waters: pH, U, Ra, Fe, Mn, TDS.
- Groundwater: pH, U, Ra, Fe, Mn, TDS.

Costs

Decommissioning and remediation(1993-1998)	50.1 million CZK (1.4 million USD)
Close out and remediation(1999-2025)	13.3 million CZK (0.4 million USD)
Water treatment, monitoring, maintenance (1999-2025)	162.0 million CZK (4.6 million USD)
Total (1993-2025)	225.4 million CZK (6.4 million USD)

Krizany mine

Facility characterisation

- Short history: Production between 1982 and 1990. 2 shafts and 24.7 km of horizontal mine workings. 665 exploration drillholes from the surface. Area of mining claim is 13.7 km². Depth of mining was 190 m under the surface. Total production: 1,108 tU. Ore was processed in chemical processing plant in Straz pod Ralskem.
- Type of activity: Uranium deep mining. Method – room and pillar with backfill, for tests also longwall mining.
- Present status: Mine partly decommissioned, underground flooded, surface decontaminated and partly reclaimed. Usable building prepared for sale.

Environmental problems and their solutions

Mine waters: flooded mine. No seepage to the surface. Neutral surface waters and waste rock dump waters partly pumped to mine and partly are to the Druzcov brook.

Type of water	Amount	Main and secondary contaminants
Neutral surface waters and waste rock dump waters	not measured	pH = 7.7-8.2 U = 0.11-0.62 /m ⁻³ ²²⁶ Ra = 60-1,310 Bq/m ⁻³ TSS = 0.5-19.3 g/m ⁻³

Tailings impoundments

None.

Waste rock dumps

- Type: waste rock dump.
- Area: 38 900 m².
- Volume of deposited material: 424 000 m³.
- Status: reclaimed.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

Costs

Decommissioning and remediation(1990-1998)	42.2 million CZK (1.2 million USD)
Close out and remediation(1999-2005)	130.2 million CZK (3.7 million USD)
Total (1990-2005)	172.4 million CZK (4.9 million USD)

Hamr mines

Facility characterisation

- Short history: Production between 1972-1993. During 1994 and 1995 production from the Hamr Mine was stopped and mine was mothballed. In 1995 decommissioning started. Production from Hamr II never started and mine has been decommissioned since 1988. Hamr I Mine has 4 shafts and 68.0 km of horizontal mine workings. 2 051 exploration holes were drilled from the surface (425 000 m). Area of all mining claims is 12.0 km². Depth of mining was 160 m under the surface. Total production: 13 205.9 tU. Ore was processed in chemical processing plant in Straz pod Ralskem. The chemical processing plant processed 77.3 million tU ore and 1.7 million t of sludge between 1979 and 1993.
- In 1999, the possibility of re-opening of mine and mill was discussed.
- Type of activity: Uranium deep mining. Method – room and pillar with backfill, for tests also longwall mining.
- Chemical processing plant and tailings deposition in tailings impoundments. Acid leach process.
- Present status: Decommissioning in the underground is being performed. Mined-out space is being backfilled with special concrete. The processing plant was decommissioned. Usable buildings are being prepared for sale.

Environmental problems and their solutions

Mine waters: water treatment in the area – central decontamination station Hamr. Managed pumping, injection, treatment and discharge are being done during decommissioning and remediation of the area. System of hydraulic barriers between deep mines and ISL operation.

Type of water	Amount	Main and secondary contaminants	
neutral waters pumped from mine workings	8 657 600 m ³ /y ⁻¹	pH = 5.5-8.0 U = 0.1-0.6 g/m ⁻³ ²²⁶ Ra = 120-400 Bq/m ⁻³ TDS = 0.8-1.2 kg/m ⁻³	SO ₄ ²⁻ , HCO ₃ ⁻ , Cl ⁻ , Fe, Al, Mn, Zn, Ni
mine waters contaminated by acid ISL solutions	1 727 200 m ³ /y ⁻¹	pH = 2.2-3.5 U = 1.5-2.5 g/m ⁻³ ²²⁶ Ra = 25 000-50 000 Bq/m ⁻³ TDS = 3.0-5.0 kg/m ⁻³	SO ₄ ²⁻ , Cl ⁻ , NO ₃ ⁻ , Fe, Al, Mn, Zn, Ni, NH ₄ ⁺

Tailings impoundments

Name	Area (m ²)	Deposited volume (m ³)	Status
Straz pod Ralskem I. stage	935 000	9 418 922	partly reclaimed
Straz pod Ralskem II. stage	935 000	828 310	not reclaimed

Tailings impoundments are used for deposition of tailings from chemical treatment of mine waters and remediation wastes.

Waste rock dumps

Waste rock dump	Area (m ²)	Deposited volume (m ³)	Status
Shaft. No. 1	17 600	42 980	Reclaimed
Shaft No. 3	47 000	488 000	Not reclaimed
Shafts Nos. 4,5	38 900	424 000	Reclaimed
Shafts Nos. 6,7	16 300	81 000	Reclaimed

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: pH, TSS, TDS, BCO₅, CHCO₅, hydrocarbons, N-NO₃, CL⁻, SO₄, F⁻, Cl⁻, N-NH₄, Fe_{total}, Zn, Ba, ²²⁶Ra, Pb, U, Ni, EOCI, P_{total}, Be, Cd, As, MN_{total}, Ca, Mg, Cr_{total}, ²³²Th, ²³⁰Th, ²¹⁰Pb, ⁴⁰K, total alpha and beta activity.

- Surface streams: U, Ra, TSS, TDS, hydrocarbons, Zn, Ni, BCO₅, CHCO, Na, Ca, K, Mg, F, Fe, Mn, Cl, NO₂, NO₃, acidity, NH₄⁺, SO₄, pH.
- Groundwater: monitoring of turonian and coniacian aquifer: pH, acidity, alkalinity, TDS, TSS, SO₄, NH₄, NO₃, Cl⁻, F⁻, HCO₃, Mg, Ca, Na, K, Al, Fe²⁺, Fe³⁺, Mn, U, Ra, Zn, Ni, NO₂.
- Air: falling dust – U, Ra, volume activity of Rn, equivalent volume activity of Rn.
- Soil contamination: gamma dose input.

Costs

Decommissioning and remediation(1990-1998)	6 107.0 million CZK (174.5 million USD)
End of decommissioning and remediation, pumping, water treatment, monitoring, maintenance (1999-2015)	6 893.0 million CZK (196.9 million USD)
Total (1990-2015)	13 000.0 million CZK (371.4 million USD)

In situ leaching plant Straž pod Ralskem

Facility characterisation

- Short history: Operation between 1967 and 1996. Since 1996, uranium is exploited as remediation by-product. 2 210 exploration drillholes and 7 684 production wells were drilled on the deposit. Thirty-five leaching fields were in production. Area of mining claim is 24.1 km². Before 1996, 15 562 tU were produced. Depth of mining was 220 m under the surface.
- Type of activity: *In situ* leach mining with wells from the surface (ISL). Acid leach (leaching agent: H₂SO₄, oxidation agent: HNO₃).
- Present status: Decommissioning and reclaiming of leaching fields. Remediation of underground.

Environmental problems and their solutions

Mine waters: groundwater were contaminated by uranium ISL on the Straž deposit. 4 000 200 t of H₂SO₄ were injected into the underground. Managed pumping and water treatment in station for liquidaion of acidic solutions (evaporation principle). Large scale remediation started.

Target status: pumping out of uranium enriched solutions from the underground; environmental remediation in the area influenced by ISL.

Type of water	Amount	Main and secondary contaminants	
waters contaminated by ISL solutions – turonian	475 700 m ³ /year ⁻¹	pH = 3-5.7 U = 0.05-0.2 g/m ⁻³ ²²⁶ Ra = 50-800 Bq/m ⁻³ TDS = 2.0-5.0 kg/m ⁻³	SO ₄ ²⁻ , Cl ⁻ , NO ₃ ⁻ , Fe, Al, Mn, Zn, Ni, NH ₄ ⁺
concentrated solutions from uranium ISL – cenomanian	978 600 m ³ /year ⁻¹	pH = 1-2.8 U ≤ 0.1 g/m ⁻³ ²²⁶ Ra = 50 000-90 000 Bq/m ⁻³ TDS = 64-100 kg/m ⁻³	SO ₄ ²⁻ , Cl ⁻ , NO ₃ ⁻ , Fe, Al, Mn, Zn, Ni, NH ₄ ⁺

Tailings impoundments

None.

Waste rock dumps

None.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Mine waters: pH, TSS, TDS, BCO₅, CHCO₅, hydrocarbons, N-NO₃, CL-, SO₄, F-, Cl, N NH₄, Fe_{total}, Zn, Ba, ²²⁶Ra, Pb, U, Ni, Cl extractable organic-fixed, P_{total}, Be, Cd, As, Mn_{total}, Ca, Mg, Cr_{total}, ²³²Th, ²³⁰Th, ²¹⁰Pb, ⁴⁰K, total alpha and beta activity.
- Surface streams: U, Ra, TSS, TDS, hydrocarbons, Zn, Ni, BCO₅, CHCO, Na, Ca, K, Mg, F, Fe, Mn, Cl, NO₂, NO₃, acidity, NH₄⁺, SO₄, pH.
- Groundwater: monitoring of turonian and cenomanian: pH, acidity, alkalinity, TDS, TSS, SO₄, NH₄, NO₃, Cl, F, HCO₃, Mg, Ca, Na, K, Al, Fe²⁺, Fe³⁺, Mn, U, Ra, Zn, Ni, NO₂.

Costs

Decommissioning and remediation (1990-1998)	880 million CZK	(25.1 million USD)
Decontamination and remediation, pumping, water treatment, monitoring, maintenance (1999-2040)	35 120 million CZK	(1 003.4 million USD)
Total (1990-2040)	36 000 million CZK	(1 028.6 million USD)

Chemical processing plant MAPE Mydlovary

Facility characterisation

- Short history: Uranium chemical processing plant was in operation between 1962 and 1991. Ore from Westbohemian, Okrouhla Radoun and Příbram uranium deposits was processed here. Total processed volume 16.8 million t of uranium ore. Tailings impoundments: 285 ha and 35.8 million t of tailings.
- Type of activity: uranium chemical processing plant and tailings impoundments. Acid leach process.
- Present status: Processing plant is decommissioned. Area of plant is decontaminated and prepared for sale. Tailings impoundments are being remediated and reclaimed.

Environmental problems and their solutions

Tailings impoundments water: overbalance water in tailings impoundments after ore leach process.

Type of water	Amount	Main and secondary contaminants	
tailings pond water	0 m ³ /year ⁻¹	pH = 4.94-7.7 U = 0.01-1.45 g/m ⁻³ ²²⁶ Ra = 80-1 540 Bq/m ⁻³ TDS = 6.0-20.0 kg/m ⁻³	SO ₄ ²⁻ , NO ₃ ⁻ , NO ₂ ⁻ , NH ₄ ⁺ , Mg, Mn, V
drainage water	111 700 m ³ /year ⁻¹	pH = 6.9 U = 0.64 g/m ⁻³ ²²⁶ Ra = 100 Bq/m ⁻³ TDS = 9.0 kg/m ⁻³	SO ₄ ²⁻ , Cl ⁻ , NO ₃ ⁻ , NO ₂ ⁻ , Fe, Mn, Mg, NH ₄ ⁺

Waters are treated and discharged into the Vltava River.

Tailings impoundments

Name	Area (m ²)	Deposited volume (m ³)	Status
K I	244 000	5 551 000	Partly reclaimed
K II	766 200	10 342 000	Not reclaimed
K III	337 400	4 354 000	Partly reclaimed
K IV / C1Z	357 100	403 000	Not reclaimed
K IV / C2	312 000	1 708 000	Not reclaimed
K IV / D	357 600	661 000	Not reclaimed
K IV / R	319 200	950 000	Not reclaimed
K IV / C1F	233 500	0	Not reclaimed

Tailings impoundments are being filled and covered by inert materials with biological reclamation. Target status – stable ecosystem of middle European mixed forests.

Waste rock dumps

None.

Environmental monitoring

Environmental monitoring in the area follows the programme of monitoring approved by competent authorities of the state administration and by expert supervision. The monitoring programme defines the extent, frequency and methodology of sampling and way of their assessment. Sampling and analytical works are done by DIAMO and external laboratories. Monitoring results are regularly evaluated and used for risk analyses, projects, management of remediation works and EIA. The environmental status of areas affected by DIAMO activities is published. Main monitored items:

- Treated tailings impoundment waters: TDS, TSS, SO₄, NO₃, U, Ra, NH₄.
- Groundwater: pH, NH₄, Cl, NO₃, SO₄, CHCO_{Cr}, alpha and beta activity, Ra, U, TDS, Cu, Zn, Cr, Pb, Ni, As, Cd, U, Al, Be, Mn, Fe, Ba, Na, K.

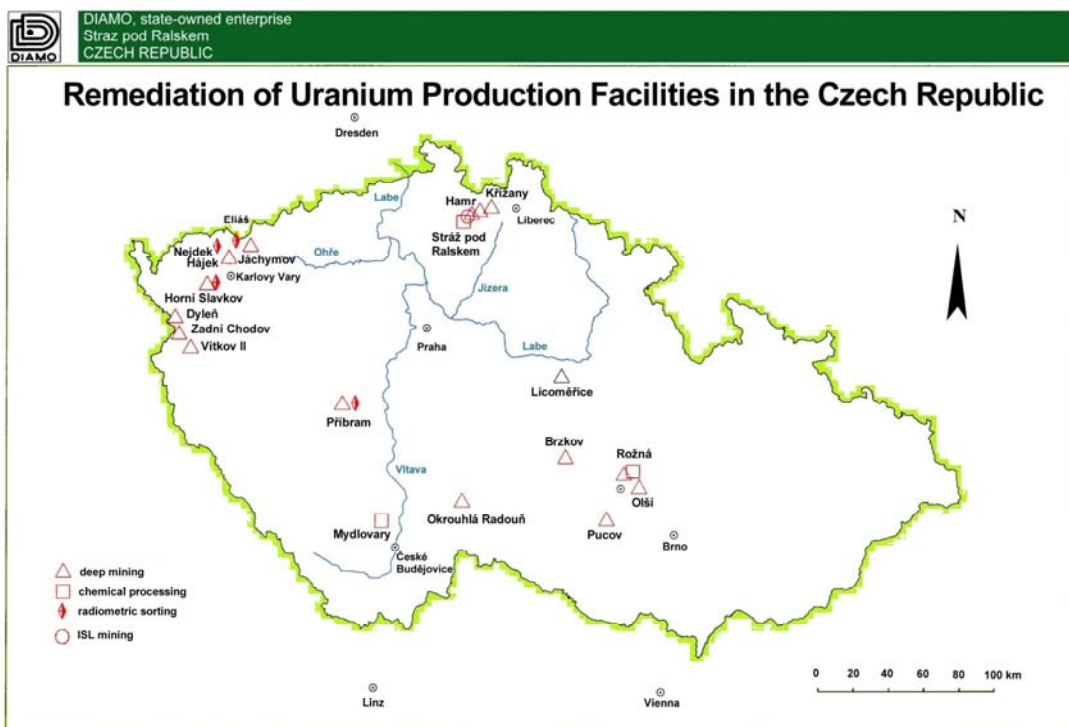
- Air: falling dust – U, Ra, Mn; average volume activity of Rn; immediate equivalent volume activity of Rn; immediate input of dose equivalent gamma radiation; average input of dose equivalent gamma radiation; concentration of soil Rn.
- Contamination of agricultural products: U, Ra, Zn, Cu, Ni, Cd, Cr, Co, Pb, As, Mo, Hg, Mn.

Costs

Decommissioning, decontamination and remediation of plant (1991-1998)	291.2 million CZK (8.3 million USD)
Remediation and reclamation of tailings impoundments (1991-1998)	205.5 million CZK (5.9 million USD)
Finalisation of remediation and reclamation of tailings impoundments (1991-2020)	2 533 million CZK (72.4 million USD)
Water treatment, monitoring, maintenance (after 2020)	Not specified
Total (1991-2020)	3 029.7 million CZK (86.6 million USD)

Conclusions

The uranium production contraction programme has been implemented in the Czech Republic since 1989. Only one deep mine and one chemical processing plant, located in Dolni Rozinka, are currently in operation. Their close-out is planned for 2002. Mines already closed-out are being decommissioned and remediated. In the framework of complex uranium production solution, old measures (Old Reminders) were revised and corrective actions are being performed. The environmental status of sites influenced by uranium mining is being systematically monitored and evaluated. The production contraction programme is being done under state supervision and activities are financed from the state budget of the Czech Republic.



• Egypt •

The objective of this report is to present a general description of the most common methods that have been used by the Nuclear Materials Authority (NMA) of Egypt in its programmes to assess the radiation exposure of individuals. This program aims to ensure that the safe working and environmental conditions are maintained and to show compliance with prescribed national standards. In pure screening programmes, the immediate objective is only to pick out critical localities where certain reference doses or standards may be exceeded, while the original survey program directly aims to assess doses as accurately as possible for the purpose of compliance checking or research.

The survey programme is concerned, to a great extent, with mines, mills and laboratories which constitute the main three areas of activities in NMA.

Uranium mines

The mining operations for the purpose of uranium exploration inevitably involve the production of some radioactive ore materials and wastes. The objectives of the environmental monitoring in such operations are often focus on radiological control and routine environmental survey. The hazards associated with the ambient air in the underground mining atmosphere are connected to two main processes: the inhalation by the involved personnel and the effect of radiation on them. The presence of radon gas and its daughters and the radioactive rock particles in the inhaled air represent hazards. Moreover, the radiation at the most heavily mineralised zone in the underground works could result in an over-exposure. To overcome these hazards, systematic air monitoring in the atmosphere and radioactivity measurements in the exploratory mining works in Gabal Gattar were performed.

Uranium mills

In uranium mills, ^{222}Rn and its daughters usually present only a minor inhalation hazard compared to ore and uranium dusts, although significant radon concentrations may occur near ore storage bins and crushing and grinding circuits. During crushing and screening, the long-lived airborne radionuclides tend to be in equilibrium, but during subsequent operations this equilibrium is necessarily disturbed and the concentrations of individual radionuclides must be measured for the assessment of hazards. After leaching of the crushed ore, most of the radionuclides except uranium remain with the wet cake, which after filtration is sent for tailings treatment. Thus airborne uranium is predominant in the filtration, and external beta and gamma radiations are also present in levels that depend on the grade of ore, type and grade of concentrate, and type of process. It is assumed that airborne uranium is present mainly in the final stages of precipitation, filtration, concentrate packing and storage.

Laboratories

External beta and gamma radiation is the main source of radioactivity in laboratories. Also in some cases measurable radon-gas concentrations are also available.

Radon gas measurement: A portable radioactive gas monitor RGM1/L was used. It is sensitive to alpha particles emitted from radon gas. The unit is picocurie/Litre (Pci/L) or microcurie per cubic meter ($\mu\text{ Ci/m}^3$). The maximum permissible concentration is $0.03 \mu\text{ Ci/m}^3$.

Radon daughters concentration: Tri Met (TM372-A) portable alpha counter with suitable pump was used. It has a time selector and displays digital reading. The detector is of ZnS (Ag) scintillator type. The instrument was calibrated with Radon daughter source (^{214}Po) and checked before use by ^{241}Am alpha standard source.

Radon daughters were measured using Kuznetz grab sampling method (IAEA, S.S.43). The maximum permissible Radon daughters concentration is 0.3 Working Level (WL).

The total cumulative energy of 1.3×10^5 Mev as alpha particle energy defines the Working Level (WL) as any combination of short-lived decay product of Radon gas (RaA, RaB, RaC and RaD) in one litre of air that will result in the ultimate emission.

The Working Level Month (WLM) is an exposure unit, which is expressed as the product of WL and duration of exposure, normalised to one month which is defined as 170 hours, i.e. $1 \text{ WLM} = 170 \text{ WLH}$.

Monitoring of external gamma radiation: A portable radiation measuring instrument as Geiger Counter type Berthold LB-1200 was used. It gives direct reading for dose rate in millirem/hour. It was calibrated using standard ^{137}Cs gamma source. It is defined that the maximum permissible value for the dose rate is 2 millirem/hour (mrem/h) or 20 micro sievert/hour ($\mu\text{ Sv/h}$).

Results and discussions

In case of mines

Environmental monitoring of the Gattar-I and Gattar-II exploratory mining works were completed. The monitoring was done in the early stages, during January 1990, of Gattar-I mining works. [1] The results of the radiation monitoring are within the accepted level, except for one sample where the radon daughters concentration reached 0.43 WL. The external gamma radiation ranged from 0.08 to 1.6 mrem/h, which is less than the permissible value. The annual effective dose equivalent ranged from 8.652 mSv to 85.764 mSv.

The Working Level Hour (WLH) is an exposure equivalent to 1 working level of Radon daughters per hour. The maximum exposure rate is 0.3 WL, while the maximum annual exposure is 4.7 WLM/Year and the maximum life time exposure is 120 WLM.

The results of radiation monitoring in Gattar-I exploratory mining works during some months in 1990 and 1991 were reviewed. The external gamma radiation ranged from 0.06 to 0.2 mrem/h, which are under the permissible value (2 mrem/h). The radon gas concentration ranged from 0.0008 to $0.02 \mu\text{ Ci/m}^3$ which is less than the permissible value ($0.03 \mu\text{ Ci/m}^3$). The average radon daughter concentration was 0.025 WL. It was also found that the radon gas concentration is inversely proportional to the quantity of air following, e.g. in the sample number 17 the activity is rather high where it reached 0.2 mrem/h. This is due to the fact that this site includes secondary uranium mineralisation. However, when the ventilation increased in this site, the radon gas concentration reached 0.0008, which represents a very small value. The estimation of the average of the annual effective dose equivalent in Gattar-I exploratory mining works is found to be 2.155 mSv. This value is below the accepted limit (50 mSv). This indicates that the ventilation is excellent at this site.

The results of radiation monitoring in Gattar-II exploratory mining works were also reviewed. The external gamma radiation ranged from 0.08 in the vertical shaft where these values are below the accepted limit of 2 mrem/h. In the eastern adit the value of the external gamma radiation increased to 0.6 mrem/h, which represents a higher value but still under the accepted limit. This increase is due to the presence of a 1.4 m thick uraniferous shear zone with secondary uranium mineralisation.

The radon gas concentration in the vertical shaft is up to $0.05 \mu\text{Ci}/\text{m}^3$; however, it reaches $0.7 \mu\text{Ci}/\text{m}^3$ in the eastern adit, which is over the accepted limit ($0.03 \mu\text{Ci}/\text{m}^3$). The radon daughters concentration increases downward in the vertical shaft. At the entrance it is 0.006 WL, while it reaches 1.6 WL at a depth of 39 m. In the eastern adit it reaches 1.7 WL, which is over the accepted value (0.3 WL). The same phenomenon is noticed in the estimated values of the annual effective dose-equivalent which were over the accepted limit in both the vertical shaft and the eastern adit. The values are based on measurements without using ventilation in the vertical shaft or adits in Gattar-II exploratory mining works. A proper ventilation system was established in this project to lower the annual total effective dose equivalent below the accepted limit of 50 mSv. The natural ventilation can be useful at this site, but it is rather difficult and expensive due to the rough topography of Gabal Gattar.

In case of mills and labs

Tables 1 and 2 show the average test results for some labs and mills, during the year 1996. In case of labs, due to good ventilation and good manipulation of the ore used, there was no accumulation for Rn-gas and its short-lived daughters. The exception was in Lab No.3 where a high-dose rate was observed and some radioactive deposits were registered on the benches. In the mill cases no high values were found also due to good ventilation.

Table 1. Average test results for laboratories

Lab Type	WL (Kuznetz)	γ-Dose Rate ($\mu\text{Sv}/\text{h}$)	Rn-concentration ($\mu\text{Ci}/\text{m}^3$)
Extraction	0.2	26	0.02
Geological Isotopes	0.005	1.7	0.003
Production Control	0.004	44	0.006

Table 2. Average test results for mills

Measuring Place: Mills	WL (Kuznetz)	γ-Dose Rate ($\mu\text{Sv}/\text{h}$)	Rn-concentration ($\mu\text{Ci}/\text{m}^3$)
	0.004	13.2	0.006
	0.003	8.7	0.004

Recommendations

1. A land use map for the site of Gabal Gattar should be constructed. The location of management offices, living facilities, machinery, radioactive waste storage should be assessed to avoid the effect of plate out radon daughters on various surface features. Also, the direction of blowing wind should be considered.

2. The biological effect on the workers should be studied very seriously and regularly according to the basic safety standards for radiation protection [2].
3. Development and calibration of the instruments used in the measurements of radon and its daughters should always be compatible with international standards.
4. A training programme should be regularly held for workers and personnel involved in uranium mining and milling [3].
5. The contamination of the water pockets in the uranium bearing granites and the water wells in the wadi deposits in Gabal Gattar environs should be investigated accurately.
6. The exploitation, transportation and storage of the radioactive ores produced from the mining operations should be treated according to safety standards.

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- [1] Abdel Monem A., Hussein M.I., El Naggat A.M., Attia K.E. and Omar S.M. (1990), *Monitoring of radon gas and daughters in uranium exploration mines, Eastern Desert, Egypt*. Regional Symposium Environment Studies (UNARC), Alexandria, p. 507-522.
- [2] International Atomic Energy Agency (1982), *Basic safety standards for radiation protection*, Safety Series, No. 9, page 172, International Atomic Energy Agency, Vienna.
- [3] International Atomic Energy Agency (1965), *The basic requirements for personnel monitoring*. IAEA Safety Series, No. 14, p. 44, International Atomic Energy Agency, Vienna.

• Finland •

Government policies and regulations

All mining activities in Finland are regulated by Mining Act No. 503/65.

The legislation concerning restoration of uranium production facilities in Finland is included in Nuclear Energy Law No. 990 of 1987. The aim of this law is to keep the use of nuclear energy within the general interests of the society. This law establishes general principles governing the regulation of the use of nuclear energy, the establishment of a licensing procedure and nuclear waste management.

Use of nuclear energy includes the following activities: (1) construction and employment of a nuclear facility; (2) mine and concentration operations in order to produce uranium or thorium; (3) possession, fabrication, production, transfer, handling, use, storage, export, transport, and import of nuclear substances and nuclear waste, as well as the export and import of uranium or thorium containing ores.

The Ministry of Trade and Industry has the supreme authority in the field of nuclear energy in Finland. The supervision of the matters in nuclear energy is in the Finnish Radiation and Nuclear Safety Authority (*Säteilyturvakeskus* – STUK).

The Nuclear Energy Law provides that the construction and operation of nuclear facilities, including spent nuclear fuel storage or radioactive waste disposal facilities as well as facilities for mining and enrichment operations the purpose of which is the production of uranium or thorium, is prohibited without a licence. Permission to construct a nuclear facility requires the approval in principle from the Council of State, which must base its decision on the requirement that the construction proposal be consistent with “the overall good of society”. If this approval is obtained, the Council of State’s decision is then submitted to the Finnish Parliament which may either accept or reject the Council’s decision. Before the Council of State makes a decision on the merits, a lengthy and wide-ranging consultation procedure must be followed, which includes an assessment in accordance with Act No. 468/94 on Environmental Impact Assessment. In particular the Ministry of Trade and Industry must obtain a preliminary safety assessment on the proposed decision from STUK, a statement from the Ministry of the Environment, and a statement from the municipal council responsible for the area proposed as a site for the facility. In addition, under Nuclear Energy Decree No. 161/88, the Ministry of Trade and Industry must submit to the Council of State a review which specifically addresses questions of nuclear waste management such as methods proposed, safety and environmental aspects, costs and suitability to Finnish conditions.

Once all the information and comments required by the Finnish legislation have been collected and submitted to the Council of State, the Council may proceed to make its decision on the application. If the Council of State’s decision is positive, it must then be submitted to the Parliament, which may either confirm or veto the decision. Once Parliamentary approval is given, the grant of the construction licence is still contingent on a number of detailed criteria relating *inter alia* to environmental protection, town planning and building requirements, nuclear waste management and final decommissioning plans. If an applicant satisfies all these requirements, a construction licence for the proposed facility may then be granted by the Council of State. Once the construction of the facility is satisfactorily completed, a separate licence is needed for its operation. This licence is also granted by the Council of State after further examination of various criteria (such as safety, environmental protection and waste management).

According to Act No. 990, subject to some exceptions, the export of spent nuclear fuel is not permitted, as well as foreign nuclear waste cannot be handled, stored or finally disposed of in Finland. The licensee is primarily responsible for the management of nuclear waste generated by the licensee’s activities and he is required to bear the costs incurred in implementing his waste management obligations. This is achieved by requiring the licensee to pay an annual fee into the State Nuclear Waste Fund (administered by the Ministry of Trade and Industry) and also to give prescribed securities to the state as a precaution against insolvency.

Both major Finnish power companies, *Teollisuuden Voima Oy* (TVO) and *Imatran Voima Oy* (IVO, presently a part of the Fortum Group), are co-operating in the final disposal of spent nuclear fuel into the Finnish bedrock. From the beginning of 1996, they established a joint company, *Posiva Oy*, for a nuclear waste disposal program. Four investigation sites had officially been selected for

detailed studies. On 18 May 2001, the Finnish Parliament ratified the governmental decision allowing construction of such final disposal at Olkiluoto in the municipality of Eurajoki. Since April 1998, low and intermediate level wastes have been disposed in underground repositories at the TVO power plant in Olkiluoto and at the IVO power plant in Loviisa.

Historical information on country's restoration activities

There has been only one uranium mine in Finland. During 1958-1961 some 40 000 tonnes of ore grading 0.14% U was extracted from the Paukkajanvaara mine in eastern Finland. The ore was treated with sulphuric acid, and the concentrate containing about 30 tonnes of uranium was exported. After the mining operations, the opening of the shaft was blocked, but the barren rock and the tailings impoundment were left in open air. The old pit and tailings were covered by uncontaminated soil in October 1993. Before that, the old concentration plant had been torn down and was also covered. The Finnish Centre for Radiation and Nuclear Safety has been monitoring the mine area and its surroundings since 1984.

Facilities with ongoing or future plans for restoration activities

There are no ongoing or future plans for restoration of uranium mines or other facilities in Finland.

Additional information

The following applies to the Paukkajanvaara uranium mine in eastern Finland:

- Mining during 1958-1961 by the company Atomienergia Oy
 - Total mine output: 70 089 tonnes.
 - Waste rock: 29 764 tonnes.
 - Ore output: 40 325 tonnes (in an average 0.14% U).
 - The concentrate containing about 30 tonnes of uranium was exported.

- Restoration in October 1993 by the land owner company Bonvesta Oy
 - Area treated about 1.5 km².
 - The shaft and the open pit were blasted.
 - The tailing ponds and waste rock piles were covered by layers of till, clay and peat, totalling 1.5-2 metres.

• France •

Government policies and regulations

French laws and regulations regarding environmental issues in uranium mining and milling are described in a 1999 report prepared jointly by the NEA and the IAEA.¹

The main categories of regulations applying to the environmental remediation of uranium mining and milling sites include:

- For mines, the basis is the “Code Minier” (Mining Code) completed by “Règlement général des industries extractives (RGIE)” (Decree 80.331 issued on May 7, 1980) (General regulation on extraction industries) and especially Decree 90.222 of March 9, 1990 for radiological protection.
- Mills and storages are classified as ICPE (“Installation classée pour la protection de l’environnement” – Classified facility for protection of the environment – Law 76.663, July 19, 1976 and Decree 77.1133, September 21, 1977).
- Environmental Impact Studies are prescribed by article 2 of Law 76.629, July 10, 1976 on Environmental Protection and corresponding Decree 77.1141 October 12, 1977.
- Decree 66.450 of June 20, 1966 sets the frame of radiological protection and Decree 90.222 of March 9, 1990, describes implementation of the radiological protection of the environment of mining and milling sites.
- In relation to radiological protection, Council Directive 96/29 Euratom of May 13, 1996, is expected to be implemented in French regulation in December 2001. Maximum annual added exposure to the public will change from 5 mSv to 1 mSv.
- A “Circulaire” or guide, No. 99-332, issued on May 7, 1999, by Ministry of the Environment describes the main facts about remediation of uranium mill tailings and heap leaching wastes storage sites and gives recommendations to evaluate its efficiency.

Historical and general information on country’s facilities

- Table 1 lists details regarding the different facilities including: dates of operation, date for end of remediation (or date of final licence after remediation), characteristics of the storage facilities and other relevant data. Table 1 also lists the reference of each site in the official ANDRA annual inventory: 20 tables in 1999 [see reference 1], 18 tables for the inventory under preparation for the year 2000 (updated at the end of 1999).
- The enclosed map indicates location of the main facilities and operation and remediation dates.

1. OECD/NEA (1999), *Environmental Activities in Uranium Mining and Milling*, Joint report by OECD/NEA and IAEA, Paris, France.

Figure 1. Location of uranium mining and milling storages



Note for dates: start to – end of operation/end of remediation (or date of monitoring license)

Facility characterisation

The facilities considered in this report are those related to uranium ore processing. They include uranium mills and the tailings ponds connected to them and heap leaching dumps.

Tailings (volume, area)

The volume and area characteristics of each facility are listed in Table 1.

Type of radiological and chemical contamination

The main concern is the radiological impact of uranium daughter products either by the air pathway (radon) or water pathway (U and ²²⁶Ra).

Potential chemical contamination is linked to the initial composition of the ore (sulphur or molybdenum for example) or to the chemicals used for the treatment (mainly sulphuric acid and necessary neutralisation).

Table 1. Inventory of COGEMA's storage facilities mill tailings

Storage sites	Andra inventory 1998 réf.	Year of operation Start / end	End of remediation	Mill tailings	
				Type of storage and remediation	AREA (ha)
GUEUGNON Dyn	BOU 3	1955 / 1980	license in 1987	ring dyke + dry cover	3
ROPHIN	AUV 2	1950 / 1955	1985	ring dyke + dry cover	3
TEUFELSLOCH Leach	ALS 2	1961 / 1963	1994	-	
TEUFELSLOCH (Poor ore)				-	
BOIS NOIRS-L Dyn	RHO 1	1960 / 1980	license in 1987	dyke + water cover	18 (impoundment)
CELLIER Dyn	LAR 1	1970 / 1990	1991	open pit+300kt inter	66
H.Leach.		1965 / 1990		-erbeded.drain+cover	
TOTAL					
ECARPIERE Dyn	PAY 3	1957 / 1991	1995	ring dyke + dry cover	72
La COMMANDERIE H.Leach	PAY 2	1967 / 1976	1994	-	
TOTAL					
BESSINES Ind.Site	LIM 3	The Ind.site groups several storages (LAV., BGD) for mill tailings			140
-LAVAUGRASSE	see LIM 3	1958 / 1978 + sludges	ongoing	ring dyke – dry cover	see Bessines
-BRUGEAUD		1978 / 1987+	ongoing	open pit – dry cover	see Bessines
MONTMASSACROT	LIM 10	1987 / 1990	entirely covered	open pit – dry cover	4
BELLEZANE	LIM 1	1988 / 1993	1997	open pit – dry cover	15
-BRUGEAUD H.Leach	see LIM 3	1964 / 1993	1999	-	
-BRUGEAUD H.Leach	see LIM 3	1964 / 1993	1999	-	
TOTAL					
LODEVE	LAR 4	1981 / 1997	ongoing	open pit - dry cover	54
JOUAC Dyn	LIM 7	1979 / operating	-	ring dyke	
H.Leach					
TOTAL					
La RIBIERE H.Leach	LIM 12	1982 / 1985	1992	-	
BERTHOLENE H.Leach	MIP 1	1984 / 1995	heap waiting for final dry cover		
St PIERRE du CANTAL	AUV 3	1977 / 1985	ongoing	open pit + dry cover	
TOTAL					
TOTAL Dyn					
H.Leach					
(Poor ore)					
TOTAL					

and heap leaching wastes *

Mill tailings (contd)		Heap leaching			
Tonnage (kt)	Ra 226 activity (Tbq)	Type of storage and remediation	Area (ha)	Tonnage poor ore (kt)	Ra 226 activity (Tbq)
185	10.4	–			
30	0.3				
		Heap - dry cover	1.3	1.45	0.03
				(2.6)	(0.04)
1300	74.6	–			
1112	20.4	mixed to heap l.wastes	see total area of	288	3.5
164	1.2	heap + cover	industrial site	4080	18.0
1276	21.6			4368	21.5
7575	167.5	heap leached wastes used as 1st cover ...		3775	15.6
		... for mill tailings	–		
		barren cover in flooded open pit		250	1.0
7575	167.5			4025	16.7
and h. leaching wastes					
5678	141.5	heap leached wastes used as 1st cover ...		1807	3.6
5776	129.5	... for mill tailings	–	1555	4.8
737	19.0		–		
1514	48.5		–	42	0.6
		heap – dry cover	see Bessines	1763	5.5
		heap – dry cover	see Bessines	3447	1.7
13705	338.5			8614	16.2
4142	173.9	poor ore used as first dry cover		(823)	(7,5)
1668	103.6			41	0.2
1668	103.6			41	0.2
		open pit - dry cover		197	0.9
		heap waiting for final dry cover		476	7.57
70	2.4	open pit + dry cover		508	5.4
70	2.4			508	5.4
29762	889.8			4063	19
164	1.2			14167	49
				(826,6)	
29926	891.0			18230	68.5

* Up-dated by end of 1999. As mentioned by *Observatoire de l'ANDRA* some storages may contain other wastes than mill tailings or heap leachings which are not considered in this table.

Objectives of remediation

For COGEMA, the main objectives of remediation works are as follows:

- Long-term stability of the remediated area in terms of safety and public health.
- Reduction as far as reasonably possible of the residual impacts.
- Prevention of risk resulting from intrusion.
- Reduction of total land consumption and resulting need for institutional control.
- Favour possible industrial or leisure activities on the land and remaining buildings.
- Landscape integration, in co-operation with local intervening parties.

Context of the remediation

Remediation works apply to the structures left after the end of mining operations: mines, mills and storage facilities of waste rocks or milled residues.

Remediation is part of COGEMA's environmental policy. Moreover, since the laws on environment of 1976, remediation is mentioned in the environmental impact study, which is compulsory for any new facility or for an important modification of an existing one.

Planned operations take into account the final remediation which should be started as soon as possible. Ideal cases include neighbouring open pits which are filled back by the waste rock from the first exploited facilities.

During operation financial provisions are set aside to cover the costs for the final remediation.

Regular information is given to the public through documentation mailed to the neighbouring population. A telephone number is provided to the public and site visits are organised to listen to any concerns arising from people outside the company. Similar communication programmes are provided for the personnel who were trained and switched from uranium production to site remediation.

Main facts about remediation

Some facts regarding remediation activities in France are provided in the 1999 joint NEA and IAEA report [2].

Inventory for site characterisation

This includes:

- History of activity on the site which sometimes allows to locate buried wastes or entrenched pipes.
- Inventory of the heaps and storages in terms of tonnages and chemical composition. Inventory of the mill to evaluate surface contamination and select reusable equipment.
- Inventory of the land properties.
- Inventory of available material for cover.

Site studies contribute to characterise the materials, the storages, the potential impacts (radioactivity map) and the environment: geology, hydrogeology and geophysics of the sites, hydrology, ground stabilization, vegetation, etc.

Geochemistry and petrographic analysis of the mill tailings have demonstrated that natural leaching of radium was limited: less than 1% of the radium content for stored mill tailings compared to 10% for fresh mill tailings. This can be explained by quick (less than 30 years) development of secondary large “specific surfaces” minerals such as smectite, iron oxy hydroxides and gypsum that trap 95% of the total radionuclides and associated heavy metals [see references 2-4]. This can be called “self confinement” which improves the chemical stability of the tailings.

An important step is implementation of test plots to characterise *in situ* the different types of covers which may be used: types of materials among those available on the site (heap leaching wastes, waste rock and/or overburden from mining), influence of compaction and correspondent impact on radon flux).

Implementation for main types of sites

Underground mines. At the end of mining works, priority is given to the safety of the public in the long term. Each communication with the surface is backfilled to avoid any intrusion and the stopes are stabilised to avoid any caving. The related procedures are submitted to regulatory authorities and may be complemented by specific studies.

Open pits – impacts on the landscape. As a first step, the pit may be partly filled up with waste rocks (several thousands or million tons of earth may be moved) and/or the geometry of the slopes may be smoothed with explosives for safety reasons. Depending on the case, the pit may be transformed into a water impoundment for irrigation, fishing, diving or other purposes.

Dumps of heap leached ores and high radioactive zones of former stockpiles areas are covered with barren rock (remaining ore of former stockpiles are scraped and may be used as first cover). Dumps are reshaped to reduce surface erosion and infiltration and for better integration in the landscape which is enhanced by revegetation.

Tailings storage: during remediation, the drainage system is maintained to allow soaking of the mass of the tailings and collection of the seepage water. Surface water is diverted to reduce volumes of water that may require water treatment.

Stability of mill tailings storages must be improved by drying up and resloping of the dykes to reach an adequate stability coefficient.

Test plots are built to determine the thickness of the rock cover to achieve reduction of external exposure and radon emanation. The thickness is adjusted by using a first layer of heap leached ore if available, in order to cope with settlement, reduce slope, erosion and infiltration and finally to reach a final topography integrated to the landscape. Final cover may be topsoil to improve revegetation.

Water treatment must be adapted from the system used during operation to cope with new water quality (water overflowing from mine workings) and new location of the collection point. The water treatment is maintained until the water quality allows direct release into the environment. Management of the sludges must be planned. An adequate storage volume must be built and cover material stockpiled in the vicinity for its final remediation. More description of remediation issues is provided elsewhere [see references 5-9].

At the end of the remediation works, the final state is controlled – topography, water circuits, radioactive mapping, and vegetation development. This control is complemented with an internal audit under COGEMA quality assurance procedures.

Type of long-term monitoring and surveillance

According to the types of storage, two types of monitoring may be necessary after remediation:

- Geotechnical monitoring to assure the stability of the wastes pile (settlements, slope stability) and the integrity of the cover.
- Environmental water and air monitoring to assure the quality of the liquid effluent and the impact to the public and the environment.

The monitoring network is adapted from what was used during the operational phase. Water treatment and monitoring can be progressively reduced according to the observed results. Monitoring is subject to a license.

For the public, the radiological impact considered is the sum of the external exposure due to radon and dust inhalation and U/Ra ingestion. D 90.222 defines a generic scenario to calculate the Annual Total Added Exposure Rate. This rate must be less than 1-5 mSv/year (maximum total exposure being 5 mSv/year).

Difficulty to evaluate the initial exposure (that is before start of operation) adds usually to the overestimation of the exposure.

Monitoring results, highlighting some examples of the direct influence of remediation work (cover and radon potential alpha energy, discharge water quality and water treatment) and implementation to the calculation of public exposure are given in Daroussin *et al.* [see reference 10].

During site monitoring, regular checks are carried out to observe the gradual return to a natural and stable equilibrium. After a probationary period, COGEMA may ask for a reduction of the level of controls and eventually obtain a definite abandonment of the site and the reuse for further activities by local parties except for milled tailings storages that must remain under COGEMA responsibility and supervision.

For the long term, the most important issue is to keep memory of the storage sites. This encompasses a three-fold strategy:

- COGEMA remains owner of the storage facilities.
- Liabilities are listed in the license issued at the end of remediation and registered to the “Hypothèques” (Land ownership register).
- A national inventory of radioactive wastes, including residues from uranium ore processing, is updated annually by ANDRA (Agence nationale pour la gestion des déchets radioactifs) [see reference 1].

Facilities with ongoing or future plans for restoration activities

Jouac was the only facility still operating in France until 31 May 2001, the date that COGEMA stopped uranium mining.

Remediation is still underway on in Bessines (the industrial site grouping Lavaugrasse and the different Brugeaud storages), Lodève, St Pierre du Cantal and Bertholène.

Bessines is an industrial site complex where underground and open pit mining started in 1955. Milling and heap leaching were developed after 1958. Lavaugrasse (ring dyke type impoundment) is the first mill tailings storage facility. The tailings were then stored in Le Brugeaud open pit. An opening in the cover has been kept on top of Lavaugrasse to store sludges from the water treatment plants of the site and from the mining sites in the vicinity.

Lodève stopped in 1997. The mill has been dismantled. Contaminated equipment, scraps and demolition products are stored on a dedicated area above the tailings and covered. Local conditions (climate and corresponding variability in flow rates, high uranium content) lead to the conception of a water treatment plant allowing:

- Flexibility in the throughput.
- Recovery of uranium with resins.
- Limitation of the production of sludges.

Remediation is progressing slowly in Saint Pierre du Cantal. Due to local conditions, work is limited to summer periods to cover the last sludge decantation pond.

In Bertholène, remediation is on stand by. In this heap leaching facility, cover materials are rich in sulphur which has not been completely leached away; consequently, after resloping, final cover has been postponed in order to allow natural dissolution of the sulphur minerals content. The water treatment is kept operating to allow a good quality water release. The sludges are pressed and trucked to Jouac to be treated for their uranium content.

Remediation costs

Aggregate cost data

Since 1990, remediation has been going on for most of COGEMA's facilities. Future costs evaluations have been made for the rest in order to take into account future spending.

Total cost for an average set of facilities producing more than 1 000 tU/year (about 500 000 t ores.year-1 or 1 500 t.day-1 mining sites, mill and corresponding storage facilities) ranges from FRF 10 to 13 per kgU.

Total costs for specific items and objects

Dismantling of the mill itself costs around FRF 15 to 20 million.

Expenses for dismantling and site remediation are on average FRF 400 000 per hectare. The highest costs are for mill facilities dismantling and tailings storages remediation, averaging FRF 1.1 million per hectare.

The total costs for remediation of a set of facilities producing uranium (from mine to tailings storage) are split into:

- Planning, engineering and licensing studies: 10%.
- Dismantling (all facilities): 20%.
- Earth moving: 45%.

- Finishing works including revegetation: 15%.
- Water treatment and controls: 10%.

The costs for remediation of a tailings storage are split into:

- Planning, Engineering and licensing studies: 10%.
- Earth moving: 75%.
- Finishing works including revegetation: 15%.

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• Gabon •

Introduction

From the start of uranium mining in 1956 until closure of all uranium production in 1999, Gabon was a major uranium producing country. All uranium production activities were conducted by Compagnie des Mines d'uranium de Franceville (COMUF). A summary of uranium production and production facilities for Gabon is given in Table 1.

Table 1. Mines with opening and closure dates

Site	Open	Operations commenced	Operations ended	Total recovered (tonnes U)	% U
Mounana Open Pit Underground	1956	1960	March 1975	3 915	0.49
		1968	1971	1 844	0.49
Bouyindzi Underground	1967	1980	April 1991	2 691	0.31
Oklo Open pit Underground	1968	1970	1985	7 242	0.45
		1977	Dec. 1993	8 100	0.32
Okelobondo Underground	1974	1989	Nov. 1997	3 500	0.33
Mikoulougou Open pit	1965	June 1997	March 1999	1 200	0.28
Total				28 492	0.38

Source: COMUF.

Relevant Legislation

- Law No. 011/99, which is the basic mining law in Gabon.
- Environmental Law No. 16/93 Relating to the Improvement and Protection of the Environment of August 26, 1993, which contains a section addressing mining activities.

Programme for restoring the COMUF sites at Mounana

The SYSMIN contract No. 1/97/6A to restore the COMUF sites at Mounana was awarded on February 1997 to the ALGADE Company by the Commissioner for the Planning and Development in the Ministry for Planning for the Republic of Gabon. The review specified the arrangements for dealing with the residues of COMUF industrial operations in Mounana (from mining and processing of uranium ore) and established a procedure for rehabilitating the sites.

The proposed methodology of restoration is based upon the principles of justification and optimisation of radiation protection recommended by the International Commission on Radiological

Protection (ICRP) in its publications No. 60 *et seq.* and set out by the IAEA in its “RADWASS” programme on radioactive waste management.

On the basis of these principles, the fundamental criterion for ensuring the safety of an installation used for storing solid wastes resulting from mining and processing uranium ore, whether in service, or following shutdown of operations, are defined. As a result, the annual effective dose liable to be received by individuals in the reference groups of the present and future population must not exceed 1 mSv. The criterion of a 1 mSv dose limit was, therefore, adopted for the restoration programme for the COMUF sites. To achieve this objective it was decided to proceed in stages:

Stage 1: Radiological characterisation of the sites

COMUF prepared a review that included:

- Counting arrangements on a 20-metre grid.
- Topographical maps of the sites.
- An assessment of radiological conditions in the immediate environment of the installations with a view to identify the areas to be contained/restored and the areas to be cleaned up.

From this review it was possible to identify seven areas to be restored totalling about 60 hectares. These areas are:

- The former Mounana MCO.
- Upper Gamambougou Valley zone between the old Mounana quarry and the sulphuric acid plant.
- Gamambougou Valley zone above the dyke (between the dyke and the sulphuric acid plant).
- Lower Gamambougou Valley zone (below the dyke down to the confluence with the Mitembé).
- The Mitembé confluence zone.
- Thalweg South new plant 2.
- Thalweg North new plant 2.

The works to be carried out in these zones include:

- Treatment and containment of processing residues.
- Covering these residues with laterite and rock.
- Replanting.

Seven zones to be cleaned up, total about 15 hectares, as follows:

- Vicinity of the Moyindzi well.
- Area of Plant I.
- Zone near the sulphuric acid plant.
- Storage area for “doubtful” and “depleted” ore near the feed unit.
- Ore storage zone near the OKLO well.

- Ore delivery zone near the OKLO well.
- Head end of OKLO MCO.

In addition to these areas identified in the ALGADE study, it is appropriate to include the following areas where the plan makes provisions for stripping the contaminated soil followed by placement of a laterite cover:

- Mitembé storage zone.
- Ore storage areas at the OKLO mine.
- Ore feed area for Plant 2.
- Plant 2 platform.
- Industrial tracks.
- Solvent plant platform.
- Plant 1 platform.

These areas were used either for transferring uranium ore, or for storing uranium ore before processing in the plant. Some were also used for storing wastes and various processing effluents.

Stage 2: Study and identification of principal tasks

The restoration works are intended to:

- Ensure the long-term safety of the public.
- Guarantee that the residual radiological impact is as low as reasonably possible.
- Ensure the physical stability of waste storage areas.
- Specify the future use of the restored areas.
- Pave the way for integration into the landscape.

These goals will be achieved by:

- Collecting together the substances to be controlled so that the areas of land that may have an impact on the public are as small as possible.
- Containing the substances, either underwater or under solid cover, taking into account the geological and radiological constraints.

Stage 3: Characterisation and evaluation of the residual impact of the site after restoration

This evaluation involved estimating the effective doses liable to be received by the reference groups of the future population at the restored sites.

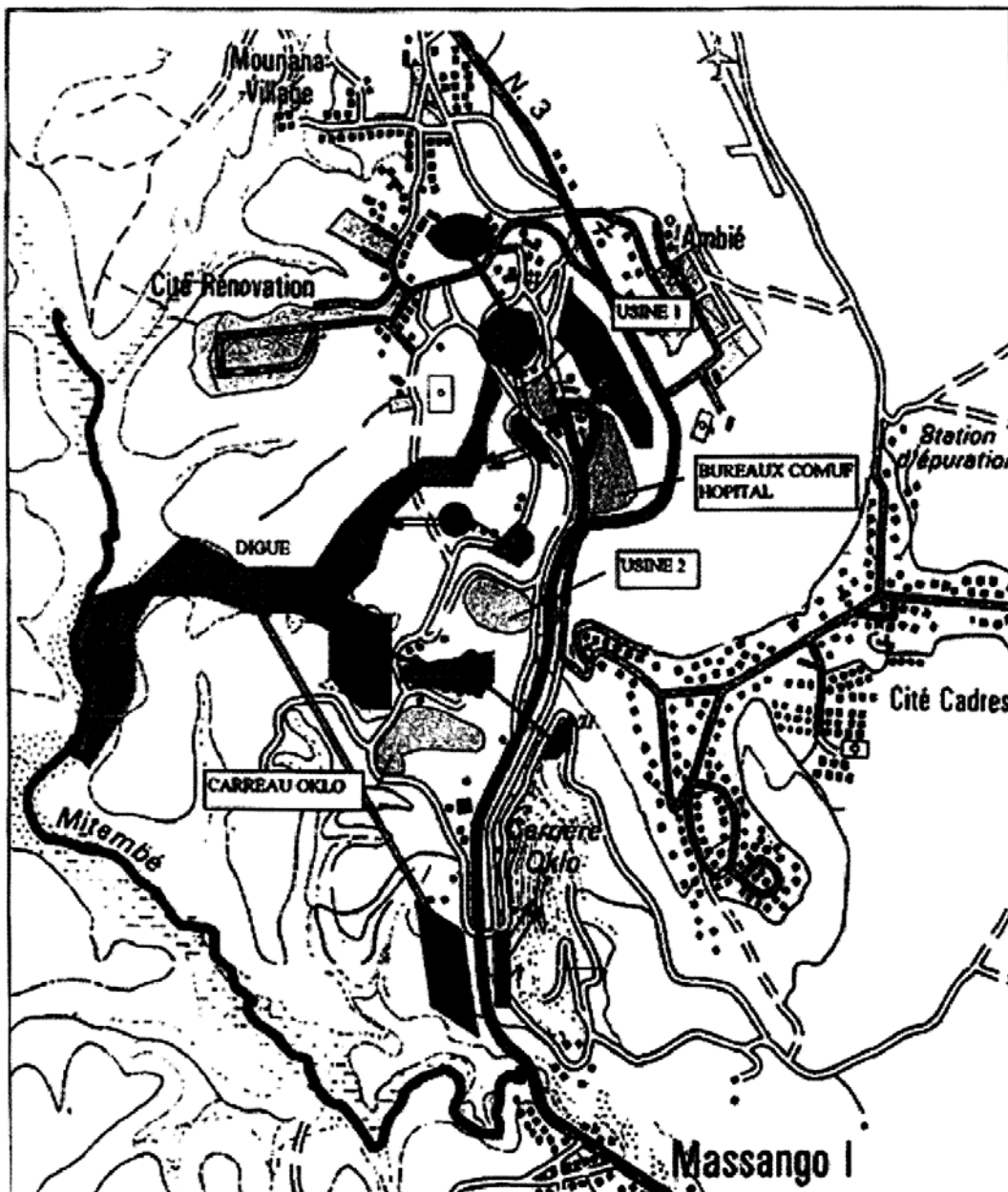
Stage 4: Nature of the clean-up work

It is essentially a matter of controlling the radiological effect of the sources rather than managing the sources themselves. Accordingly, for each zone to be treated, the nature of the work to be carried out was defined taking into account the radiological objective to be reached.

Progress of restoration work

The schedule for completing the restoration programme is given in Table 3.

Figure 1. Restoration of the COMUF site (Identification of areas to be rehabilitated)



ZONES FOR RESTORATION

- 1 MOUNANA MCO
- 2 Gamambougou valley: above point 402
- 3 Gamambougou valley: above dike
- 4 Gamambougou valley: below dike
- 5 Area of confluence with Mitembé River
- 6 Thalweg South
- 7 Thalweg North

ZONES TO BE CLEANED UP

- I Boyindzi area
- II Area of old plant 1
- III Area below sulphuric acid plant
- IV Feed zone
- V Ore storage
- VI Ore storage
- VII Head end of Oklo MCO

Table 2. Schedule for the dismantling and rehabilitation of the site

YEARS	1998				1999				Post 1999				
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	2000	2001	2002	2003	2004
Algade study													
Dyke on the Gamambougou													
Dismantling of the Boyindzi well	Done in 1997												
Rehabilitation of the Mounana quarry													
Thalweg North													
Thalweg South													
Upper Gamambougou valley zone													
Zone below dyke down to Mitembé													
Closure of structures open to the air													
Stripping off contaminated soil													
Replanting													
Restoration work													
Dismantling: substances to be controlled													
Old plant + rehabilitation													
New plant													
Oklo well													
Entire rack													
Sulphuric acid plant													
Solvent plant													
Plant silos													
Post-closure surveillance													

Source: COMUF

• Germany •

Government policies and regulations

Uranium mine decommissioning and remediation in Germany is regulated by a number of federal and state acts, ordinances and guidelines. Among the most important are the following federal acts and ordinances discussed below.

The Federal Mining Act (Bundesberggesetz – BbergG, August 13, 1980)

The legal basis for the operation and restoration of uranium exploration projects in former West Germany was the General Mining Act (Allgemeines Berggesetz ABG) and after 1980 the Federal Mining Act (Bundesberggesetz – BbergG). These acts stipulate that, in the licensing process, the mines inspectorates take into account requirements of other regulations, concerning, for example, water protection and radiation protection.

The Radiation Protection Ordinance (Strahlenschutzverordnung, June 30, 1989)

Because there were no significant uranium mining and production activities in the former West Germany, the Radiological Protection Ordinance covers the special situation of uranium mining operations only marginally. Exploration, mining and processing of radioactive mineral resources were included in the ordinance only for completeness, and specific requirements and conditions of uranium mining operations were not taken into account. Therefore, the ordinance was not fully applicable to the remediation of waste rock piles, tailing ponds and facility areas. For that reason, the German unification treaty stipulates that the regulations of the former Germany Democratic Republic (GDR) on radiation protection should continue to apply to the decommissioning and remediation of uranium mining.

Nuclear Safety and Radiation Protection Ordinance (VOAS, October 11, 1984)

This ordinance was enacted by the government of the former GDR. It has been carried over by the unification agreement because it contains provisions dealing with the specific requirements and conditions of uranium mining and processing. It is still in effect for uranium mine decommissioning and remediation in Saxony and Thuringia.

The Wismut Act (Wismut Gesetz, December 12, 1991)

The Wismut Act regulates the responsibilities of the federal government for the decommissioning and remediation of the uranium mining and processing facilities operated by the former SDAG Wismut. This act mandates the newly formed Wismut GmbH to shut down the former mines and to remediate the associated sites.

Other federal laws and regulations

Other federal laws and regulations to be considered in the licensing process for decommissioning and remediation are:

- The Atomic Energy Act.
- The Radiation Protection Regulations.
- Federal Emission Control Act.
- The Environmental Liability Act.
- Act on Managing Water Resources.
- The Waste Water Charges Act.
- The Drinking Water Ordinance.
- Closed Substance Cycle Waste Management Act.
- The Ordinance for Supervision of Waste Materials.
- The Federal Building Code.
- Federal Regional Planning Act.
- The Federal Nature Conversation Act.
- The Federal Forest Act.

Based on the federal acts and ordinances, it is the state governments that have the responsibility for licensing particular decommissioning and remediation activities. In the process, they will take into account a number of state acts and regulations, most prominently those concerning air, water and soil protection. The federal government has sole responsibility for regulating all matters relating to nuclear issues, including uranium mining and processing. This gives the federal government the authority of supervising the licensing activities of the state governments in matters concerning the radiation protection ordinance and the atomic safety ordinance.

In addition, guidelines concerning the reuse of land and material employed in uranium mining and processing, which have been formulated by the German Commission on Radiation Protection, are being considered for deciding if remediation is required or if land, material or equipment can be released for unrestricted use. The guidelines are based on the 1 mSv/a principle. This principle suggests that no person should be exposed to an additional dose equivalent of not more than 1 mSv/a by living in or near a site, or by using equipment or material, formerly used in uranium mining or processing.

History of uranium mining in Germany

The history of commercial uranium mining in Germany began after the Second World War and took a very different course in the two parts of the then divided country.

Uranium mining and processing in East Germany was performed on a large scale. By 1990, former East Germany had produced approximately 232 000 tonnes of uranium, putting it in third place after the United States and Canada.

It was in East Germany where German commercial uranium mining started 1946 in the Aue area of the Ore Mountains, a historic silver mining district in Saxony. At this site, in the fall of 1945 Soviet geologists began assessing old geological records, and by 1946, the first uranium ore was mined. In 1947, the Soviet-owned company SAG Wismut was established, which, in 1954, was transformed into the state owned bi-national Soviet/German company SDAG Wismut. Each government held a 50% interest in the company. After unification, the Soviet government transferred its share in the company to the German government, which has been the sole owner of Wismut since 1991. Subsequently, the legal status of the bi-national stock company SDAG Wismut was changed into the limited liability company Wismut GmbH.

Economic and ecological reasons had prompted the German and Soviet governments to agree on shutting down all mining and processing activities at Wismut even before the German government became the sole owner. By the end of 1990, all production operations were discontinued.

West Germany saw uranium mining and processing activities starting as late as 1960 and only on a small, exploratory scale. Privately owned companies carried out all mining and milling activities. By 1990, all test mining and processing activities had come to an end in West Germany as well.

Uranium mine remediation

Whereas uranium mine remediation in West Germany is essentially complete, remediation work in East Germany is still in progress on sites operated by the Wismut GmbH. Other sites in Saxony, Thuringia and Sachsen-Anhalt, which were used earlier by the former SDAG Wismut and its precursor SAG Wismut, but which are now under the jurisdiction of the respective state governments, have seen little or no remediation so far. Figure 1 shows the locations of uranium mining and processing sites, which are presently in the process of remediation or where remediation is finished.

Remediation of Wismut sites

Forty years of intense mining left many liabilities in East Germany. When operations ceased in 1990, the Wismut sites covered approximately 36 square kilometres. It contained a large number of shafts, waste rock piles, sub-grade ore piles, contaminated buildings, several tailing ponds, 4 extensive underground mines, and one open pit. Table 1 shows the situation at the end of 1990.

Table 1. Number and size of Wismut-liabilities in 1990

	Aue	Königstein	Ronneburg	Seelingstädt	Total
Area, ha	570	140	1 600	1 300	3 610
Shafts	8	10	38	0	56
Waste Rock Piles					
• Number	37	3	16	9	65
• Area, ha	340	40	600	500	1 480
• Volume, million m ³	45	4	190	70	309

Table 1. Number and size of Wismut-liabilities in 1990 (contd)

	Aue	Königstein	Ronneburg	Seelingstädt	Total
Tailing Ponds					
• Number	1	3	3	7	14
• Area, ha	4	5	9	700	718
• Volume, million m ³	0.3	0.2	0.3	160	160.8
Mine workings					
• Area, km ²	30	7	70	0	107
• Open drifts etc, km	240	110	1 000	0	1 350
Open pits					
• Number	0	0	1	0	1
• Area, ha	0	0	160	0	160
• Volume, million m ³	0	0	84	0	84

For the clean-up of the Wismut sites, the federal government has committed a total of DEM 13 billion as part of the federal budget. The funds are appropriated annually by the federal Ministry of Economics and Technology. The ministry mandated Wismut GmbH to optimise ecological, economic, and social effects in planning and executing the decommissioning, clean-up, and remediation of the uranium mining and processing facilities.

By the end of 1999, Wismut GmbH had spent some DEM 6.2 billion for remediation planning, preparation and implementation. Medium-term financial planning anticipates spending an additional DEM 2.4 billion on remediation during the period from 2000 to 2004. Completion of the project, to be achieved between 2010 and 2015 for the various sites, will again require additional DEM 4.4 billion.

Closure of underground mines

The method of choice for underground mine remediation at Wismut is mine flooding. Before the mines are allowed to flood, a number of preparatory measures have to be taken:

- Removal of grease/oils and hazardous chemicals from underground mines.
- Damming and sealing of individual mine fields to ensure control of water and air circulation.
- Backfilling of mine workings that may cause a subsidence at the surface.
- Permanent filling and plugging of pit shafts, adits, and large diameter bore holes.

Flooding has actually started at the Gittersee, Ronneburg and Aue underground mines. At Königstein, mine flooding is to start in 2001.

Since remediation began, Wismut GmbH has spent about DEM 3 billion on underground clean-up to prepare for the flooding. Table 2 shows the status of underground mine remediation achieved by the end of 1999.

Figure 1. Location of uranium mining and processing facilities in Germany



- | | |
|---|--|
| 1. Menzenschwand underground mine, Baden-Württemberg. | 7. Crossen processing plant, Saxony. |
| 2. Ellweiler open pit and processing plant, Rhineland-Palatinate. | 8. Ronneburg open pit and underground mine, Thuringia. |
| 3. Wäldel underground mine, Bavaria. | 9. Königstein underground mine, Saxony. |
| 4. Höhenstein underground mine, Bavaria. | 10. Gittersee underground mine, Saxony. |
| 5. Großschloppen underground mine, Bavaria. | 11. Seelingstädt processing plant, Thuringia. |
| 6. Aue underground mine, Saxony. | |

Table 2. **Remediation of underground mines** (as of 12/99)

Activities	Results achieved	Percent complete
Clean-up and abandonment of open cavities	1 300 km	93
Underground barrier construction	170 units	92
Plugging and sealing open shafts	46 units	80
Backfilling of near-surface mine workings	125 000 m ³	69
Flooding	45 million m ³	64

Remediation of waste rock piles

During active uranium mining, stockpiling of sub-grade ore, waste rock and overburden created 48 waste piles at the different sites of Wismut GmbH. At the end of uranium ore mining, these piles contained approximately 310 million m³ of waste rock and covered a surface area of approximately 1 500 hectares.

For remediation of waste rock piles, Wismut GmbH follows two different approaches:

- Moving waste rock piles to the mined-out open pit at Ronneburg or to engineered sites.
- *In situ*, i.e. in-place remediation.

Which of the two options is applied depends on local conditions. Table 3 shows the status of waste rock pile remediation achieved by the end of 1999.

Table 3. **Remediation of waste rock piles** (as of 12/99)

Activities	Results achieved	Percent complete
Excavation of waste rock material	60 million m ³	40
Placement of waste rock material	10 million m ³	56
Filling of open pit	51 million m ³	42
Waste rock pile regrading	2 million m ³	40
Waste rock pile covering	1 million m ³	20
Waste rock pile revegetation	275 ha	20

Dismantling and demolition

The majority of installations and buildings owned by Wismut GmbH are destined for dismantling and demolition. Their continued use is not feasible for various reasons.

At Wismut, steel without radioactive contamination will be recycled. Demolition debris is crushed before being reused inside the Wismut project for various purposes such as interim cover layers on tailing ponds. Products made of asbestos cement will be disposed of in a hazardous waste disposal facility.

After regulatory approval, radioactively contaminated material (e.g. scrap, rubble, timber/wood, excavated soil) is either disposed of underground in obsolete mine workings or above ground where it is integrated into waste rock piles, tailing ponds or in the Lichtenberg open pit. Excavated soil that is contaminated with both radionuclides and hydrocarbons will first have its hydrocarbon concentration reduced to a prescribed level before it is eligible for disposal in the Lichtenberg open pit or for incorporation into waste piles. Hydrocarbon contamination is treated microbiologically in temporary treatment plants on Wismut terrain.

Demolition at Wismut sites has produced more than 520 000 m³ of debris and approximately 140 000 tonnes of scrap metal since the beginning of the clean-up. Table 4 shows the status of dismantling and demolition achieved by the end of 1999.

Table 4. **Dismantling and demolition** (as of 12/99)

Activities	Results achieved	Percent complete
Demolition rubble	520 000 m ³	70
Scrap metal	140 000 tonnes	70

Tailing pond remediation

Tailing pond remediation aims at a safe long-term storage of tailings by isolating them from the atmosphere, biosphere and hydrosphere as much as possible. The techniques applied to achieve this must ensure that emissions via air and water pathway are minimised to comply with regulatory requirements.

At Wismut, these objectives are going to be achieved by *in situ* stabilisation of tailings. Further planning will be based on this general approach, while design details (contouring, covering, seepage collection, vegetation, etc.) have to be optimised for each tailing pond under consideration.

Tailing pond stabilisation will involve the following steps:

- Removal, treatment and discharge of supernatant pond water.
- Interim covering of exposed tailing areas.
- Regrading of dam and tailing surfaces.
- Final covering of contoured surfaces.
- Landscaping and revegetation.
- Collection, treatment and discharge of seepage.
- Long-term monitoring.

For tailing pond stabilisation, removal of pond water is a prerequisite. Radionuclides and other contaminants contained in supernatant and pore waters have to be removed and immobilised. For this purpose, a water treatment plant installed at the Helmsdorf site to treat water from the Helmsdorf and Dänkritz 1 tailing ponds has been on stream since mid-1995. By the end of 1999, this facility had treated some 7 million m³ of pond water. Immobilised residues from the water treatment process are deposited in an engineered disposal site within the Helmsdorf tailings facility where they will be encapsulated as part of the final cover construction. Another water treatment plant is under construction at the other large tailing pond area in Seelingstädt.

Placing of an interim cover is at various stages of completion at the different sites. Table 5 shows the status of tailing pond remediation achieved by the end of 1999.

Table 5. **Tailing pond remediation**

Activities	Results achieved	Percent complete
Pond water removal	160 million m ³	80
Placing interim cover	350 ha	61
Placing final cover	0 ha	0

Water treatment

Contaminated water from Wismut remediation operations has to be collected and treated in special water treatment plants to protect ground and surface waters from pollution. Such waters are primarily:

Flood water	Ground water that is pumped from a mine for flood control purposes or that overflows at the surface when mine flooding is completed.
Pond and pore waters	Mill process waters and precipitation contained in tailing ponds.
Seepage	Infiltrated surface and pore water seeping from the toes of waste rock piles and tailing dams.

Depending on site conditions, contaminant removal and immobilisation impose different water treatment requirements. The wide range of treatment methods in use or being considered includes ion exchange, precipitation techniques as well as ultra filtration and reverse osmosis.

Since Wismut GmbH started to remediate its uranium mining liabilities, water treatment has been one of the main tasks on the company's agenda. Over the past nine years, approximately 200 million m³ of contaminated water have been treated. Water treatment produced approximately 500 000 m³ of residues which were disposed of properly. Water treatment costs to date amount to some DEM 300 million.

Water treatment will continue to be a requirement for decades to come. After the closure and remediation of mines, tailing ponds, and waste rock piles, contaminated water will continue to flow or seep from these objects for some time and will need treatment.

Remediation of various sites in West Germany

From the beginning of the 1960s, five uranium mines and one ore processing plant operated in West Germany. They were:

- Ellweiler open pit, Rhineland-Palatinate
 - Operating period: 1960-72.
 - Production: 57 400 t of ore with about 0.03% U₃O₈; a total of 15.3 t U₃O₈.
 - Remediation: 1972.
 - Remediation cost: no data available.
- Menzenschwand mine, Baden-Württemberg
 - Operating period: 1961-90.
 - Production: 98 900 t of ore with about 0.7% U₃O₈; a total of 687.2 t U₃O₈.
 - Remediation: 1991-93.
 - Remediation cost: DEM 1.496 million.

- Wäldel mine, Bavaria
 - Operating period: 1969-82.
 - Production: 4 800 t of ore with about 0.06% U₃O₈; a total of 1.36 t U₃O₈.
 - Remediation: 1993 -94.
 - Remediation cost: DEM 5.923 million.

- Höhenstein mine, Bavaria
 - Operating period: 1978-82.
 - Production: 13 900 t of ore with about 0.08% U₃O₈; a total of 10.8 t U₃O₈.
 - Remediation: 1993.
 - Remediation cost: DEM 0.926 million.

- Großschloppen mine, Bavaria
 - Operating period: 1984-87.
 - Production: 18 600 t of ore with about 0.19% U₃O₈; a total of 35.7 t U₃O₈.
 - Remediation: 1989.
 - Remediation cost: DEM 1.729 million.

The total production of these five mines amounted to 750.6 t U₃O₈ (636.5 t U).

- Ellweiler ore processing plant, Rhineland-Palatinate
 - Operating period: 1960-89.
 - Processed ore: 173 300 t.
 - Production: 766.6 t U₃O₈ (650 t U).
 - Area covered by the tailings heaps: about 25 000 m².
 - Surface area of the tailings heaps: about 27 000 m².
 - Remediation: 1998-2000
 - Remediation cost: DEM 43 million

The Ellweiler plant was set up in 1960 near Birkenfeld, Rhineland-Palatinate, as a research facility and was first supplied with ore from the Ellweiler open-pit mine. From 1961, it received ore from the Menzenschwand mine. During the 1970s, Ellweiler also processed some of the ore from the Wäldel and Höhenstein mines. In a “substitution procedure”, the state government of Rhineland-Palatinate commissioned and directed the remediation work at the site since the former operator of the plant became insolvent.

• Hungary •

After the shut down of the Hungarian Uranium Industry at the end of 1997, the Mecsekérc Environmental Corp. began the closing and remediation works. The total project was prepared by this company and has been approved and financed by the Hungarian Government.

In 1998, the company prepared 130 studies, projects and reports that allowed a successful co-operation with authorities and local governments in 1999.

During 1999, thirty public procurements were started in addition to two international competitions established in the frame of PHARE and ISPA programmes.

Main activities in 1999

The main environmental related activities performed in 1999 include:

Closing of underground facilities

- Reorganisation of ventilate routes.
- Dismantling of mechanical and electric equipment.
- Building of “final” closing dams.
- Removing of polluted areas: anfo, oil, alcali, acid.
- Filling back of transportation and ventilation shafts (in part and completely).

Final evaluation of the Uranium Resources and Reserves

Remediation works on the surface facilities

- Investigation of polluted areas: radiation, petrol, alcali, acid.
- Decontamination: buildings, structures, instruments, tools, materials.

Remediation works on the waste heaps

- Maintenance on the revegetated heaps: control of thickness of covering soil, replacement of earlier planted vegetation.
- Transportation of covering soil on the other heaps, including the leached heaps.
- Building of the drainage ditch around the largest waste heap.

Remediation of the leached heap No. 2

Because of the proximity of a water-table, it was necessary to remove material from the leached heap No. 2. In 1999, 1 703 490 m³ of material was transported to the largest waste heap.

Remediation works on the Tailing Ponds

- The feasibility study of the total remediation of tailing ponds was accepted by the authorities and preparation of the licensing plans was started in 1999.
- Investigation of covering was finished.
- Investigation of load for the stabilisation was finished.

Handling of the mine water

- The conceptual plan is ready.
- The technological, licensing and implementation plans are ready.

Reconstruction of water and sewerage system

Development of Environmental Protection

- 604 m new boreholes for monitoring.

Creation of database on final state of health of former employees

Main activities in 2000

Finishing of the underground works

Remediation of the surface facilities

- Dismantling and demolition in the ore processing plant.
- Revegetation of the main transport and supply facility site.
- Finishing of the material removal from the leached heap no. 2.

Remediation works on the Tailing Ponds

- Pollution containment.
- Water handling.
- Restoration of water quality.
- Storage for the precipitation of the water treatment.
- Finishing and accepting of the implementation plans for the total remediation of tailing ponds.

Aggregate cost data

The expected total cost for the site in 1997 prices is HUF 18.4 billion or about USD 92 million.

The total uranium produced between 1956 and 1997 was 21 251 tU.

Total cost based on the following specific items

- Planning, engineering and licensing: ~ 2%.
- Tailing ponds: = 163 ha = 11 734 000 to ~ 20 417 000 m³.

- Waste rock piles: area is 82.57 ha; surface is 85.33 ha; and volume is 9 872 600 m³.
- Processing plant facilities: ion exchange – 1 000 t ore/day; closed.
- Mining facilities: underground – 1 000 t ore/day; closed.
- Reclaimed areas: 303 ha.

Relevant Legislation

There is no legislation dealing specifically with the prospecting for and mining of uranium ores. General mining legislation would, therefore, apply (Act No. XLVIII of 1993, as amended by Act No. XII of 1997).

Under the Atomic Energy Act of December 10, 1996, the President of the Hungarian Mining Authority is empowered to enforce technical and safety aspects of mining, in so far as they relate to the activities licensed by the HAEA or licensed by the Minister for Health.

• Japan •

Government policies and regulations

Wastes from past uranium production activities have been controlled in accordance with all related regulations. Regulations applicable for the shutdown of uranium mines and mills are as follows:

- Uranium mining and milling facilities: *Mines Safety Law* (No. 70, 1949), *Mine Safety Regulations*.
- Nuclear raw materials: *Law on Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors* (Atomic Control Act No. 166, 1957) and *Regulation for Nuclear Raw Materials and Nuclear Fuel Materials Milling Operation*.

Mine Safety Law and Regulations

The regulations are not only aimed at uranium mining and milling but also at commodities such as oil, coal, limestone and metal mines. The regulations include radioactive safety clauses for uranium mining and milling to prevent radiation hazards.

If the mining right is transferred or abandoned, the *Mine Safety Law* requires that responsibility be established to take measures to prevent mine pollution from a waste rock dump, tailings disposal site or an abandoned excavation. The act also establishes the entity that is responsible for this issue.

A holder of mining rights is only allowed to dispose of waste rock, tailings and precipitates using a form of piling and layering. Technical standards for reclaiming wastes are established in the regulation.

Waste rock and tailings are allowed to be disposed as piles. Protective walls and dams to prevent collapse of effluents are required. After piling of the wastes is terminated, a disposal site is required to be covered by soil and revegetated, if necessary.

The above regulations are applied to all mines, including uranium mines. In an uranium mine, the level of external radiation and radioactive materials in the air and water are of special concern. They are regulated to prevent radiation hazard to both workers and the public. Nothing is mentioned following closure of a facility. It is interpreted, however, that the regulations for preventing radiation hazards to humans in an operating facility apply to the closing of a facility.

Atomic Control Act (1957)

This Atomic Control Act is aimed at (1) restricting uses of nuclear raw materials, nuclear fuel materials and nuclear reactors to civil purpose only, (2) preventing disasters and (3) securing public safety. This act applies only to milling, not to exploration and mining activities.

When a milling facility is closed, the operator removes all nuclear fuel material and decontaminates the facility and disposes the contaminated materials. The regulatory minister requires that necessary measures be taken if the close down actions have not been carried out properly. When contaminated nuclear fuel materials are disposed outside the facility, safety measures are required under the ministerial ordinance. The minister will require necessary measures to be taken when the manner of disposal violates the ministerial ordinance.

Historical information on country's restoration activities

Currently, no uranium mining and milling is carried out in Japan. Environmental restoration plan strategy for mining and milling facilities at the Ningyo-toge area, Okayama and Tottori Pref. is under consideration. The plan may consist of stabilisation, disposal, and controlling of wastes such as uranium mill tailings, precipitates and waste rock and other contaminated material. The mill facility has been dismantled since 1983.

Facilities with ongoing or future plans for restoration activities

All of the activities described below are related to environmental restoration activities at facilities of the Ningyo-toge site, Okayama, Pref. as an example.

Mill facility

The operation of mill was started in 1964 and finished in 1981. Dismantling of the facility was gradually carried out from 1983 to 1990 and from 1998 to 2001. The building is used for storage of the disassembled materials.

Heap leaching facility

Uranium recovery from the low-grade ore was carried out experimentally at the heap leaching facility from 1979 to 1987. At present, the facility is inactive and under maintenance. Dismantling of the facility is under consideration.

Mill tailings dam (tailings impoundment)

The mill tailings dam was constructed in 1964, and has disposed wastes consisting of mill tailings, precipitates, filter sand from the mill facility, the heap leaching facility and the wastewater treatment facility. The amount of wastes is about 34 000 m³ as of 1999. Additionally, mine water discharged from old gallery is also stored temporarily. At present, a closet plan of the dam is under consideration.

Waste rock dumps

From 1957 to 1986, 18 waste rock dumps were constructed. At present, all waste rock dumps are inactive and being maintained. Closet activity plans of all dumps are under consideration.

Environmental monitoring

The environmental monitoring of the site, which is required by the mining safety act and regulation, has been carried out since mining activity started. It includes the measurement of environmental gamma ray, equilibrium equivalent radon concentration in the air, and the concentration of U and Ra in the surface water near the boundary of the site.

Waste rock dumps, sub-grade and ore stockpiles (number, volume, area)

	Waste rock dumps	Tailings impoundments
Number	18	1
Total volume in m ³	432 000	34 000
Total area in m ²	77 000	125 000
Costs: restoration action plan including the cost estimate is under consideration at present.		

• Kazakhstan •

Government policies and regulations

Kazakhstan was one of the largest uranium producing regions of the former USSR. More than 100 occurrences of uranium mineralisation are located in the territory of Kazakhstan. Forty of them are commercial deposits. Uranium extraction or exploration by mine works with radioactive waste formation was carried out at 100 sites.

Three large Combines for uranium ore processing were operated in Kazakhstan: Pricaspian Combine, in the West part of the Republic; Tselinny, in the North; and Ulba Combine, in the East. These Combines have formed large volumes of radwaste. Currently, uranium ore processing has practically been stopped and radwaste are not being produced. Some wastes are produced at the Ulba Combine during uranium pellet production.

Currently, uranium is being extracted in Kazakhstan using *in situ* leach (ISL) mining technology. In this case, the volumes of solid wastes are almost entirely eliminated. At the same time, considerable radionuclide contamination of ore bearing aquifers happens in the ISL process. If this aquifer is a source of water supply for a population, the problem of groundwater restoration is a very expensive and complex problem. If the groundwaters were previously not suitable for water supply, authorities can give permission to leave the water without restoration after uranium extraction.

Most of the suitable deposits for ISL method in Kazakhstan are located in the territory where ore bearing aquifers are not suitable for water-supply due to high salinity and/or primary contamination by the natural radionuclides near the geochemical barrier of the redox front. In this case uranium producers are permitted to rely on self-restoration (natural attenuation) for restoring the aquifers. This generally takes 30-40 years.

In the future, uranium extraction in Kazakhstan will not create large volumes of waste. Use of ISL will help reduce the problem of radwaste management. At the same time, the radwaste located at former conventional milling sites is an important problem for Kazakhstan.

The first economic uranium deposit in Kazakhstan, Kurday, was discovered in the South of Kazakhstan in 1954. Mining of this deposit began soon after. For ore processing of this deposit and as well as other South Kazakh mines the Kirgiz Production Centre (mine-ore combine) was put into production in 1959. Now the Kirgiz Combine together with its process tailings are situated in the territory of Kirgizstan. Further discoveries of uranium deposits and their extraction led to the construction of the above named Combines. Mines and Combines have formed about 235 million tonnes of waste rock dumps and tailings. During operation of these enterprises, some reclamation work was carried out, but most remain unrehabilitated.

The former USSR had no legislative base for radwaste management. All work was carried out through departmental instructions. After the collapse of the USSR, Kazakhstan began to create a legislative base. Now Kazakhstan has the Law *On Using of Atomic Energy* and a Draft Law *On Radwaste Management*. There are regulatory codes on decommissioning and reclamation of production areas. Several projects for reclamation of areas with mining and milling wastes have been

established. However, none of these projects are being carried out due to financial difficulties in Kazakhstan.

The first document regarding radioactive waste was the *Regulation on the Use of Atomic Energy, Radioactive Waste and Spent Nuclear Fuel Management* adopted by Resolution No. 364 of 11 April 1994. On the basis of this Regulation, the radwaste management system in Kazakhstan was created. But this work was stopped due to financial difficulties in the country. The main complication of this problem is that the largest volumes of existing radwaste have no owners, due to the liquidation of enterprises after the collapse of the USSR. The Government of Kazakhstan by special decree assigned the responsibilities for radwaste management (including mine and milling waste) to the state-owned company NAC Kazatomprom. However, they were given no budget for this work.

Radioactive waste management by the existing and projected enterprises is implemented on the basis of the Law *On Licensing* of 17 April 1995 and Governmental Decree No. 100 *On Licensing Activity Connected with Atomic Energy Use* of 12 February 1998. The authority responsible for licensing is the Atomic Energy Committee of Kazakhstan. Surveillance functions are carried out by the Ministry of Health, Ministry of Natural Resources, and the Agency on Emergency Situations.

Historical information on the country's restoration activities

Systematic investigation and inspection of mine and mill waste in Kazakhstan started in the 1990s. First investigations were carried out by the geological enterprise Volkovgeologia under projects approved by Ministry of Ecology. The goal of this investigation was to determine the volume and condition of waste rock dumps. Such works were carried out in the south of Kazakhstan at the sites of 3 deposits (Ulken-Akzhal, Kurday, Panfilovskoe). The geological enterprise Stepgeologia began to carry out similar work in the north of Kazakhstan (Kosachinoe deposit and others). But soon this work stopped due to budget difficulties.

Investigation within the framework of the TACIS Programme of the European Union: *Assessment of Urgent Measures to be taken for Remediation at Uranium Mining and Milling in the Commonwealth of Independent States*, Regional Project No G42/93, Project No NUCREG 9308 in Kazakhstan were carried out in 1996-1998. This project included four phases:

1. Identification of sites.
2. Radiological survey of the selected sites and measurements.
3. Geochemical and hydrogeological modelling.
4. Assessment of remediation options and ranking.

In connection with the condition and results of projects, in the framework of this project only the work of the first and second phases were carried out in Kazakhstan. As a result of the first phase, 100 sites of mine and mill radioactive waste storage were revealed. The sites are located in different parts of a huge area of Kazakhstan and are characterised by various features. Three criteria were used for determination of the degree of danger of the sites: proximity to populated area, climate of sites (precipitation) and grain size of waste. 78% of sites are located farther than 3 km from populated places, 80% are located in an area with precipitation less than 300 mm/y. 70% of volumes of radwaste are characterised by grain size less than 1 mm. The last factor is the factor of greatest risk.

According to these criteria and some other circumstances, 6 sites were selected for carrying out further investigation under the second phase of the project: measuring, sampling and analytical works. Sites were selected to include the entire spectrum of situations. Two sites include exploration waste

(Kyzyl and Kosachinoe), 2 are mining sites (Kurday and Botaburum) and 2 sites have tailings accumulations (Pricaspian and Ulba Combines). Of these, Kyzyl, Botaburum and Pricaspian Combine are located in a zone with precipitation of less than 300 mm/y and Kosachinoe, Kurday and Ulba Combine—of more than 300 mm/year.

According to the detailed plan of the second phase of the project, the following activities were carried out at each site: radiometric survey (if needed); lithochemical sampling; water sampling; vegetation sampling; aerosol sampling; and radon measurements.

The types of sampling are determined on the basis of the task of dose assessment for the population. In this case, lithochemical sampling and radiometric measurements are being carried out for determination of mainly external exposure dose. Water and air sampling data allow the assessment of internal exposure dose caused by water and food use. Based on the results of data analysis at each site, the directions of diffusion flow are determined and the points of sampling are planned. The sampling volume is used so that it is possible to determine the area of the radionuclide contamination, as well as the radionuclide diffusion flow and characteristics of the area of the radioactive material removal from waste dumps. In addition, sampling was carried out for the determination of the background.

Lithochemical sampling is carried out by the “envelope method” (1m × 1m). At all points, a common assay and small fraction (up to 0.2 mm) are sampled. Water sources are sampled up and down the hypsometric level of the waste sites. Vegetation sampling is carried out at the same places as litho-chemical sampling. The top part of plants (higher than 3-5 cm from earth surface) are used for assay material. Aerosol assays are sampled on 0.5m × 0.5m sticky screens which are left in place for 48 hours and then burnt. The ashes are analysed and then, taking into account the exposition time and sticky screen square, the radioactive fallout intensity is determined (as Ci/sq. m per day). These sticky dust-radiation screens are placed according to the wind direction during measurements. Radiometric measurements are carried out using a radiometer SRP-68-01. Measurements of radon concentration near the ground surface are carried out using the radonmeter “Ramon-01”.

All the lithochemical samples from the investigation sites are analysed for total α -activity. The same is done for vegetation and aerosol samples after ashing. The radionuclide composition is assayed for normal samples. The ^{238}U , ^{226}Ra and total chemical composition are determined in water samples.

The assessment of the radioactive waste impact with application of hazard criteria allows the following conclusions to be drawn. The soil and vegetation sampling shows the radionuclide concentration for the areas contaminated by dump materials exceeds the maximum-permissible concentrations. Higher radioactivity was found in the Kosachinoe deposit (44 500 Bq/kg in soils and 1 200 Bq/kg in vegetation), at the sites where the recultivation is not yet finished or was not carried out in an acceptable manner. The contamination and gamma-activity exceeding the maximum-permissible values at all other sites are located only in, or very close to the waste dumps.

The study of the dust related radiation shows there is a problem only at the Kosachinoe deposit. This is in areas where radwastes are fine grained. Here an increase of radioactive fallout of up to 1.08 Bq/m² day was detected. This figure may be considered as near the permissible level of contamination. No significant increase of dust related radiation is observed at any other site.

Analysis of water samples from surface water sources and wells show an increase of contamination at Kashkarata lake (disposal site for liquid radwaste of Pricaspian Combine), at Kurday, Botaburum and Kosachinoe deposits and especially at the Ulba Combine. An increase of radionuclide concentrations of up to 2.2 Bq/l at the Kurday deposit may be directly explained by the transport of

radionuclides from the dump material to the river. In the samples of the Kashkarata Lake region (a small isolated reservoir), Botaburum and Kosachinoe deposits, the increase of radionuclide concentration may be explained by manmade contamination and by the intensive evaporation processes in the respective areas. In such conditions, the water of the intermittent Iman-Burluk River (Kosachinoe) has radionuclide concentrations slightly exceeding the maximum permissible concentrations of up to 7.8 Bq/l. This undoubtedly originated from the adjacent dumps. This water must not be used. The contamination of water in the rivers is increased by the intensive evaporation processes in the very arid area.

The most serious contamination found was at the Ulba Plant. This is a site that does not involve uranium production. It should be noted however that underground water radionuclide concentrations exceed the maximum permissible concentrations (up to 17.9 Bq/l), as defined by the well sampling programme in the area of the operational sites and waste dumps at the Ulba Plant. This contaminated aquifer is used for the Ust-Kamenogorsk water supply.

The Stage II investigations have found that, in spite of the establishment at some sites of a radionuclide enrichment of vegetation, for example the ore dump areas (Kosachinoe deposit) and water sources (Kurday and Kosachinoe deposits) located near waste site, most of the radioactive wastes that resulted from the exploration and mining activities in general may be considered as not dangerous for the environment of Kazakhstan. At the same time, the radioactive wastes may be of potential danger for the resident population due to usage of the waste as construction materials for dwellings or other purposes. Thus protection measures have to be implemented to prevent the uncontrolled usage of radioactive wastes, or the waste disposal sites should be recultivated.

The situation is more complicated in the areas of mill tailings and other process wastes: abandoned processing impoundments of Pricaspian Combine in west Kazakhstan (Kashkarata Lake), tailings of the active Tselinny Combine in north Kazakhstan and both closed and active waste impoundments of the Ulba Combine in east Kazakhstan. Kashkarata Lake is located on a clay horizon. Therefore, no contaminated water leakage is likely to take place from this reservoir-impoundment. Kashkarata Lake is situated 6 km from the town of Aktau. The Pricaspian Combine is currently shut down, possibly forever, so the potential exits for a 10 km² surface to be transformed to a dust producing area due to the local intensive sun and wind. The same problems may arise at the Tselinny Combine in the event of its shutdown. Due to the related economical problems, as well as a number of other reasons.

Particular attention should be drawn to the Ulba Combine. It is a healthy enterprise with a long-term industrial programme. The main problem is that it is located practically at the town limit of Ust-Kamenogorsk. At the Ulba Combine, leakage of radionuclides into the aquifer has been revealed. This aquifer is one of the sources of the water-supply for Ust-Kamenogorsk. Therefore, along with the remediation procedures for the old closed waste surface, investigations of aquifer contamination are required using new hydrogeological monitoring wells and water sampling.

Facilities with ongoing or future plans for restoration activities

Currently in Kazakhstan, restoration activities are neither being carried out nor planned due to financial difficulties. However, as shown above, some of the sites are somewhat dangerous. The greatest risk is related to the situation at the 3 tailings disposal areas. If, for example, in connection with shutdown of Pricaspian and Tselinny Combines, the water pumping in the tailings impoundment is stopped, then “a dry dust producing zone” of 17 km² could be formed.

The programme at the Ulba Combine includes some activities to decrease the environmental impact of waste from the production of uranium pellets. However, the danger of existing uncontrolled waste material remains.

In the table below, the data are shown for the 22 sites each of which contains more than 10 000 t of radioactive waste. The other 78 sites hold from 0.1 to 10 000 tonnes. However more than 98% of total waste volumes are located in the first group of 22 sites.

Table 1. Distribution and description of the waste rock dumps and tailings impoundments in Kazakhstan



	Name of deposit or combine	Region (Oblast)	Status of production facilities	Type of waste	Volume (1x10³t)	Surface (ha)	Closest settlement (km)
1.	Ulba Combine*	East Kazakhstan	Operating	Tailings	420	11	0.5
2.	Pricaspian Combine	Mangistau	Mothballed	Tailings	120 000	1000	6
3.	Tselinny Combine	Akmola	Mothballed	Tailings	88 330	722	5
4.	Deposit Botaburum	Zhambyl	Worked out	Dumps	3 681	28	1.5
5.	Deposit Kurday	Zhambyl	Worked out	Dumps	6 280	35	3
6.	Deposits Sections 2 and 4	Zhambyl	Worked out	Dumps	2130		6
7.	Deposits Sections 7 and 11	Zhambyl	Worked out	Dumps	396	24	20
8.	Deposit Chaika	Akmola	Worked out	Dumps	1 772	4.8	12
9.	Deposit Balkashin-skoe	Akmola	Standby	Dumps	576	9.3	5
10.	Deposit Shokpak-Skoe	Akmola	Standby	Dumps	866	5.6	3
11.	Deposit Ishimskoe	Akmola	Worked out	Dumps	568	12.8	6
12.	Deposit Manybay	Akmola	Worked out	Dumps, Heap Leaching piles	4 860 1 480	30 46	0.5
13.	Deposit Ulken-Akzhal	East Kazakhstan	Unperspect.	Dumps	19		27
14.	Deposit Panfilivskoe	Almaty	Unperspect.	Dumps	13.5	10	0.1
15.	Deposit Kosachinoe	Kokshetau	Standby, Partial reclamation	Dumps	290	2.5	1.5
16.	Deposit Glubinnoe	Kokshetau	Worked out	Dumps	123	2.7	0.5
17.	Deposit Zaozyornoe	Kokshetau	Worked out	Dumps	568	4.6	6
18.	Deposit Shatskoe	Kokshetau	Worked out	Dumps	430	8	2
19.	Deposit Tastykol	Kokshetau	Worked out	Dumps	632	8	6
20.	Deposit Grachyov-skoe	Kokshetau	Standby	Dumps	448	2.1	2
21.	Deposit Agashskoe	Kokshetau	Standby	Dumps	131	2.2	2
22.	Deposit Viktorovskoe	Kokshetau	Standby	Dumps	100	1	2

* This facility produces uranium fuel pellets.

Figure 1. **Distribution of Radwaste storages in Kazakhstan**



(figures on the map correspond to figures in the table)

-  Combines (tailings)
-  Uranium deposits (exploitation dumps)

• Portugal •

Government policies and regulations

Production of uranium in Portugal is regulated by the national mining laws, Decree-Law (D.L.) 90/90 and D.L. 88/90, of March 16, 1990. These laws determine conditions for exploration and exploitation of mineral deposits. Uranium ores in Portugal are owned by the State.

Other laws specifying environmental remediation conditions include:

- D.L. 186/90 of June 6, 1990, amended by D.L. 287/93 of August 20, 1993, and D.R. 38/90 of November 27, 1990, amended by D.R. 42/97 of October 10, 1997. D.L. 186/90 provides that approval of both mining and mineral processing plants is subject to a prior environmental impact assessments.

- D.L. 162/70 and D.L. 345/96. Health and safety at mining site works.
- D.L. 348/89 of October 12, 1989, implemented by D.L. 9/90 of April 19, 1990 and amended by D.L. 3/92 of March 6, 1992, D.L. 34/92 of December 4, 1992 and D.L. 311/98 of October 14, 1998. D.L. 348/89 established the National Radiation Protection Commission as an advisory body to the General Directorate for Health and set out the institutional framework for radiation protection. Radiation protection in respect of uranium mining activities are found in Decree 34/92.

An alternative to the actual juridical framework for the preparation of Environmental Impact Studies (according to Directive 87/11/CE) will be issued in the near future, as well as a law about tailings dumps in the mining industry.

The closing down and the reclamation of uranium mines are guided by D.L. 90/90 which mandates that any project for restoration of mining sites must be approved by qualified authorities.

National Uranium Enterprise (*Empresa Nacional de Uranium S.A* – ENU) is the only limited public company that owns the mining rights for uranium exploitation in Portugal. This company recently prepared an inventory of the abandoned uranium mining sites and delineated a plan of surveillance which is being assessed by the Institute for Geology and Mines (*Instituto Geológico e Mineiro* – IGM) and the Ministry of Environment.

Restoration activities

The environmental restoration and mine reclamation activities related to uranium and radium mines started consistently in 1990. Before 1990, ENU started with the monitoring of water quality and air quality, with co-operation of governmental organisations. Since 1993, more mitigation measures are under way after completion of an Environmental Assessment related to the older uranium and radium mines. Also, the ENU's Environmental Strategic Programme has been carried out. In 1997, ENU started several environmental restoration studies.

Ongoing and future restoration activities

After the environmental strategic programme was defined, ENU started studies over the mines with higher environmental risk and stabilisation procedures were initiated at some of these mines.

The Portuguese uranium mines are classified in two groups: Group A, that includes operating and production centres or mines recently closed, and Group B, that includes mines with higher environmental risk, which are all the other older mines.

Group A

Urgeiriça – underground mine and processing plant

The mine started in 1913 and was closed in 1991. The processing plant started in 1951 and is still operating. The total production through 1998 was 3 693 tU contained in concentrate. The plant at Urgeiriça uses the acid leaching solvent extraction process (IX/SX). A programme to minimise environmental impact is under study. The characteristics of this site and information on the environmental procedures and plans include:

- Potential contamination of surface waters due to the presence of the tailings ponds, and waste stockpile. Dust losses, radon gas emanation and gamma radioactivity.

- Continuous monitoring of effluents treatment plant, periodic monitoring of groundwater, and air quality around all the industrial area.
- One waste stockpile with a volume close to 150 000 m³.
- Two tailings ponds, covering an area of 100 000 m², with a volume close to 2 500 000 m³.
- Estimated cost of the environmental restoration project: USD 2 220 000.

Bica – underground mine

The mine started in 1951 and was closed in 1998. The washing of old stopes is under way as well as environmental stabilisation. The characteristics of this site and information on the environmental procedures and plans include:

- Potential contamination of surface waters and groundwater due to the acid residue on the mine and natural leaching of the waste stockpile. Dust losses, radon gas emanation and gamma radioactivity.
- Continuous monitoring of effluents treatment plant, periodic monitoring of groundwater, and air quality around the mine concession area.
- One waste dump with 300 000 tonnes.
- No tailings pond.
- Studies for mitigation measures are under way. Estimated cost of USD 1 257 000.

Quinta do Bispo – open pit mine

The mine started in 1979 and was closed in 1987. Heap leaching of low-grade ores has continued since 1992 and is still in production. The characteristics of this site and information on the environmental procedures and plans include:

- Potential contamination of surface waters and groundwater due to the acid residue on the mine and natural leaching of the waste stockpile. Dust losses, Radon gas emanation and gamma radioactivity.
- Continuous monitoring of effluents treatment plant, periodic monitoring of groundwater, and air quality around the mine concession area.
- One waste dump with 1 500 000 tonnes.
- No tailings pond.

Vale da Abrutiga – open pit mine

The mine started in 1982, and was closed in 1989. Mine reclamation project is under way. The characteristics of this site and information on the environmental procedures and plans include:

- Pit with close to 100 000 m³ of contaminated water (acid and significant uranium and radium content); potential contamination of surface waters, groundwater and Aguieira Dam reservoir due to the risk of the pit water overflow and natural leaching of the low grade ore stockpile. Dust losses, radon gas emanation and gamma radioactivity.

- Periodic monitoring of the pit water, groundwater and air quality around the mine concession area.
- One waste dump with about 1 000 000 tonnes. One low-grade ore stockpile with about 400 000 tonnes. The concession area is about 80 000 m².
- No tailings pond.
- The restoration/reclamation programme has an estimated cost of USD 278 000.

Cunha Baixa – underground and multiple open pit mine (with heap and “in place” leaching)

The mine started in 1970 and was closed in 1993. Restoration started in 1990. Environmental stabilisation and studies for mine reclamation are under way. The characteristics of this site and information on the environmental procedures and plans include:

- Potential contamination of surface waters and groundwater due to the acid residue on the mine, and leached ore lying on the main pit. Dust losses, radon gas emanation and gamma radioactivity.
- Continuous monitoring of treatment effluents plant, periodic monitoring of groundwater, and air quality around the mine concession area.
- Two waste dumps with 1 100 000 tonnes.
- No tailings pond.
- Estimated cost of mine reclamation: USD 1 616 000.

Group B

This group includes all other mines exploited by ENU, ex-Junta de Energia Nuclear and C.P.R. (Companhia Portuguesa de Radium). This group includes about 50 old mines.

The potential environmental, radiological and/or chemical impacts are the same as for the mines described in the Group A, according to the size and type of each mine.

The project for a mine reclamation programme, proposed by E.N.U, was completed for six mines included in Group B. These mines are: Barroco I, Ribeira do Boco, Canto do Lagar, Maria Dónis (Guarda district) and Espinho and Corga de Valbom (Viseu district). The estimated cost of implementation is USD 1 123 000.

ENU also completed a guide programme for environmental mine restoration and mitigation for some of the older mines with an estimated implementation cost of USD 6 014 000.

At the operating centres, the Urgeiriça plant and Quinta do Bispo mine, ENU has environmental management costs estimated at around USD 160 000 to USD 214 000 per year with activities such as: monitoring (17.5%); effluent management (41%); radwaste disposal (19.5%); regulatory activities and environmental assessment (22%).

The current programme of Environmental Management for the older mines represents a cost estimated between USD 107 000 to USD 134 000 per year with activities such as: monitoring (23%); effluent management (45%); decommissioning/decontamination (21%); radwaste disposal, regulatory activities and environmental assessment (11%).

• Romania •

Governmental policies and regulations

In recent years, an important goal for Romania is integration with the European Community. Efforts are being undertaken to update national regulations to those of the European Community and also to restructure activities related to geological surveys and mining exploitation.

Within this new approach, ecological remediation works are being conducted where the uranium production activities had ceased or have been considerably reduced.

Activities such as geological surveys, uranium exploration, exploitation, and processing, are regulated by the following main laws established during the last several years:

- Law No. 111/1996 on the Safe Conduct of Nuclear Activities of October 10, 1996, as amended by Laws No. 16 of January 8, 1998 and No. 384 of July 10, 2001.
- Law No. 137/1995 for the environment protection.
- Water Law No. 107/1996.
- Technical Specifications for Drinking Water, STAS 1342-91.

Recently, the following specific norms have been established:

- Government decision for technical and economical indicators approval, concerning investment objectives for “Ecological and environment protection works in the zones with geological exploitation and processing activities within the autonomous Regie for Rare Metals–Bucharest”, No. 400/1996.
- Order No. 15.2/1998 of the Trade and Industry Ministry (TIM) for methodological norms approval concerning the closing and preserving of the mines.
- Order No. 1670/1998 of the TIM concerning establishing a Central Group for the mine closing programme.
- Decree No. 51/1997 concerning the closing of mines.

These documents are added to former relevant documents including:

- Order No. 320/1975 from CSEN; National norms for nuclear safety for geological survey activity extraction and processing of nuclear raw materials.
- Order No. 133/1976 from CSEN; National norms for nuclear safety. Work regime with nuclear radiation sources.

In addition, the national nuclear authority initiated a project to define the new National Radio-protection Norms. The new standard decreased the maximum allowable radiological dose for persons from 5 mSv to 1 mSv.

The former practices concerning nuclear material activities lack:

- Specific regulations since the beginning of such activities in Romania (from 1950 to 1975).

- Environmental protection considerations necessary for geological surveys using mining methods undertaken during 1975-1989.
- Funding from the national budget for environmental remediation during the period 1990-1997.

Information concerning some remediation activities

Specific measures for environmental protection and remediation funded after 1980 include:

- The commissioning of radioactive water treatment plants for mine and waste industrial waters located at Lisava and Ciudanovita (Banat region), Crucea (Suceava region), Feldioara (Feldioara region).
- The installation, in 1995, of covers for railway wagons used for radioactive ore transport.
- The removing of radioactive ore stockpiles located at the entrance of Dobrei North, Dobrei South, Avram Iancu mines, and also of the stockpile located within the perimeter of Barzava Village, Arad County.
- The removal in 1997 of relatively small radioactive ore stockpiles. They are located on some sterile dumps, and resulted from geological survey activities undertaken especially within the vicinity of Primatar, Bradu, Mehadia (Tulghes and Alba Iulia locations – Magurele region), Ranusa and Valea Leucii (Bihor region).

In 1994, a complete inventory was undertaken of the areas where nuclear material activities took place and that need remediation works.

In 1995, the feasibility study named “Environment protection and remediation works in the zones affected by geological activities, exploitation and ore processing within the Autonomous Regie for Rare Metals” was prepared. The Autonomous Regie for Rare Metals is now the Uranium National Company S.A. (UNC-SA). The cost for this activity was estimated at an initial budget of ROL 32.716 billion, spread out over three years. The estimate was brought up-to-date in June 1999, at a value of ROL 194.79 billion (about USD 12 500 000). Of this amount, about ROL 997 million (USD 65 000) were spent for technical execution documents and building works up to March 1999.

The UNC-SA has made contacts with the European Community within the PHARE programmes with the aim of obtaining support for environment remediation activities. Three programmes are being conducted and the fourth to be implemented in the Barzava location will be detailed in future.

The PHARE project related to the remediation of areas affected by mining and processing has a value of about 100 000 EURO. In the framework of this project, equipment was delivered to Romania for radiological risk evaluation. Romanian personnel were trained to use this equipment.

The ongoing projects under the programme “Remediation concepts for environment affected by uranium mining and processing activities in central and east-European countries” are underway at the Ciudanovita mine from the Banat Region. The cost of these projects is about 450 000 EURO including conserving and rehabilitating of radioactive tailing ponds.

Future of remediation projects

According to the modified programme of the UNC-SA, ore exploitation activities will stop at Ciudanovita, North Dobrei, South Dobrei, and Avram Iancu in the near future. The closings will reduce risk of contamination of the environment and ground waters. New regulations specify that for

the closing of radioactive mines the financial resources should be provided by the Government starting in 1999. In addition, funding approved by Government Decision no.400/1996 for ecological works will be provided at locations subjected to geological survey, mining exploitation and uranium ore processing.

The main environmental remediation works are:

- Long-term preservation of some 130 dumps having radioactive contents.
- Decontamination of 20 locations with ore stockpiles or ore sorting stations.
- Revamping of three water decontamination plants for mine water flowing from closed mines.
- Long-term closure of a uranium tailings pond from ore processing.
- A long-term monitoring system for decommissioned locations.

Achieving this programme requires the following estimated funding:

- About USD 20 million for dump remediation and decontamination.
- About USD 5 million for closure of the radioactive tailings pond.

These cost estimates do not include funds for closing the Ciudanovita, North Dobrei, South Dobrei and Avram Iancu mines.

Romania recognises the importance of cooperation between UNC-S.A. and the European Community organizations. This cooperation includes closing, decommissioning and environment remediation of the zones affected by the uranium industry. It includes using the experience, procedures and models available today and in practice within the western countries. International funding for environmental work is very important when economical conditions in Romania are limited to implement these projects.

Radioactive wastes resulting from underground uranium mining

The exploration and mining produced waste in the form of sterile rock with low contamination (by natural radionuclides) and low grade ores (0.02-0.05%U). These rock types are stockpiled on dumps at the entrance of mines as follows:

- Oravita-Banat zone: 21 dumps.
- Baita-Avram Iancu zone; Bihor county: 10 dumps.
- Crucea-Botusana zone, Suceava county: 30 dumps.
- Tulgkes zone, Neamt zone: 70 dumps from geological exploration, having a low radioactive level and small volume.
- Arad county (Milova, Ranusa): 7 dumps.
- The total volume of these dumps is about 5.5 million m³ and the surface area is about 140 ha.
- Wastes are of LLW type.

Wastes have a maximum 0.03%U content, and are at equilibrium with radionuclide daughters. The dumps are for intermediate term storage until completion of the national programme for long-term dump stabilisation, conservation and ecological remediation. The programme will either close-in place or relocate the tails for permanent closure.

Another type of waste is mine waters contaminated by natural radioactive elements (radioactive liquid wastes). The volumes of contaminated water are:

- Oravita zone, about 4 500 m³ /day.
- Baita-Bihor zone, about 3 000 m³/day.
- Crucea-Botusana, about 3 000 m³/day.

The uranium content is less than 3 mg/l and radium is less than 0.20 Bq/l. These waters are held in setting ponds and then decontaminated by ion exchange. The recovered uranium is sent to the processing plant and the treated water (“clean” concerning radioactive content) is discharged to surface river waters.

Radioactive wastes from uranium ore processing (Feldioara plant)

Liquid radioactive wastes include contaminated water and sludge with the following characteristics:

- 5 000 m³/day, with a solid liquid ratio of 1/3.
- The liquid phase (water) has an uranium content up to 5-7 mg/l, and radium to 0.5 bq/l.
- These are LLW type wastes.

The liquid waste flows to the Cetatua and Mitelzop sedimentation ponds. The liquid phase is treated using ion exchange process followed by recycle to still active “R plant” milling circuits or/and discharge in the Olt river. Within the tailings ponds are stockpiled about 4.3 millions tons of solid radioactive wastes (consolidated sludges). They accumulate at a rate equal to 120 000 t/year. The global radiological activity stored is about 1 100 GBq. The tailing pond surface is 37 ha.

Solid radioactive wastes include old iron, wood and ceramic materials. Their ultimate storage is on a platform build between the 2 tailing ponds (Cetatua and Mitelzop), in layers that will be covered by rock. The total quantity stored is 16 600 t, as follows:

- 2 900 t old iron.
- 13 000 t wood.
- 700 t miscellaneous.

These wastes are of LLW type, consisting of fixed contamination. The total radiological activity of this waste is about 3.5 MBq.

• Russian Federation •

Relevant Legislation

- Federal Law on the Use of Atomic Energy of October 20, 1995, as amended.
- Law on Special Ecological Programmes for the Rehabilitation of Radioactively Contaminated Areas of June 6, 2001.
- Law No. 2060-1 on Environmental Protection of December 19, 1991, as amended.
- Law on Ecological Expert Review of November 23, 1995.
- Water Code of 1995.

JSK “Priargunsky Mining-Chemical Production Association” (PPGHO)

Site characterisation

The state Joint Stock Company (JSK) “Priargunsky Mining-Chemical Production Association” (PPGHO) has been the only active uranium production centre in the Russian Federation in the last decade. It is located in the Chita region, 10-20 km from Krasnokamensk, which has a population of about 60 000. PPGHO includes the following facilities (Figure 1):

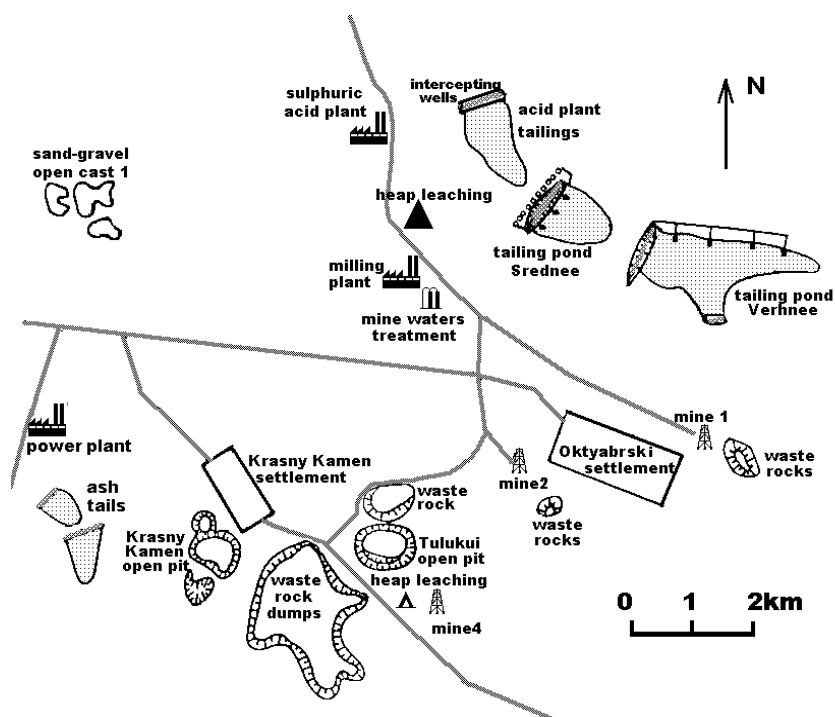
- 3 active underground uranium mines and 2 depleted open pits.
- Hydrometallurgical and sulphuric acid plants.
- Urtui coal and manganese open cast mines.
- Krasnokamensk steam power plant.
- Workshops and engineering works.

Table 1. **Important environmentally-related historical dates**

1969	Plant for civil and industrial effluents treatment was built.
1973	Building tailing ponds for acid and milling plants
1974	Uranium milling and production started.
1977	Environmental laboratory was organised
1988	Environmental department was organised.

Mining has recently taken place from two open pits (both are depleted) and three underground mines. Milling and processing has been carried out at the local hydrometallurgical plant by sulphuric acid leaching with subsequent recovery by solvent-extraction ion exchange scheme. Currently dominant production comes from underground mining of relatively high grade ores (0.3 to 0.4% U). A limited amount (up to 100 t U/year) is produced from the low-grade ores by heap leaching and in place (or block) leaching methods since the end of 1980s. The high level of total U production (about 100 000 tU) marks Priargunsky as one of the outstanding production centres worldwide.

Figure 1. Priargunsky's operational units



The production is based on 19 volcanic-type deposits of the Streltsovsk region with an average U grade of about 0.2%U, situated in an area of 150 km². Approximately 75% of the resources of the Streltsovsk district are in the depth interval from 200 to 600 m below the surface. These ore lodes are distributed at several levels in stratified sedimentary and volcanic rocks. About 25% of the resources are situated at lower levels between 400 and 900 m deep. They are related to two large and relatively high-grade deposits hosted by granite (Antei deposit) and marble (Argunskoe deposit) of the basement.

Mineralisation is largely controlled by structures in vein and stockwork ore lodes. Monometallic uranium and polymetallic uranium-molybdenum ores are distinguished. Since the discovery of the district in 1963, ten deposits have been brought into production, eight by underground and two by open pit mines.

Type of contamination

A significant amount of solid, liquid and gas wastes have been produced since 1968 (Table 2) in connection with uranium production.

Table 2. General wastes characteristics

Type of waste	Area (ha)	Amount (million t)	U grade (%)	Radioactivity (x 10 ⁻⁹ Ci/kg)	Radon emanation (x 10 ⁻³ Ci/m ² year)
Mill tailings	377	40.0	0.009	30-750	0.93-23.2
Acid plant wastes	125	5.6	Traces	30-250	–
Mine waste rock dumps	340	153.0	0.002	27-80	0.84-2.50
Piles of low grade ores	70	28.0	0.009	27-350	0.84-11.0

The total area of radioactive contamination covers 842 ha:

- 723 ha at industrial sites with an activity level of 60 to 240 $\mu\text{R/hr}$.
- 119 ha in the controlled sanitary protection and observation zones with an activity level to 60 $\mu\text{R/hr}$.

An environmental assessment extending its view for more than 20 years into the future emphasises two main problems:

- Increasing accumulation of liquid and solid radioactive wastes.
- Progressive radioactive contamination of natural hydrogeological systems, which create a potential threat to the water supply.

The main risk for ground water contamination comes from potential seepage of waste from tailings ponds of the hydrometallurgical and sulphuric acid plants.

Mining waste piles

Mining activities result in the following contamination:

- Release of radioactive and blasting gases to the atmosphere.
- Release of contaminated mine waters.
- Accumulation of waste and sub-grade waste rock dumps.

Currently uranium mining is carried out mainly by using underground methods. About 0.2 to 0.4 tonne of waste rock or sub grade ore are extracted per ton of mined ore. Over 150 million tonnes of waste rock and more than 2.7 million tonnes of sub-grade ore have been accumulated in 30 waste rock dumps since 1968. Over 5.6 million tonnes of low and sub-grade ore are placed for heap leaching. The total area of the waste rock piles is more than 340 hectares.

Most of the rock dumps are not very radioactive. Nevertheless, they can be a potential source for migration of radionuclide into the atmosphere, soil and water. It is necessary to note that radon and long-lived alpha-nuclides concentrations at the distance 100 to 250 m from piles are close to background levels. The radioactivity decreases from 50-100 $\mu\text{R/h}$ at the waste piles to 20-25 $\mu\text{R/h}$ at a distance of 200-250 m.

Mine waters treatment

Mine waters are radioactive, bacterially infected and have a degree of high mineralisation. Their annual production volume is about 8.5 million m^3 . Since 1993, mine waters and waters from mill ore preparation have been treated at a special water treatment plant installed at the milling plant. It has a precipitation circuit using chemical reagents – lime milk, polyacrylamide as flocculent and green vitriol. Its nominal capacity is 1 000 m^3/hour , and actually processed 456 m^3/hour in 1999. Treated waters are cleared of suspended matter, radionuclides, manganese, heavy metals and uranium. The effectiveness for U, Mn and radionuclides treatment is over 90%.

About 5.4 million m³ of treated mine waters are used annually for milling plant needs and the remaining 2.6 million m³ is discharged to Umykei Lakes. The underground back fill is also prepared with this water. However, treated mine water can not yet be used for other needs (agriculture, municipal services etc.). Modernisation of the equipment to permit these uses is now in progress.

About 4.0 million m³ of mine waters were treated in 1999 and the remaining 4.4 million m³ were discharged in tailing ponds. 5.8 t U and 263 t manganese dioxide were recovered from mine waters in 1999.

Milling plant

The milling plant processes large volumes of uranium ore (up to 3 500 ton/ore per day) with high water consumption (up to 3-4 m³ per ton of leached ore). Only treated mine water is used in the milling process.

The concentration of gas-aerosol emissions, long-life alpha nuclides, radon, and its decay products and ore dust is low. More often non-radioactive, harmful chemical substances affect the environment. For example, ammonia and nitrogen oxides are released to the atmosphere. The limit for each contamination source is established at the milling plant and monitored regularly. Significant amounts of solid and liquid wastes produced during processing are disposed of in tailing impoundments.

Tailings

Two tailings impoundments hold milling plant wastes: Verhnee and Srednee (Table 3). The Verhnee tailings impoundment is the main one used for the last several years. Srednee was used only during pipeline repair. Table 3 shows the tailings pond volumes and Tables 4 and 5 show liquid, solid wastes and groundwater chemical composition. The uranium grade in solid mill wastes amounts to 0.010%.

Table 3. Volumes of tailing ponds impoundment

Parameters	Tailings pond-Verhnee	Tailings pond-Srednee	Acid plant tailings
Upper level of embankment (metres)	706	660	648.8
Water table (metres)	697.8	656.7	642.3
Permitted level (metres)	698	658	646.1
Level of protection cover (metres)	699	659	347.7
Volume of impoundment (m ³)	46 055 000	3 377 000	6 179 000
Square of impoundment (m ²)	3 025 000	741 000	1 251 000
Area of liquid table (m ²)	1 775 000	384 000	1 021 000

The tailings impoundment is a significant source of potential environmental contamination. Mill tails contain initial (prior to processing) amounts of such radionuclides as ²²⁶Ra, ²³⁰Th, ²¹⁰Po and ²¹⁰Pb. The principal emanation comes from ²²²Ra and its short-lived decay products as the result of airborne dust. Liquid waste seepage through the tailing pond bed can affect underground waters and contaminate them. Elevated concentrations of sulphate-ion, manganese, copper and nitrate ion are noted in some intercepting wells located close to mill tailings.

Table 4. **Chemical composition of mill and acid plant tailing waters and local ground waters in mg/l** (radionuclides in 10^{-11} Ci/l)

Component	Mill waste water	Tailings Srednee clarified water	Tailing pond Verhnee		Acid plant tailings pond		Ground water of Shirondukui valley
			Recycling water	Water in intercepting wells	Water in intercepting wells	Waste water	
PH	5.7	6.9	5.9	6.6	7.0	3.0	7.4
NH ₄	401	49	92	17.4	7.4	14.5	7.5
SO ₄	9 110	5 760	8 841	4 100	2 462	4 376	70
NO ₃	333	571	492	161	205	328	20
F	136	27	152	1.61	1.2	32	3.4
Fe	80	5	18	0.1	20.4	229	3.4
Pb	0.23	0.2	0.24	< 0.2	0.28	0.75	0.08
Cu	0.2	0.2	< 0.2	< 0.2	0.5	67.0	0.1
Zn	13	0.43	14	< 0.2	0.2	173	0.2
U	1.68	0.25	0.9	0.14	0.35	0.39	0.05
Mn	1 256	370	1 270	8.0	0.1	90	0.6
As	0.6	0.55	0.56	–	–	5.5	< 0.5
Ra-226	2.66	0.63	2.28	0.33	0.91	1.21	0.27
Th-230	9.13	3.88	6.29	1.12	2.79	5.12	–
Po-210	4.37	1.35	2.66	0.54	1.18	1.11	–
Pb-210	4.7	1.58	3.1	0.73	1.26	1.31	–

Table 5. **Chemical composition of solid wastes in mill and acid plant tailings in 1999** (in % and in Bq/kg for radionuclides)

Component content	Mill wastes	Acid plant calcine
SiO ₂	62.6	11.18
Al ₂ O ₃	11.8	3.48
CaO	7.4	2.5
CaF ₂	1.06	0.35
Fe ₂ O ₃	4.13	75.8
S. total	2.86	4.02
Zn	0.016	0.21
Cu	0.005	0.37
U	0.010	0.002
Ra 226	5 180	55
Th 230	35 431	1 066
Po 210	40 774	736
Pb 210	32 449	1 058

Waste management

Waste management is carried out by the environmental survey according to the state laws and instructions. The environmental survey of PPGHO consists of:

- Environmental department co-ordinating environmental activities of all services and divisions.
- Environmental services of facilities monitoring atmospheric pollution and harmful chemical substance concentrations in liquid wastes.
- Radiation and radio-ecology safety service, monitoring industrial wastes and radioactive emissions to the atmosphere, soil and water.

The annual limits for solid and liquid wastes accumulation and discharge at Priargunsky consist of: uranium sub-grade ores 150 000 t/year; waste rocks 300 000 t/year; treated mine water 2 800 000 m³/year; and, total wastewater discharge 22 500 000 m³/year.

The following activities are performed to decrease the negative influence of waste rock on the environment:

- Irrigation of dust producing waste surfaces and roads.
- Waste rock pile rehabilitation.
- Non-radioactive waste rock utilisation for industrial needs, i.e. for tailing pond dam, road and hydraulic engineering construction.
- Development of heap and block leaching for low-grade ores.

The problem of waste rock utilisation and dump rehabilitation is considered urgent, and should be soon resolved. The project of Tulukui and Krasny Kamen open pits rehabilitation has been adopted.

One of the main environmental problems relates to the water supply. Currently all water effluents (technical drains, power plant effluent, cleared mine water) are removed in the system of Umykei inland lakes. 69% of treated mine waters is used for milling and processing and the other 31% is discharged to Umykei lake. The modernisation of old plants and the installation of new mine water treatment plants were planned to be finished in 2000. Further development of recycled water supply systems, as well as clarification of mining and technical waters will allow PPGHO:

- To stop taking water from the Argun river and to preserve the storage pond.
- To return the surplus of clean domestic and industrial water to the Argun river.
- To reduce waste water discharge in the Umykei Lakes.

The tailing pond has the greatest associated risk, because of the large amount of radioactive waste and the excess filling. The potential threat of a dam failure with waste seepage to Urulungui and Argun Rivers exists at the milling tail pond. The related environmental activities include:

- Control for tail neutralisation to reduce the toxic substance content in the clarified tailing water.
- Strengthening of dams, and building a protective dam close to potable water wells.

- Construction of new recovery wells below the tailing pond dam and increasing the effective working of existing wells.
- Hydrogeological monitoring through special wells.

However, construction of a special plant for liquid waste treatment is considered to be the most effective solution.

The following measures are being taken to reduce radionuclides emission in the atmosphere:

- Closure of old or stand-by mines trunks, bore pits and ventilating shafts.
- Isolation of underground mines by special backfill and concrete.
- Complete water saturation of tailing ponds surfaces and beaches for dust prevention.
- Modernisation of power plant filters to reduce ash emission to the atmosphere.

Environmental activities, including rehabilitation of the territory and waste disposal sites, will be completed as the facilities are closed.

Monitoring

The Laboratory of Radiation Safety and the Laboratory of Waste Testing and Radiochemistry perform systematic monitoring.

Atmosphere

The integrated sanitary protective zone exceeds 100 km². A number of permanent atmospheric monitoring stations are placed within the zone to monitor concentration of the most toxic chemical elements, ²²²Rn and long-lived alpha nuclides, e.g. natural uranium, ²²⁶Ra, ²³⁰Th, ²¹⁰Po and ²¹⁰Pb. The emissions of toxic substances do not exceed the limits and come from non-uranium units. Radiation control of reference level for personnel and environment in mines and mill show that the level for harmful factors (latent energy, radon emanation, alpha-contamination, dose rate, etc.) are generally within allowable limits.

Atmosphere monitoring within the industrial and civil zone is performed for sulphuric dioxide, nitrogen oxide, carbon dioxide, ammonia and dust. Their amounts comprise 9 to 74% of allowable limits. Maximal concentrations relate to nitrogen oxide and sulphuric dioxide effluents from power plant and the sulphuric acid plant.

Results of about 500 annual air samples in Krasnokamensk show that only ammonia and sulphur dioxide exceed limits in minor levels. The toxic substances contents (dust, NO_x, NH₃, SO₂) are monitored also at uranium heap leaching sites, mill and sulphuric acid plant tailings. Only in some cases amounts of dust exceed the limits.

The annual radiation dose rate for population does not exceed 1 mSv. The environmental situation for radiation and toxic chemical substances now basically meets the state sanitary norms and requirements.

Ground water

Monitoring for ground water quality is performed through a system of 111 local monitoring wells surrounding tailings, heap leach sites, slag heaps, etc. Monitoring around the tailings show that contamination plume migration was stopped in 1997 due to construction of a new system of recovery wells. 326 water samples were analysed (with 7 800 element-measurements) in 1998. Portable water quality satisfies the sanitary norms except for fluorine concentration, which comes from the natural composition.

Surface

Monitoring within the sanitary – protective zones of the mill and acid plant tailings (42 observation sites), power plants tailings (8 observation sites) and waste rock piles is performed to identify radioactive contamination of the soil. The principal activities include the chemical composition and physical properties, estimation of volume and areas of the impoundment, etc.

In September 1999, monitoring of soil and grass was performed in the zone near tailing ponds to evaluate the contamination in the sanitary-protective zone.

Environmental costs

The PPGHO complex is an integrated facility including uranium (mines, mill, and mill tailings impoundment) and non-uranium (power plant, coal and manganese open casts, etc) units, which require environmental activities. Some facilities are listed in Table 6. It is necessary to note that the cost of environmental activities at uranium related facilities comprises only about 30% of the total costs and will significantly increase in 2000 versus 1999. Most of uranium-related costs result from surface and waste treatment and rehabilitation at the mill, tailings impoundment, rock dumps and mines.

Lermontov State Enterprise “Almaz”

Site characterisation

The first organisation responsible for uranium production in Russian Federation was the Lermontov Complex, presently – Lermontov State Enterprise “Almaz”. “Almaz” is located 1.5 km from the town Lermontov, Stavropol Region of the Russian Federation. The region included Beshtau and Byk vein-type uranium deposits with total uranium resources of 5 300 tonnes at 0.1%U grade. Two underground mines operated since 1950. Mine 1 (Beshtau) was closed in 1975 and Mine 2 (Byk) in 1990. Ore was processed since 1954 at the processing plant in the town of Lermontov by sulphuric acid leaching, and from 1965 to 1989, also by in-place underground leaching and by heap leaching. From the 1980s until 1991, uranium ore from Ukraine and Kazakhstan were also processed at “Almaz”. After 1991 uranium production was stopped, but apatite flotation concentrate is being processed at the plant for fertiliser production. The uranium production totalled 5 685 tonnes, with 3 930 tonnes extracted by underground mining and 1 755 tonnes using in-stope technology.

Table 6. **Environmental activities and related costs for 1999 and planned for 2000** (1 000 USD)

Activities, costs	1999 Costs	2000 Costs
Atmosphere protection activities: mining and tailing pond areas dust prevention activities; power plant filter modernisation, acid plant repair work, coal and manganese open casts dust prevention activities, etc.		
Atmosphere protection costs	636	287
U-related atmosphere protection costs	2	36
Water protection activities: acid and sludge line reconstruction, mine water treatment plant modernisation, coal pit overflow, civil effluent treatment, power plant tower cooler, etc.		
Water protection costs	143	1 654
U-related water protection costs	83	79
Surface rehabilitation and waste management: Mill, tailing ponds and mine site rehabilitation, gamma survey, new mine site development, open pit waste dump rehabilitation, power plant reconstruction, etc.		
Surface rehabilitation and solid waste management costs	448	1 321
U-related surface and waste management costs	179	962
Monitoring: general monitoring, ground water, atmosphere, heap and in-stope block leaching sites, tailing impoundments.		
Monitoring costs	28	39
TOTAL:	1 255	3 320
Sub total-uranium related	292	1 116

Type of contamination

The radioactive contamination covers 134 ha, including 79.7 ha of the mill tails pond and 54.4 ha of mine waste rock dumps. Their characteristics are given in Table 7

Table 7. **General waste characteristics of “ALMAZ”**

Wastes	Area (ha)	Amount (t)	Alfa activity, Ci	Beta activity, Ci
Tailing pond	79.7	14 047 000	26 998	18 624
Waste mine 1 (Beshtau)	36.0	4 425 000	1 353	2 343
Waste mine 2 (Byk)	18.4	3 961 000	830	586
Total	134.1	22 433 000		

The main source of environmental contamination came from the tailings pond exhalation of radon and migration of toxic substances (including radionuclides) from the tailing pond to ground water (Table 8).

Contamination of ground water took place due to drainage of mill water to the first aquifer below the tailing bed aquifer in Eocene marl, especially during the first years of milling plant operation. The average annual uranium content in the marl aquifer amounted to 30 to 94×10^{-6} g/l, reaching 170 in some observation wells (versus 7 to 25×10^{-6} g/l U background). Currently the qualities of ground waters do not exceed permissible values.

Other potential contaminants are residual leach solutions from underground block leaching.

Table 8. Content and emission of ^{222}Rn in atmosphere

Area	Radiation $\mu\text{R}/\text{hour}$	^{222}Rn content		Radon emission Ci/year
		Bq/l	$\text{Ci}/\text{l} \times 10^{-10}$	
Tailing pond	120-230	2.7-12.0	0.7-3.2	125
Waste rocks of Mine 2 (Byk)	40-100	2.0-7.0	0.5-1.9	35

Waste management and rehabilitation

Mine 1 (Beshtau deposit)

The rehabilitation of most waste dumps has been carried out. The equipment for mining material restoration was installed in 1993, but currently it is not in operation (Mining waters contain up to 2.2mg/l U).

Mine 2 (Byk deposit)

About 30% of the waste rock rehabilitation has been completed. The rehabilitation of heap leaching sites has been completed.

Milling plant

The partial decontamination and dismantling of buildings and areas, which are not used now for apatite processing, has been carried out. Rehabilitation of some areas, including ore stockpile, needs to be continued.

Tailings pond

The upper parts are currently partly covered by the phosphogypsum layer, which is produced as wastes of apatite concentrate processing. It is considered to be a good cover to control radon exhalation. Water fills the lower part of the tailings pond.

The plan for rehabilitation and decommissioning of the mill tailings pond is being reviewed by the state government examination. The main tasks of this project are:

- Organisation of the special environmental service.
- Arranging a 1.5m thick cover of phosphogypsum and the overlying soil drainage layer.
- Reconstruction and extension of the monitoring system.
- Construction of a storm water diversion system.

Monitoring

Atmosphere and water (ground, rain, mine, tail, mill) monitoring is regularly performed by the environmental laboratory of the enterprise. Monitoring is done for radionuclides and toxic components (see Tables 8 and 9).

The current programme for environmental assessment includes:

- Data analysis of the ground and surface water composition within the mines and mill site.
- Civil water supply and mineral water evaluation.

- Systematic gamma-spectrometry survey of the territory.
- Radiometric, radiological and geochemical studies for environmental assessment within industrial and civil zones.

Table 9. ^{222}Rn content in near surface air

Site	Radiation, $\mu\text{R}/\text{hour}$	^{222}Rn , Bq/m^3
Tailings pond, dum 4		
Northern part and sludge line	130-210	2 700-3 000
Tailing pond sites	200-230	4 000-12 000
Mine 2 and Mill		
Mine tunnel mouth	40	17 000
Mine 2 and Mill		
Mine sites	15-100	2 000-71 000
Rehabilitated rock waste	46	3 000
Non-rehabilitated rock waste	95	3 000
Rehabilitated ore stockpile	38	–
Non-rehabilitated ore stockpile	620	800

• Spain •

Government policies and regulation

Current

Regulations

Law 25/64, dated 29 April 1964, on Nuclear Energy, regulates all aspects and activities in the nuclear energy field in relation to nuclear installations, radioactive installations, radioactive material mining and transport.

Law 15/80, dated 22 April 1980, on the Setting up of the Nuclear Safety Council (*Consejo de Seguridad Nuclear* – CSN). CSN, independent from the State's Central Administration Organisation, is the only organisation qualified to deal with radiological protection and nuclear safety issues. CSN's functions are the following:

- To propose to the government required regulations in nuclear safety and radiological protection issues.
- To inform the industry and energy ministry on the reports of licenses for the construction, start-up, operation and closure authorisations of the nuclear and radioactive installations.
- To perform inspections.

- To collaborate in the emergency plans.
- To monitor and survey radiation levels in the installations.
- To issue the required licenses for the operation personnel.
- To advise public administration, courts and institutions.
- To maintain official relations with similar foreign organisations.
- To inform the public.

Royal decree 783/2001, dated 6 July 2001, on Health Protection Regulations concerning Ionising Radiations. The purpose of this decree is to incorporate into the Spanish legislation the Euratom Directive 96/29, laying down basic safety standards for the protection of the health of workers and the general public against the danger arising from ionising radiation.

Royal decree 1836/1999, dated 31 December 1999, on Nuclear and Radioactive Facilities regulations. These regulations determine the proper regulation of administrative licenses, installations, testing and start-up, inspections, personnel and their documentation. Uranium ore processing plants are classified as first category radioactive installations, and for their construction and operation, the following authorisations are required: siting, construction, start-up and decommissioning.

Guidelines

Safety Guides lists, published by the Nuclear Safety Council , and applicable to uranium mining and milling activities:

- GS-5.6. Requirements for the obtaining and use of licenses for personnel in radioactive installations.
- GS-5.8. Guidelines for elaborating information regarding radioactive installations exploitation.
- GS-7.2. Requirements for obtaining classification as an expert in protection against ionising radiation to qualify being responsible for the corresponding Technical Unit or Service.
- GS-7.3. Guidelines for establishing Technical Protection Services or Units against Ionising Radiation.
- GS-7.4. Guidelines for medical care for workers exposed to ionising radiation.
- GS-7.6. Manuals outlining radiological protection for nuclear fuel cycle installations.
- GS-7.7. Drinking Water Radiological Control.
- GS-10.11. Quality Assurance in Radioactive Facilities (Draft).

Decommissioning specific regulations

Spanish regulations require that the facility owner, prior to finishing production activities, present a dismantling programme to the Ministry of Economy (MINECO). This will be evaluated by the Nuclear Safety Council before authorisation is granted to permit the owner to undertake the facility dismantling and decommissioning operations.

The dismantling programme comprises the following sections:

- Safety analysis.
 - Operation history of the facility describing the facility and the process, as well as an inventory of installations, waste rock and tailings affected by the decommissioning.
 - Decommissioning criteria analysing the different alternatives considered and corrective actions to be implemented in relation to land decontamination, materials declassification, protection from barrier degradation and human intrusion.
 - Radiological site characterisation, paying special attention to natural background radiation of the area, which will serve as a reference for achieving decommissioning objectives. Evaluation of characteristic parameters related to meteorology, hydrology, hydro-geology, water and soil factors of use, geology, seismicity and geotechnology, demography as well as socio-economic factors.
 - Analysis of the radiological impact on workers and public, both during operations of the decommissioning phase as well as the final impact on public. Once decommissioning operations have been concluded, radiation sources and different exposure pathways are evaluated.
 - Post-decommissioning monitoring programme of radiological condition of the decommissioned site, to be implemented during a final verification period (minimum five years/maximum ten).
- Operating procedures paying special attention to organisation and rules to be implemented in normal conditions and in cases of accidents.
- Technical specifications applicable during the dismantling step.
- Quality assurance programme ensuring that operations are carried out in compliance with established criteria. These procedures include aspects such as organisation, control and design, verification, operating procedures and instructions, document and archive control, inspections and audits.
- Radiological protection programme.
- Emergency plan (internal).
- Radioactive wastes management plan.
- Site land restoration plan, in which technical bases of designing monitoring and treatment of liquid wastes, solid materials and waste management are established, as well as the design of covers and stability analysis of the decommissioned structures and final restoration of affected areas.

Table 1. **Historical information on country's restoration activities**

Mining zones	Owner/ remediation responsible	Facilities	State of the site	Current activities
FUA (Andújar/Jaén)	CIEMAT/ ENRESA	Mill/tailing Pile	Closed and remediated (1991-1994)	A ten year (1995-2005) supervision programme to verify the compliance of restoration design criteria (groundwater quality, erosion control, infiltration and radon control)
Lobo-G (La Haba/ Badajoz)	ENUSA/ ENUSA	Open pit/ Mill tailing dam	Closed and remediated (1991-1997)	A five year (1998-2003) supervision programme to verify the compliance of restoration design criteria (groundwater quality, erosion, control, radon and gamma radiation exposure)
Old mines Extremadura (13) Andalucía (6)	Different owners/ ENRESA	Underground and open pit mines	Remediated (1998-2000)	Enusa has been commissioned by Enresa

Facilities with ongoing or future plans for restoration activities

Facility characterisation

Since 1973, Enusa has carried out uranium mining and milling activities in the area of Saelices el Chico (Salamanca); they were based on open pit mining, heap leaching and hydrometallurgical plant (Elefante Plant) for obtaining uranium concentrates from pregnant liquids. During 1993, the Elefante plant was phased out and a new plant (Quercus mill) was started with dynamic leaching. The nominal capacity of the new plant is 950 t U₃O₈/year. Nowadays, because of the low prices of uranium, the facility is running with a production rate of 300 t U₃O₈/year. At the end of 2000, the mining activities in Saelices el Chico (Salamanca) were ended, because of economic reasons.

Current status

- Elefante plant: closed and remediation still in progress.
- Quercus plant: under operation.

Type of radioactive and chemical contamination

- Acid mine water.
- Radionuclides (uranium, radium, etc.).
- Major ions (sulphate, ammonium, etc.).
- Trace metals (iron, manganese, etc.).

Type of long-term monitoring and surveillance

There is a compliance period of five or ten years to control ground water quality, erosion control, infiltration and radon control.

Waste rock dumps, sub-grade stockpiles

Waste rock dumps: four, representing a volume of 40 million m³. Heaps leaching depleted: twenty, representing a volume of 5 million m³ and an area of 35 ha.

Tailings

Number of impoundments: one with a volume of 2.2 million m³ and an area of 20 ha.

Cost

Table 2. Aggregate data per site

Mining zones	Type of facility	Uranium produced (t U₃O₈)	Tailing (m³)	Waste rock (t)	Cost ESP million/million
Lobo-G (La Haba/Badajoz)	Open pit Experimental plant Tailing dams	160	1×10 ⁵	8×10 ⁶	1 300/7.81 (actual)
Elefante (Saelices /Salamanca)	Open pit Heap leaching	3 500	4×10 ⁶ Heap leaching Depleted 3.6×10 ⁵ Sludges of neutralization	44×10 ⁶	4 200/25.24 (expected)
Quercus (Saelices /Salamanca)	Open pit Dynamic leaching	2 300	2.2×10 ⁶ (tailing) 0.8×10 ⁶ Heap leaching Depleted	24×10 ⁶	2 100/12.62 (expected)

Total cost for specific items and objects

Taking into account the aggregate cost data for Lobo-G facility (La Haba/Badajoz), mentioned above, the current decommissioning costs for specific items are listed below.

Table 3. **Representative Remediation Costs in Spain**

Items	Cost (euro)	Remarks
Planning, engineering and licensing	5×10^5 (total cost)	EIS project Natural background evaluation Radiometric study Safety analysis
Tailing ponds	1×10^6 (total cost)	Volume = $1.5 \times 10^5 \text{ m}^3$
Waste rock piles <ul style="list-style-type: none"> • <i>In situ</i> stabilising • transport and backfilling open pit mine 	0.5 Euro/t 1.0 Euro/t	Size = $8 \times 10^6 \text{ t}$ Surface = 20 ha
Plant disassembling and ground clean-up	5×10^5 (total cost)	Experimental plant (heap and dynamic leaching) Capacity = 500 tonnes/day
Mining facilities	3×10^6 (total cost)	Open pit Surface = 25 ha Capacity = 3 000 tonnes/day
Reclaimed areas Restoration and revegetation	1.0 Euro/m ²	Surface = 60 ha
Forced evaporation of liquid effluents	1.5 Euro/m ³	Volume = $4 \times 10^5 \text{ m}^3$
Post-decommissioning surveillance programme	2×10^5 Euro/year	Five years

• Sweden •

Relevant Legislation

- Act on Nuclear Activities [SFS 1984:3].
- Radiation Protection Act of May 19, 1988 [SFS 1988:220].
- Mineral Act of December 1991 [SFS 1991:45].
- Environmental Code of January 1, 1999 [SFS 1998:808].

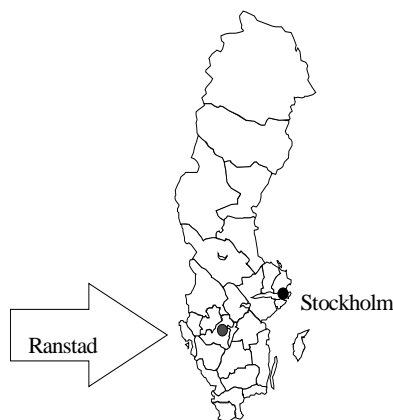
Decommissioning of the uranium mine in Ranstad

At the beginning of the 1960s, a uranium mine was opened in Ranstad in the southern part of Sweden as a part of the Swedish Nuclear Power programme. Uranium was extracted from the alum shale in the bedrock. The license for the Ranstad plant expired in 1984 and discussions about a restoration of the open pit and the tailings initiated. A restoration project started in January 1990 and the greater part of the restoration ended in 1992. At present, one of the major issues for the project is to minimise and control the environmental effects from the leachate produced in the tailings.

Government policies and regulations

Initially, the Swedish Company, Studsvik AB, was responsible for the project planning, sub-contracting and performance of the restoration as well as for the environmental control. Since 1992, Ab Svafo, owned by the Swedish nuclear power industry, is responsible for the restoration. The financing of the project is regulated by a law which states that a certain amount of the charge on nuclear produced electricity is to be used for the restoration. The total cost of the restoration is calculated to be about 150 million SEK.

Figure 1. Location of the Ranstad site in Sweden



The county administrative board has stated environmental criteria for a nearby recipient, which must be fulfilled before ending the treatment of the leachate. The project organisation is also bound to present yearly reports on hydrological and chemical data according to the predefined environmental control programme.

Restoration and history of tailings

From 1965 to 1969, about 1.5 million tonnes of alum shale were processed and about 215 tonnes of uranium were produced. The result of the process are tailings with a total amount of 1 million cubic meters now covering an area of 250 000 m². The tailings contain about 100 tonnes of uranium.

Between 1990 and 1993, a tight cover was established on the tailings and a tailings impoundment was created. The purpose of the cover is to minimise the infiltration of rainwater and penetration of oxygen into the tailings. The construction of the cover is a system of different layers consisting of moraine-mixtures, clay and crushed limestone.

The pollutants in the leachate water are heavy metals, such as nickel and zinc, and the leachate also contains uranium. The leachate contains relatively high concentrations of manganese and iron. The formation of flocculating iron- and manganese hydroxyoxides stains the water mass, but is more a problem of appearance than an ecological problem.

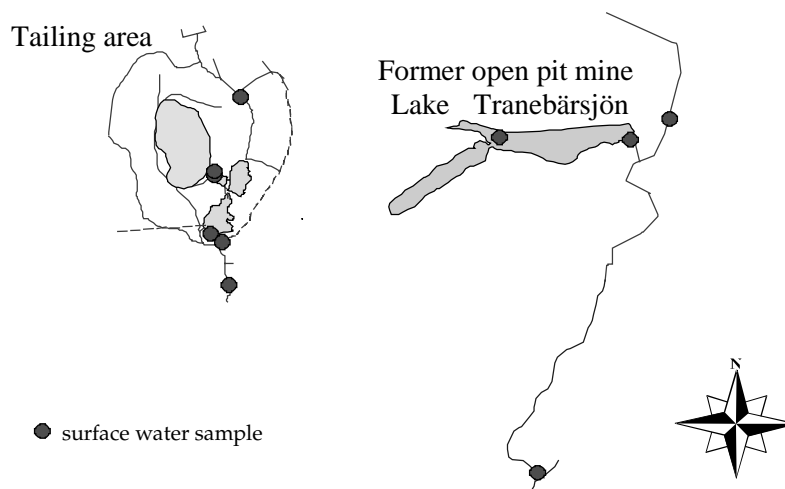
In the chemical treatment system, the collected leachate from the tailings impoundment is treated with calcium carbonate. The product is sludge, consisting of relatively insoluble metal compounds, which is allowed to sediment in a dam before the treated leachate can be led to the nearby recipient.

Measurements of radiological activity are made regularly. Analyses of ²²⁶Ra in the leachate show an activity of less than 20 mBq/litre.

Restoration and history of open pit

The open pit is about 2 000 metres long, 100-200 metres wide and maximum 15 metres deep. During the mining operation, infiltrating groundwater was evacuated by pumps and led to a stream nearby. Overlaying moraine, limestone and top alum shale were removed in order to reach the ore body. These masses were placed around the pit, and have consequently been exposed to weathering processes during 30 years.

Figure 2. **The tailing area and Pit Lake in Ranstad**



The open pit mining area was restored between 1990 and 1993. This was done by refilling the pit partly with masses left from the mining operation and by letting the groundwater level rise. A lake was created with an open area of 250 000 m² and a volume of 1.3 million m³. When the evacuation of the infiltrating groundwater ceased, large amounts of weathered products were exposed to water. The geochemical conditions changed from aerobian to anaerobian. The chemical alteration affected the weathered products and the lake became a transport media for dissolved and mobile species, e.g. heavy metals.

According to the environmental control programme, measurements of heavy metals, uranium and other chemical substances are made regularly. The concentrations of metals are low except for nickel and arsenic. As with the leachate from the tailings impoundment, formation of flocculating iron- and manganese hydroxyoxides stains the water mass.

Ongoing and future restoration activities

The most extensive efforts of the restoration activities can be considered as ended. The restoration project is now aiming to maintain reclamation activities such as revegetation. Effort is also being put into the environmental control programme to follow the environmental effects caused by the artificial lake and the tailings impoundment.

In 1999, a project started with the purpose of finding out alternatives to the chemical treatment system of leachate. Different kinds of natural filters, such as peat, for sorption of pollutants are to be tested during the next few years.

• Ukraine •

Government policies and regulations

Ukrainian uranium production activities started more than 50 years ago. Up to 1992, the restoration of uranium production facilities was based on the former USSR regulations such as:

- Statement of Cabinet of Ministers of USSR N 407 dated 2 June 1976 “About Restoration of Land”.
- Sanitary Rules for Dismantling, Conservation of Mines and Mills working with radioactive ores. (SP-1324-75).
- Norms of Radioactive Safety NRB-76, NRB 76/87.
- Sanitary Norms for Designing SNP-77.

At present, the environmental restoration projects are carried out based on the new laws:

- Law of Ukraine No. 40/95 on the Use of Nuclear Energy and Radiation Safety of February 8, 1995, as amended.
- Law of Ukraine No. 256/95 on the Management of Radioactive Waste of June 30, 1995.
- Sanitary Rules for the dismantling, conservation and changing of the profile of mining and processing of uranium companies (CP-LKP-91).

Ukraine also adopted a Law on Uranium Ore Mining and Processing on November 19, 1997.

The government policy is based on the following main principles:

- Priority is given to the safety of the life and health of personnel and population, and to the environment from the influence of radioactive waste.
- Implementation of the state policy through the long-term state programme.
- Reviewing and verifying the state programme every three years.
- Banning the accumulation of radioactive waste without control.
- Implementation of the state control of radioactive waste.
- Guarantee the proper isolation of radioactive waste from the environment.
- International co-operation in the area of management of radioactive waste.

Historical information on the country’s restoration activities

The beginning of the uranium industry in Ukraine is related to the range of uranium deposits which were found in the Kirovograd and Dnepropetrovsk regions more than 50 years ago. There are now 20 deposits. Out of all these deposits, four have been mined out: Zheltorechenskoye and Pervomayskoye by conventional underground method, and Bratskoye and Devladovskoye by ISL method. Two deposits are in production: Vatutinskoye and Michurinskoye mined by underground

methods. The rest of the deposits have not been exploited. Uranium ore is transported from the mines to the processing plants in Zheltiye Vody and Dneprodzerzhinsk.

Characteristics of uranium sites and restoration activities

Zheltiye Vody uranium site is the main ore processing plant for all uranium mines which exist in Ukraine. This industrial zone includes: a uranium processing plant (hydrometallurgical plant) and a sulfuric acid plant; two open pits: Gabaevsky and Veseloivanovsky; two mines: Olkhovskaya and Novaya (dumps of waste rock after mines Novaya and Olkhovskaya – 550 000 m³) and a range of subsidiary facilities.

Three tailings impoundments are located in the area:

1. The “KBZh” tailings impoundment is situated in the zone of the hydrometallurgical plant. A mined out iron ore open pit was used for this purpose. The volume of the quarry was almost filled by 1987 and after some renovation it is used only for accidental situations. The total area of the impoundment water surface is 55 ha. Quantity of the tailings is 19.34 million t and the uranium content is 0.007%. The ²²²Rn exhalation from the surface is 0.05-3.0 Bq/m² sec.
2. The “Sch” tailings impoundment is located 1.5 km South from the town and was used since 1979. The area of the storage is 250 ha; Quantity of the tailings is 34.54 million t; Uranium content is 0.007%. The ²²²Rn exhalation from surface is 0.05-2.0 Bq/m² sec.
3. The “R” tailings impoundment is located on the left side of Zheltaya River. It was used since 1989 for iron ore tailings from the processing plant of the Novaya Mine. The tailings impoundment area is 230 ha.

The total area which must be restored at the Zheltiye Vody site is 968 ha, including 19.1 ha of waste dumps; 17 ha in the caving zone; 50.6 ha of quarries; and 645.6 ha of tailings impoundments. At present, restoration at the Zheltiye Vody site has been made for Olkhovskaya mine territory. The mine was closed down in 1980 and restoration activity has taken place since 1979-1982. Olkhovskaya is a uranium and iron ore by-pass mine. The restoration activity included selective separation of dump waste rock and removal of the contaminated soil under the dumps. During this activity, 550 000 m³ of rock were used. Part of the rock was transported to the hydrometallurgical plant for processing, part was used for building of tailings impoundments, and part was placed in the nearest open pit. Contaminated soil under the dumps was removed up to a 1 m depth and placed in the same quarry. The total restored area is 15 ha.

Restoration of the tailings impoundment “KBZh”

Restoration activity on this site was started in 1991 and continues till now, because of financial problems. At the present time 85% of tailings impoundment is covered by a loam layer 0.4 m thick that prevents the tailings dust spreading by wind. Area of tailings impoundment is 55 ha. The restoration project plan is to build a multilayer covering. The structure of the cover is: 0.4 m loam; 0.4 m waste rock; 3.5 m loam; and 0.3 m soil.

Ingulsky uranium site

This site is situated to the south of the town of Kirovograd. The site includes three shafts (depth up to 700 m). The mined ore is separated into uranium ore which is transported to Zheltiye Vody processing plant; barren ore; and waste rock. Barren ore and waste rock are stored in the dumps. The dump area is 44.7 ha; the dumps volume is 2.5 million m³; ²²⁶Ra content is 843-1 389 Bq/kg; ²²²Rn exhalation is 0.85-1.28 Bq/m² sec. After treatment the mine water is released. The water volume is 2.6 million m³/year. There is a designed restoration project for dumps at the Ingulsky site. The idea of the project is to restore the site to the natural relief, for example a gully. It is planned to move into the gully 500 000 m³ of dump rock, and cover them with a suitable structure. Results of modeling tests show that underground water will be contaminated during the next 1 000 years. Radon exhalation from surface of restored territory will not be more than natural for this area. The restoration area is 7.4 ha.

Smolino uranium site

This site is situated 3 km from the small town of Smolino. The site includes 4 shafts (depth up to 500 m), identical to the Ingulsky mine shaft; mined ore is sorted for uranium ore (which is transported to Zheltiye Vody processing plant) barren ore, and waste rock.

The Barren and waste rocks are stored in the dumps. The area of the dumps is 5.3 ha. Dump volume is 1.06 million m³. The mining water following treatment is released. Radiological survey shows that radioactive contamination is present on the mine territory and dump area.

Devladovo uranium site

This site is situated 30 km to the south-east of Zheltiye Vody. The Devladovo deposit was mined from 1966-1983. The mining method was ISL, and reagents were sulfuric and nitric acids. The plant site is 12 ha. The ore body covers 218 ha. The area of underground storage is 120 ha. During the mining, underground water was contaminated by residual solutions at the 80 m depth. The contaminated plume spreads 1.7 km in the direction of flow and 0.35 km across the direction of flow. The volume of residual solutions in the Buchak aquifer after uranium mining is 7.09 million m³. The volume of water in the settling ponds is 1 million m³. The volume of contaminated silt in the settling ponds is 40 000 m³. The volume of contaminated soil in the vicinity of the pipelines is 50 000 m³.

The large contamination occurred because the deposit was the first mined by the ISL method and the technology was not properly designed. Restoration of the surface started in 1973 and was completed in 1987. The restoration technology included removing the contaminated layer to the 0.25 m depth; filling this area with clean soil; liming the area; and ploughing the soil 0.5 m deep. To monitor the underground situation a net of monitor wells were installed. These wells are still in use.

Bratskoye uranium site

This site is situated 200 km to the south of Zheltiye Vody. At Bratskoye, uranium was mined from 1971-1989. The mining method is ISL and the reagents are sulfuric and nitric acids. The area of ore body is 95.5 ha. During the mining, the underground water was contaminated by residual solutions at a depth of 50 m. The contaminated plume spread for 3 km in the direction of water flow and 1.2 km in the direction across the flow. The volume of residual solution in the aquifer is 5.2 million m³. For surface restoration of the Bratskoye site the same technology as for the Devladovskoye site was used.

Pridneprovsky Chemical Plant (“PChZ”)

This uranium site is situated on the Dniper River in the town of Dneprodzerzhinsk. It is the second processing plant in Ukraine and processed uranium ore from 1947 until 1991. Since 1991 “PChZ” has been producing other chemical products. The site includes a plant covering 6 ha and the tailings impoundment “S” of 78 ha. Section I (1968-1983) produced a volume of 8.55 million t, and Section II (1983 until now) a volume of 4.4 million t. The reloading site “S” covers 35 ha, and the tailings impoundment “D” (1957-1968) includes 73 ha (a volume of 22 million t.).

Facility with ongoing or future plans for restoration activities

At the present time there are no restoration activities in Ukraine because of economic problems. Some sites are being monitored. However, following the law designated by the *State Programme for improving radioactive safety of Nuclear Industry facilities in Ukraine* the Government has designed a new programme. The programme includes 7 tasks:

- Task I** includes the following restoration activities: finishing the restoration of the tailings impoundment “KBZh”; restoration of waste dumps on the Ingulsky and Smolino uranium sites; and restoration of “PChZ” uranium site including tailings impoundment “D” and “S” I Section.
- Task II** includes plans for creating an environmental monitoring system for Zheltiye Vody and Pridneprovsky chemical plant sites. The planned system includes analyses of air, soil, surface and underground water, vegetation etc.
- Task III** includes upgrading the system of personnel dosemetric control.
- Task IV** includes the technological plan to decrease the radiological influence to personnel and the environment at the operating companies.
- Task V** includes design of new regulations for radioactive safety taking into consideration the Ukrainian situation and existing international rules.
- Task VI** addresses questions related to the Chernobyl nuclear power station accident.
- Task VII** includes the fulfillment of a range of scientific and research projects to support the completion of all the programme tasks.

The total cost of the programme amounts to USD 360 million.

• United States of America •

Introduction

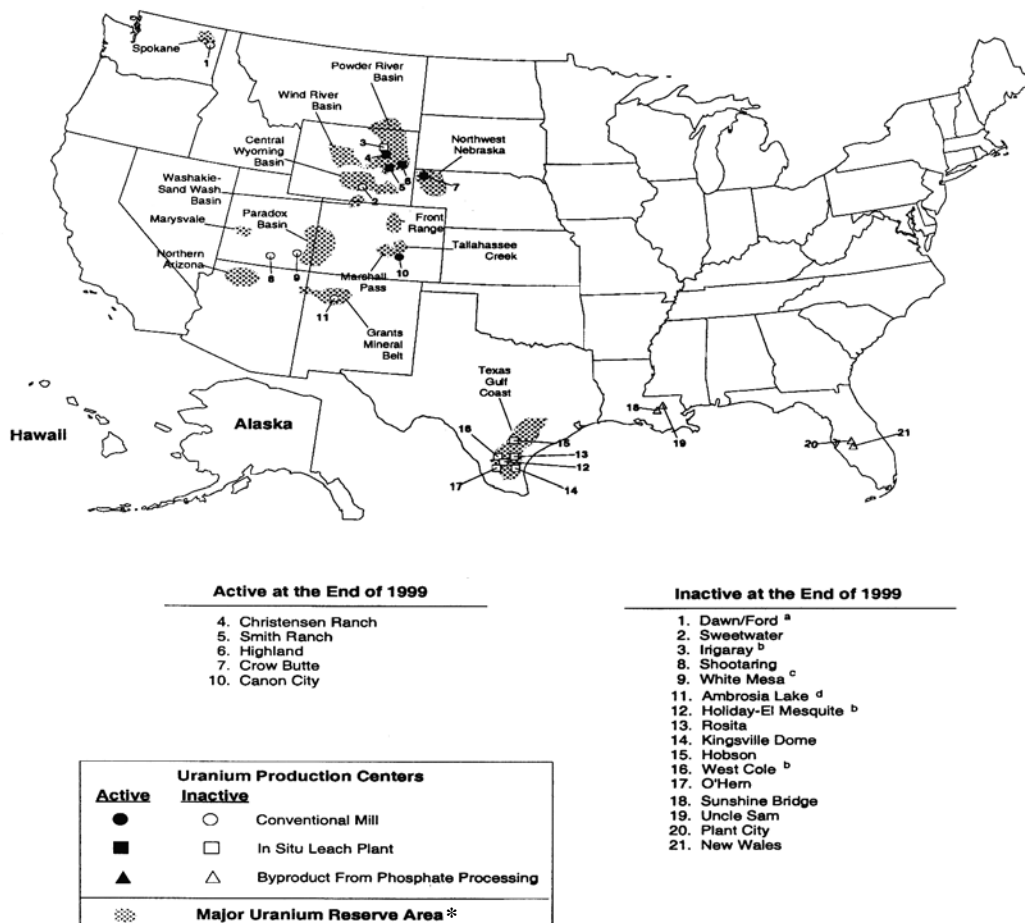
Brief history of the United States uranium industry

Soon after radium was discovered by the Curies in 1898, commercial mining of uranium-bearing ore in the Colorado Plateau province of the western United States was begun to meet research needs. By the early 1920s some 250 000 tons of ore had been mined primarily for radium in the Colorado Plateau.¹ At the Uravan site in western Colorado, radium was recovered in 1915-1923 and vanadium in 1936-1945 from locally mined vanadium-uranium ores.² During these periods, the commercial demand for uranium was relatively small, and uranium values mined were largely discarded in the mill tailings. From 1942 to 1944 uranium was recovered at four mills from these radium-vanadium tailings and from newly mined ore under Federal defence-programme contracts.³

The private-sector uranium-raw-materials industry in the United States from 1947-1970 grew primarily in response to the Government's source material (uranium) requirements for ongoing defence programmes undertaken after World War II. The U.S. Atomic Energy Commission (AEC) began in 1947 a broad programme to develop new domestic sources of supply to decrease dependence on overseas sources. The programme's incentive was a guaranteed market with minimum prices to the mining industry and was accompanied initially by direct Government exploration. With the expanded domestic private industry exploration, major new deposits were discovered by the mid-1950s. Production capability expanded rapidly after 1955 to handle production from the new districts. By late 1958, with reserves growth and production capability achieved and seeing that production could exceed projected requirements, the AEC adopted a programme designed to better manage uranium receipts and requirements and to provide for a private industry to supply the anticipated commercial nuclear fuel market. During the AEC uranium procurement programme (1947-1970), approximately 174 000 tons of domestically produced U₃O₈ were purchased for use in Federal programmes. During those years, in definable stages, the market for uranium concentrates changed from a monopoly with the Federal Government as the only buyer, to a completely commercial market with no government purchases.⁴

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1. W.I. Finch, *Uranium, Distribution Its Impact of the National and Global Energy Mix - And Its History, Production, Nuclear Fuel-Cycle, Future, and Relation to the Environment*, U.S.G.S. Circular 1141, (U.S. Government Printing Office, Washington: 1997), 24 p.
 2. H. Albrethsen, Jr., and F.E. McGinley, *Summary History of Domestic Uranium Procurement Under U.S. Atomic Energy Commission Contracts, Final Report*, GJBX-220(82) (Grand Junction Area Office, Grand Junction, Colorado, October 1982), p. A-39.
 3. *Ibid.*, U.S. Department of Energy, *Commingled Uranium-Tailings Study, Volume II, Technical Report*, DOE/DP-0011 (Grand Junction Area Office and Bendix Field Engineering Corporation, Grand Junction, Colorado, June 30, 1982), p 13.
 4. *Ibid.*, p.3.

Figure 1. Major U.S. Uranium Production Areas and Status of Mills and Plants, 1999



* Defined as areas containing reasonably assured resources at \leq USD 50/lb U_3O_8 .

Desiring to enhance development and utilisation of atomic energy for peaceful purposes, the AEC announced in May 1958 that U.S. producers of uranium ores and concentrate could sell those materials to domestic and foreign buyers for peaceful uses.⁵ Forecasts in 1966 for the domestic civilian nuclear power reactors called for rapidly increasing uranium requirements, and, responding to the anticipated demand for uranium, the U.S. raw materials industry began expansion of its exploration and development efforts at what would prove to be an unprecedented scale. Between 1966 and 1998, over 418 million feet of combined exploration and development drilling was completed at a total expenditure of over USD 1.2 billion.⁶ The bulk of that drilling was completed between the years 1966-1982. In those years, the amount of land reported as held at year end for uranium exploration and mining purposes remained well above 16.5 million acres for each year with annual totals peaking in 1970 at about 27.3 million acres and in 1981, at about 35.6 million acres.⁷

5. *Ibid.*, p.5.

6. U.S Department of Energy, *Statistical Data of the Uranium Industry*, GJO-100 (83) (Grand Junction Area Office, Grand Junction, Colorado, January 1, 1983), p56 and *Uranium Industry Annual* (DOE/EIA-0478 (93) (Washington, DC, September 1994) & (DOE/EIA-0478 (98) (Washington, DC, April 1999).

7. *Ibid.*, DOE-100 (83), p. 62.

Records maintained by the U.S. Department of Energy (DOE) indicate that during the years 1947-1998, the domestic industry explored over 5 300 properties for uranium in the United States. Of that number, mining of ore was undertaken at approximately 3 900 properties. Through 1970, a total of 34 commercial uranium mills had produced uranium concentrates for delivery under AEC contracts. In addition, various ore buying stations, pilot plants, concentrators, upgraders, solution mining, and heap leach facilities were operated in support of the AEC's programmes. By year end 1998, approximately 100 facilities had been constructed in the United States for uranium-slurry and/or concentrate production, and only a few of those had never been placed into full operation.

In the United States, uranium mining has been primarily in the western States, in Alaska, Arizona, Colorado, Nebraska, New Mexico, South Dakota, Texas, Utah, Washington and Wyoming. Significant production also has been from North Dakota and Oregon. Each of these States, excepting Alaska and North Dakota, also has hosted at least one conventional ore milling facility. Uranium mill tailings were leached at several sites to recover uranium. *In situ* leach plants have been operated in Nebraska, Texas, and Wyoming, and pilot-scale facilities have been operated in New Mexico. At two copper mines in Arizona and Utah, uranium was recovered from waste-rock-dump leach liquors. Uranium was recovered as a by-product of wet-process phosphoric acid manufacture at plants in Florida and Louisiana, although production had ceased by the end of 1999. Marine phosphate rock mined from Florida deposits was processed at the Florida and Louisiana plants. Marine phosphorite ore was mined also in Idaho for processing in Canada. Figure 1 shows the location of the U.S. mining districts and mines as of 1999.

Compilation of environmental restoration data for this study

A large number of uranium production facilities, including uranium mines, mills, *in situ* leach plants, and other facilities associated with production, were developed in the United States over the long history of the domestic uranium raw materials industry. Most of the large-scale production facilities, including mines, were developed during the years 1947 to 1998 to supply uranium initially for Federal programmes designed to meet national defence needs (1947-1970) and later to meet civilian nuclear power reactor requirements for nuclear fuel (1966-1998). Given the very large number of sites involved and the complex history of uranium production facilities in the United States, to compile in detail a report relating to lessons learned, analysis of the costs incurred from environmental restoration of U.S. production facilities, and the current practices and technology would be a major undertaking. Also, in the United States, environmental restoration work at mine and mill sites must be handled differently, because the reclamation concerns and processes, financial responsibilities, and the regulatory authorities are, in many cases, different.

For this country report, it was decided to prioritise the production facilities by rank order of those having had the greater environmental impact, including mills and mines, and to then work down the list covering as many sites as feasible within the limits imposed by budgetary, operational, and time constraints. In this way, data were compiled relating to the environmental restoration projects undertaken for the top 75 U.S. uranium production facilities. These facilities accounted for more than 95% of the U.S. U₃O₈ concentrate production through 1998 and, it is estimated, at least 85% of the environmental restoration management costs committed or incurred as of yearend 1998. The report reflects both publicly available information as well as summary information previously compiled by International Nuclear, Inc. (INI), for its proprietary data base on the environmental restoration projects performed in the United States. Additional information on the volumes of waste rock, primarily overburden containing Technologically Enhanced Naturally Occurring Radioactive Material, and status of mine site restoration was provided by the U.S. Environmental Protection Agency (U.S. EPA, 2000, in preparation) and was compiled for EPA by the U.S. Geological Survey under an interagency agreement.

Uranium deposits

In the United States, uranium deposits can be assigned based on their general geological setting and the nature of the enclosing host rock into four general deposit categories: strata bound, solution breccia pipe, vein, and marine phosphorite deposits. Sandstone type (strata bound) comprise approximately 88% of all reserves at the USD 80/kgU forward cost category for U.S. 1999 uranium reserves. Uranium in limestone, vein, co-product, and other deposit accounts for the remaining 12%.⁸

The uranium content of the US ore historically has been low, on average less than 0.25% by weight. Between 1947-1992, large volumes of uranium ore and overburden waste rock were mined by open pit and underground (conventional) mining. Most of the domestic uranium production came from conventional mining, and the milling of ore materials resulted in large quantities of uranium tailings. The mining and milling wastes, such as the contaminated overburden, acid-leach piles, and tailings, are radioactive and potentially hazardous. Volumes of solid waste materials generated by uranium recovery from mine waste water, *in situ* leaching, and wet-process phosphoric acid effluents has been relatively small, and these usually are deposited in licensed tailings impoundments.

Because of the geologic characteristics of ore distribution in many parts of the Colorado Plateau (small to moderate-sized isolated ore pods or linear sinuous channels of ore), thousands of mines were developed in Colorado, Utah, Arizona, and New Mexico on small ore bodies sometimes as small as a single uraniferous petrified log weighing a few metric tons. In many cases, these ore bodies are clustered into districts and ores were shipped from producing properties to centralised mills. These small mines produced small quantities of waste rock typically discarded within several meters to a hundred meters of the mine opening or pit. Mine maps in the literature typically show extensive underground mining following ore zones with only small piles of waste rock at the mouth of the adit. Mines of this type are scattered over wide areas of south-eastern Utah, south-western Colorado, north-western New Mexico, and north-eastern Arizona. By the end of the AEC buying programme in 1970, several hundreds of small to intermediate-sized underground and open-pit mines were either mined out or had become uneconomic and were abandoned.⁹

Many mining properties proved to have much larger ore bodies, both on the Colorado Plateau and in areas in other states, and extensive mining operations were developed at these sites. Since the early 1960s, most uranium mining was done on a scale larger than earlier mining efforts and conventional mining methods were established to recover the ores. Open pit mining is employed for ore deposits that are located near the surface, while underground mining is used to extract ore from deeper deposits.^{10,11,12,13}

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8. W.I. Finch, *et al.*, *Characteristics of Uranium Deposits, USA*, U.S. Geological Survey, (Denver, Colorado, 2000). Paper prepared for the 31st International Geological Congress, Rio de Janeiro, Brazil, August 2000. <http://www.31igc.org/ingles/ifirst.htm/cbrazil.dominal.com/si.203e.pdf>. (October 2000).
 9. U.S. Environmental Protection Agency, in preparation, *Uranium Mining Technologically Enhanced Naturally Occurring Radioactive Materials*, Washington, DC.
 10. U.S. Department of Energy, Energy Information Administration (1991). *Uranium Industry Annual 1990*. DOE/EIA-0478 (90), Distribution Category UC-98, Washington, DC.
 11. U.S. Department of Energy, Energy Information Administration (1993), *Domestic Uranium Mining and Milling Industry 1992, Viability Assessment*. DOE/EIA-0477 (92), Distribution Category UC-98, Washington, DC.
 12. U.S. Environmental Protection Agency, Office of Radiation Programmes(1983), *Report to Congress: Potential Health and Environmental Hazards of Uranium Mine Wastes*. U.S. Government Printing Office, Washington, DC.

Mining and milling wastes; overview of milling methods

Since the mid 1970s, production from *in situ* mining in the United States has steadily increased, while that from conventional mining has steadily decreased. No ores were mined by conventional mining between 1993 and 1998. In 1996, less than 7% of the total U.S. production originated from underground mines, and no ores have been produced from open pit mines since 1992.¹⁴

Uranium ore, and to a lesser degree the associated mine waste rock, can contain arsenic, cobalt, copper, molybdenum, nickel, lead, selenium, vanadium, and zinc as trace elements in addition to uranium and its radioactive daughter elements.¹⁵ Metallic ions of these elements can occur in varying quantities in mill tailings. Because these ions are potentially toxic, the tailings reclamation programme must be designed to assure retention and prevent excursions that may contaminate nearby soils and groundwater. The naturally occurring uranium isotopes ²³⁸U and ²³⁵U are long-lived parents of separate decay series consisting of a number of short-lived radioactive daughter elements.¹⁶ The naturally occurring isotopes of the ²³⁸U decay series, ²³⁴U, ²²⁶Ra, ²²²Rn, ²³⁰Th, ²¹⁰Po, and ²¹⁰Pb, exist in the tailings materials in low concentrations and are of special concern in regards to the final-design cover for tailings impoundments. Of these isotopes, the ²¹⁰Pb, ²¹⁰Po, ²²⁶Ra, ²³⁴U, and ²³⁰Th can be absorbed by vegetation and translocated upward from the tailings materials; ²²²Rn potentially can be released into the air and poses a significant concern. A noble gas with a half-life of 3.82 days, ²²²Rn, should it escape and become wind borne, can be carried long distances downwind from waste piles, although any potential human exposure would most likely be at a very low level.¹⁷ Studies have shown that radon levels at distances less than one kilometre from tailings impoundments are indistinguishable from background concentrations.¹⁸

Chemical and physical characteristics of tailings can influence the success of reclamation efforts. The tailings materials often are either strongly acidic or strongly alkaline. Pore water from acidic and alkaline piles can contain high levels of heavy metal ions (if acid) and elevated levels of boron (if alkaline). These toxic contaminants can be detrimental to establishing an effective vegetative cover over reclaimed waste piles and, if excursions should occur, potentially harmful to nearby groundwater. Most tailings materials offer very low amounts of plant nutrients, and, being nearly microbiologically sterile, are extremely low in plant nutrient content. The tailings wastes can be of very fine texture, with a high (up to 60%) clay size fraction or very sandy: either extreme can present problems in achieving effective vegetative ground cover. Water-saturated hydraulic conductivity in uranium mill tailings can be low, restricting the availability of water for use by cover vegetation.¹⁹

The reclaimed uranium waste sites constitute a potential health hazard for human populations and require specific management strategies to assure the effective long-term isolation of all radioactive

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13. Grey, C. (1993), *Uranium: From Ore to Concentrate*, The Nuclear Engineer, Vol. 34:1.
 14. Energy Information Agency (1997), *Uranium Industry Annual 1996*, U.S. Department of Energy, DOE/EIA-0478(96).
 15. E.E. Farmer and G.E. Schuman (1987), *Reclamation of Uranium Mining and Milling Disturbances*, in *Environmental Consequences of Energy Production: Problems and Prospects*, Edited by S.K. Majumdar, et.al., The Pennsylvania Academy of Science, pp.182-197.
 16. A.H. Brownlow (1979), *Geochemistry*, Prentice-Hall, Inc., Englewood Cliffs, N.J., pp. 40-41.
 17. E.E. Farmer and G.E. Schuman (1987), pp.182-197.
 18. Shearer and Sill, *Evaluation of Atmospheric Radon in the Vicinity of Uranium Mill Tailings*, Health Physics, 1969, p. 17, in S. Johnson and C.A. Moss, *An Overview of United States Uranium Mine and Mill Reclamation*, U.S. Council for Energy Awareness Washington, D.C., August 1993, p. 3.

materials and toxic heavy metal ions within the engineered containment structures. The specific regulations and policies that have been created to deal with the uranium wastes are discussed in the section on “restoration policies”.

Open pit mining

The depth to which open pit mining technology is suitable for recovery of uranium ore from a deposit depends on a range of factors, including the ore grade and distribution, hydrologic properties of the host rock, anticipated stability of the host rock material on exposure, geological environment of the deposit, nature of the overburden, and the stripping ratio. The maximum depth for an open-pit mining operation in the United States was about 170 meters. Stripping ratios describe the amount of overburden (waste) that must be removed to extract one unit of ore. One report indicates that stripping ratios for open pit uranium mines ranged from 10:1 to 80:1 with an average of around 30:1.¹⁹

Underground mining

At the mine surface installation, mined ore is placed in stockpiles arranged by ore grade, and development and waste rock brought to the surface are placed in waste rock dumps. Underground mining techniques permit leaving much of the non-ore bearing material in place, the waste (development/waste) rock-to-ore ratio for an underground mine is generally much lower than the similar stripping ratio for an open pit mine. The ratio of waste rock to ore in U.S. mines ranged²⁰ from 1:1.5 to 1:16. In shallow underground mines that are entered by means of an adit, ore and waste rock may be brought to the surface by train, motorised conveyor belt, or diesel powered heavy equipment trucks. In underground mining, the removal of ore often progresses in a planned sequence of mining stages from the outer boundary of the ore-grade material or a limiting property boundary inward towards the shaft or adit used as the primary haulage way designed for moving mined ore to the surface.

Beneficiation (uranium milling-acid leach process)

At a uranium mill, uranium oxide (U_3O_8) is extracted from ores and concentrated into “yellow cake”. Ore received at the mill is weighed and sampled for moisture content and then stored in bins (lots) by ore source or mineral grade. Blended ore is finely ground with water to prepare a slurry ready for chemical leaching. Sulphuric acid leaching is most commonly used in the United States. After leaching, the slurry product passes through multiple-stage washing/scrubbing, and the economically recoverable uranium, (90-98% of the raw-ore assay) is recovered. Precipitation, filtering, washing and drying yields the “yellow cake” product containing up to 90% uranium oxide.

Washing of mill-process solids (sand and slimes) lowers the loss of chemical reagents, as wash water can be recycled for reuse in crushing-grinding or leaching. Washed solids ultimately are stored in the tailings pond. The remaining solid wastes from the extraction process are termed by-product under U.S. law i.e. the Atomic Energy Act, and must be kept in special regulated tailings impoundments.

19. U.S. Environmental Protection Agency, Office of Radiation Programmes (1983), *Report to Congress: Potential Health and Environmental Hazards of Uranium Mine Wastes*. U.S. Government Printing Office, Washington, DC.

20. *Ibid.*

In situ solution mining

In situ leaching, or ISL, is the most commonly utilised solution mining technique and has been employed at mines in Wyoming, Texas, and Nebraska, and pilot scale operations have been operated in New Mexico.

When uranium recovery from a well field drops below a pre-determined value, lixiviant injection is terminated, and the well field restoration phase is begun. Well-field aquifer restoration begins at termination of the uranium recovery as required under State regulatory programmes. An aquifer's pre mining water use classification normally must be restored, although all water quality parameters are not necessarily returned to baseline values. Under U.S. law, solid wastes generated by *in situ* mining operations during the beneficiation process are considered by-product materials and generally are shipped to mill tailings facilities. Bleed-off waters from extraction wells during restoration are also sent to evaporation ponds. Sludge accumulated in ponds is either disposed of in landfills licensed to receive radioactive materials or it is injected into underground disposal wells.

Environmental regulation of uranium recovery facilities

In the United States, a growing appreciation of the extent and severity of the damage that had accumulated in the natural environment resulting from lenient, and in some cases the lack of, regulatory oversight in governing mine discharges, hazardous waste disposal, and unreclaimed mining sites led to the passage, beginning in the 1970s, of several U.S. Federal and State laws designed to protect air, water, and land resources. Environmental effects resulting from uranium extraction and beneficiation derive chiefly from two sources: mining activities and radionuclides present in the waste products. Open pit mining activities potentially may create environmental surface disturbances, e.g., increased surface water runoff and increased erosion by wind and water. De-watering procedures conducted at surface and underground mining operations may create depression cones that can persist in a groundwater reservoir after mining ceases. The potential environmental effects from *in situ* mining activities are primarily groundwater-related. In general, the degree of disturbance of the natural surface at *in situ* mining sites normally is not extensive; however, the impacts associated with *in situ* mining operations (e.g. bore hole cuttings, engineered ponds, burial of solution flow lines, etc.) are not well documented, nor has an overarching evaluation of the impacts of settling- evaporation pond waste volumes and their associated radioactivity been undertaken.

Mill tailings, and particularly the contained radionuclides, appear to be a major source of environmental impact to air, soil, surface and groundwater. Findings in EPA (1985), *Report to Congress: Potential Health and Environmental Hazards of Uranium Mine Wastes*, indicated that use of uranium mill tailings in off-site construction most seriously threatened human health. The EPA also found such usage of unreclaimed mine spoil overburden²¹ to constitute a similar problem. At some *in situ* mine sites, the ineffective control of lixiviant excursions beyond the intended well field boundaries has resulted in localised pollution of ground water aquifers.

According to EPA (1995), *A Technical Resource Document, Extraction and Beneficiation of Ores and Minerals, Volume 5 – Uranium*, the statutes (and associated regulations) which provide environmental controls over reclamation of uranium recovery facilities include: the Clean Water Act (CWA), as amended (33 USC 1251 *et seq*); the Clean Air Act (CAA), as amended (42 USC 7401 *et seq*); the Safe Drinking Water Act (SDWA), as amended (42 USC 300 (f) *et seq*); and the Atomic Energy Act (AEA) (42 USC 2021 *et seq*), as amended by the Uranium Mill Tailings Radiation Control Act (UMTRCA) (72 USC 7901 *et seq*). For clean-up of facilities which meet certain ranking criteria

21. U.S. Environmental Protection Agency, in preparation, *Uranium Mining Technologically Enhanced Naturally Occurring Radioactive Materials*, Washington, DC.

due to their potential hazard to the public and the environment, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 U.S.C. 9601 *et seq*) is controlling. The primary Federal agencies responsible for implementing the aforementioned statutes include: the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and the Department of Energy (DOE). The paragraphs below introduce each of the major statutes, which are described in more detail in subsequent sections.

The CAA gives EPA the authority to regulate emissions of both “conventional” pollutants, like PM₁₀ (particulate matter less than 10 microns) and hazardous pollutants, such as radon. Both of these air pollutants are emitted by uranium extraction and beneficiation activities.

The CWA gives EPA the authority to impose effluent limits, via permits, on point-source discharges, including those from active uranium extraction and beneficiation sites, to waters of the United States. It also gives EPA the authority to regulate storm water discharges from both inactive and active mine sites through permits.

EPA established an Underground Injection Control (UIC) programme under the authority of the Safe Drinking Water Act. Through this programme, EPA established a permit system to ensure underground sources of drinking water are protected from the injection of process fluids and liquid wastes into the subsurface via wells; this includes those produced during uranium extraction and beneficiation.

Under UMTRCA, EPA has responsibility to establish standards for the public exposure to radioactive materials originating from mill tailings and standards for clean up and control of inactive uranium tailings sites and any so called associated vicinity areas. The EPA was given a mandate to establish standards for managing uranium tailings and wastes at active sites. Under UMTRCA, the DOE's role is to actually clean up and control inactive uranium tailings piles to comply with EPA standards.

UMTRCA requires the Nuclear Regulatory Commission (NRC) to concur with DOE- selected remedies for clean up and control of inactive mill sites. Under UMTRCA, the NRC also is responsible for licensing active uranium mills and licensing remediated inactive uranium tailings sites. Although NRC has promulgated radiation protection standards for regulation of active and inactive uranium milling sites, it has no regulatory authority over uranium mines except the aboveground activities at *in situ* mines. The sections below explore more fully the regulatory roles of each of these agencies.

CERCLA created a tax on the chemical and petroleum industries and provided broad federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. Over five years, USD 1.6 billion was collected and the tax went to a trust fund for cleaning up abandoned or uncontrolled hazardous waste sites. CERCLA established prohibitions and requirements concerning closed and abandoned hazardous waste sites; provided for liability of persons responsible for releases of hazardous waste at these sites; and established a trust fund to provide for clean-up when no responsible party could be identified. This law previously and currently is being used for clean up of abandoned uranium mines.

Authority for State agency regulation of uranium extraction and beneficiation activities comes from federally delegated programmes and state statutory authority. Federal programmes that apply to uranium extraction and beneficiation activities and can be delegated to States include: the UIC programme, the NPDES programme, and NRC licensing and radiation protection standards. In order for a state to be able to administer any or all of these federal programmes, the state must have requirements that are equally as stringent as the respective federal programmes.

Reclamation methods

In situ leach operations restoration

Restoration of groundwater reservoirs can be accomplished using several techniques: groundwater sweep, forward recirculation, reverse recirculation, and directional groundwater sweeping. In some cases, a reducing agent may be injected into a mined out well field to re-reduce the oxidising environment created in the ore horizon during the mining process prior to beginning a long-term restoration project. A reducing agent may also be injected at a later stage of the project, should it become difficult to achieve stabilisation of the groundwater in the ore horizon.²²

Groundwater sweep involves the selective pumping of water from the mined ore horizon so as to induce a controlled flow of uncontaminated groundwater into the mined zone. The contaminated water withdrawn from the mined ore horizon can be disposed of in lined evaporation ponds or cleaned by passing the water through the ion exchange circuit and discharging it to the natural surface. Groundwater sweeps are most effective for restoration of well fields that are bounded by “leaky” confining layers, since uncontaminated groundwater can be induced to flow into the mined areas. Typically, two or more pore volumes of uncontaminated groundwater are required to improve the water quality parameters of the mined out zone. One disadvantage of groundwater sweeping is its consumptive use of groundwater.²³

Forward recirculation involves the withdrawal and reinjection of groundwater through the same injection and production wells that were used during the mining operation. Groundwater withdrawn from the mined aquifer is treated using ion exchange or reverse osmosis technology and the clean water is then reinjected and recirculated through the mined zone. The reinjected water is treated to assure that it meets or exceeds the groundwater quality requirements desired at the endpoint of restoration. The method does not allow the removal of any lixiviant or mobilised ions that may have escaped from the mined aquifer. For this reason, forward recirculation is most effectively used in restoring the interior mined-out portions of the ore horizon.²⁴

An alternate reverse circulation technique is to reverse the functions of production and recovery wells. In this method, “clean” water is injected into the mined-out ore through the former “recovery” wells and, at the same time, groundwater from the ore horizon is withdraw from the former “injection” wells. This method also is more effective in restoring the aquifer in the interior of the well field than along its perimeter.²⁵

Directional groundwater sweep involves pumping contaminated groundwater from specific wells while simultaneously injecting water of baseline (or surpassing) quality into the aquifer outside the mined out zone in the aquifer. Uncontaminated (clean) groundwater is drawn into the mined out ore horizon allowing removal of mobilised ions from the aquifer. Such sweeps can be designed so as to progress in stages across a well field to maximise the recovery of remaining mining contaminants.

Relatively small quantities of uranium may be recovered during early stages of aquifer restoration by passing water from production wells through the ion exchange circuit. As the restoration continues,

22. Lucht R. (1990), Personal communication between Mr. Robert Lucht, Underground Injection Control Coordinator, Wyoming Department of Environmental Quality, and Ms. Laurie Lamb, Science Applications International Corporation, September 12, 1990.

23. Osiensky J.L. and Williams R.E. (1990), *Factors affecting efficient aquifer restoration at in situ uranium mine sites. Groundwater Monitoring Review*, p. 107-112.

24. *Ibid.*

25. *Ibid.*

the amount of uranium recovered will eventually decline below a pre determined economic cut-off at which uranium recovery is abandoned. Flushing typically requires the use of multiple aquifer pore volumes to achieve a desired level of restoration. The number of pore volumes required depends on how quickly the aquifer groundwater returns to baseline conditions and to State established permit requirements.^{26,27}

Demonstration of successful restoration is accomplished through extended monitoring of groundwater conditions in the restored, mined-out zone. For example, Wyoming requires that selected wells continue to be monitored for groundwater stability for a minimum six-month period after the groundwater has returned to baseline parameters.²⁸

Monitoring

In situ operations maintain monitor wells and a monitoring plan to detect any migration of the lixiviant from the production zone. Such movement of the lixiviant or any of its constituents from the mined portion of the aquifer into adjacent or overlying aquifers is termed an excursion. Excursions may be either vertical or horizontal. Horizontal excursions typically occur within the ore horizon when pumping rates from production wells do not create a large enough groundwater depression cone to maintain the lixiviant within the uranium-production zone. These excursions are brought under control by adjusting the pumping rates of the injection and production wells. Vertical excursions occur when lixiviant constituents are detected in an aquifer typically above the ore horizon. Vertical excursions may develop as a result of a leaky confining rock layer, improper construction of injection or production wells, or, more commonly, lixiviant leakage from the production zone via previously drilled bore holes that were not adequately plugged before mining operations were begun. Vertical excursions are more difficult to remedy and may require extensive testing to identify the exact source of the “leak”. Such bore holes may need to be resealed, depending on the source and severity of the vertical excursion. The number of excursions occurring during *in situ* mining operations has been decreased over time due to increased understanding of the causes, enhanced monitoring techniques, *in situ* mining technological improvements, and the application of specific methods to control and reverse the excursions impacts. Through the 1980s, additional knowledge was developed about the causes of and remedies for excursions, and this has permitted wider application of *in situ* mining.²⁹ Under the monitoring programme, upper control limits (UCLs) are established during baseline data collection. UCLs consist of groundwater parameters that would be expected to rise in the event of an excursion.³⁰ Total dissolved solids, chloride, sulfate, bicarbonate and sodium have been used as UCLs. Since horizontal and vertical excursions can occur, monitor wells are regularly drilled above, below, and laterally adjacent to the production zone in order to permit access for testing of groundwater conditions. The monitoring is conducted routinely as specified in the mine sites operating permit.

26. *Ibid.*

27. U.S. Department of the Interior, Bureau of Mines (1979). *Environmental Assessment of In situ Leach Mining, Final Report*. Prepared by PRC Toups and Mountain States Research and Development. 292 p.

28. Wyoming Department of Environmental Quality, Land Quality Division. (1990), Guideline No. 4, *In situ Mining*.

29. U.S. Nuclear Regulatory Commission, Division of Waste Management (1986), *An Analysis of Excursions at Selected In situ Uranium Mines in Wyoming and Texas*. Prepared by W.P Staub, N.E. Hinkle, R.E. Williams, F. Anastasi, J. Osiensky and D. Rogness.

30. *Ibid.*

Restoration policies and regulations and reclamation status

The regulations and policies (standards and guidelines) for reclamation and restoration of uranium production facilities fall into three classifications:

- Federal (U. S. NRC and DOE) regulations and policies for UMTRCA Title I mill facilities.
- Federal (U. S. NRC and DOE) regulations and policies for UMTRCA Title II mill facilities.
- State regulations and policies for uranium mines and federal and state regulations for radiation protection and for clean up of radioactively contaminated sites.

Following in this section is a description of each of the federal agencies responsible for regulating the restoration of uranium recovery facilities, as well as principal standards or rules for the restoration they have developed. This is followed by information on the restoration status of mines and mills by state.

Much of the discussion which follows comes from U.S. EPA, (1995) *A Technical Resource Document, Extraction and Beneficiation of Ores and Minerals, Volume 5, Uranium*.

Atomic Energy Commission

Under the Atomic Energy Act of 1946, the Atomic Energy Commission (AEC) was created to administer and regulate the production and use of atomic power. The AEC had responsibilities for production of source materials of uranium and thorium, research in biology, health, and metallurgy and production of electric power from the atom. The 1946 Act put atomic energy under civilian control, although nuclear materials and facilities remained in government hands. Amendments to the Act in 1954 allowed licensed private ownership of facilities to produce fissionable materials, and in 1964, private ownership of nuclear fuels was allowed, which aided the growing nuclear power industry.

Under the Energy Reorganisation Act of October 1974, the AEC was abolished, and two new federal agencies were established to administer and regulate atomic energy activities: the Energy Research and Development Administration and the Nuclear Regulatory Commission. In 1977, the responsibilities of the former were transferred to the newly established Department of Energy.

Nuclear Regulatory Commission

The NRC's mission is to ensure adequate protection of the public health and safety, the common defense and security, and the environment in the use of nuclear materials in the United States. The NRC's scope of responsibility includes regulation of commercial nuclear power reactors; nonpower research, test, and training reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and the transport, storage, and disposal of nuclear materials and waste. As such, the NRC regulates active uranium milling and inactive uranium mill tailings disposal sites through licenses. It does not regulate the actual mining of uranium, except the above ground activities associated with solution mining. The NRC establishes its procedures and criteria for the issuance of licenses to receive title to, receive, possess, use, transfer, or deliver source and by-product materials.³¹ The authority for issuing these rules comes from the AEA, Title II of the Energy Reorganisation Act of 1974, and Titles I and II of UMTRCA.

31. 10 CFR 40 (1992).

Environmental Protection Agency

Created by Presidential Reorganisation Plan No. 3 of 1970 and Executive Order 10831, the Environmental Protection Agency (EPA) consolidated the federal government's environmental regulatory activities. With respect to radiation, EPA brought together the Bureau of Radiological Health of the Environmental Control Administration (previously in the Department of Health, Education, and Welfare), as well as certain functions in developing radiation criteria and standards previously vested in the Atomic Energy Commission and the Federal Radiation Council.

Consequently, EPA develops standards, provides guidance, and establishes criteria to protect the public and the environment from radiation exposure, cleans up radioactively contaminated sites, identifies and evaluates new radiation sources to determine any public health significance, participates in federal radiological emergency preparedness and response activities. It has developed the radiation protection standards adopted by the Department of Energy and Nuclear Regulatory Commission for closure of uranium mills, standards for radiation protection at geological repositories for nuclear wastes (Waste Isolation Pilot Project and Yucca Mountain), emission standards for radon at uranium mill sites, maximum radionuclides and radiation contaminant limits for drinking water (co-operatively with EPA's Office of Water), and soil clean-up standards for radioactively contaminated soils. Programmes of the Radiation Protection Division are currently focusing on the hazards of Technologically Enhanced Naturally Occurring Radioactive Materials, which include radioactively contaminated uranium mining overburden, interburden, unreclaimed sub-economic ores, "barren" rock, and drill cuttings. Information on uranium waste volumes and status of restoration by state in this report were provided from that programme.

Department of Energy

The Department of Energy (DOE) was created by the Department of Energy Organisation Act which brought most of the federal government's energy agencies and programmes into a single agency. The Department of Energy, activated on October 1, 1977, assumed the responsibilities of the Federal Energy Administration, the Energy Research and Development Administration, the Federal Power Commission, and parts and programmes of several other agencies. DOE works to increase the U.S. diversity of energy and fuel choices and sources, bringing renewable energy sources into the market, strengthening domestic production of oil and gas, supporting commercial nuclear energy research, and increasing energy efficiency. With respect to uranium, DOE is responsible for the clean-up and safe treatment, storage, and final disposal of radioactive wastes, surplus nuclear materials, and spent nuclear fuels. This includes those that remain at sites of the nation's nuclear weapons facilities and energy research and development sites, and mills that generated uranium for weapons and nuclear power in previous decades. It is also responsible for operating the Waste Isolation Pilot Project nuclear waste storage facility, and is studying the Yucca Mountain site in Nevada as a possible geological repository site for nuclear waste storage. The Energy Information Administration (EIA) is a statistical agency in the U.S. Department of Energy created by Congress in 1977. EIA's mission is to develop energy data and analyses that help enhance the understanding of energy issues on the part of business, government, and the general public. As such, it has compiled statistical data on the U.S. uranium industry operations which form part of this report.

U.S. Department of Interior, Office of Surface Mining

With the passage the Surface Mining Control and Reclamation Act of 1977, the Office of Surface Mining (OSM) in the U.S Department of Interior assumed responsibilities for regulation and standards development for clean up of active and abandoned coal mines nation-wide. As a result of a fee placed

on the mining of every ton of coal, a reclamation fund was established that could be used in every coal mining state for land reclamation of abandoned coal mines and for the closure of hazardous mine openings (adits and shafts) in other types of mining operations. States which had successfully restored their legacy of abandoned coalmines could use those funds for cleaning up other abandoned hard rock mines, including uranium mines. This approach has been used in Wyoming, and through an agreement with the OSM, it is also being used by the Navajo tribal government in Arizona (see below).

Uranium mills – Restoration Status

Background

The underlying basis for federal regulation of uranium mills is now the Nuclear Regulatory Commissions 10 CFR 40, specifically Appendix A, which sets forth the standards for isolation of uranium production by-product (mill tailings, waste solutions, and other residues of uranium milling and recovery). These standards, developed by the U.S. EPA, then adopted by the NRC, were established after Title I sites ceased operation but apply to both Title I and Title II sites equally for site reclamation and restoration. Since then, a number of policies and regulations have been established for the reclamation of uranium mill sites as detailed in the following references.

Title I Mills

Since the 1940s, large quantities of tailings have been generated by the uranium milling industry. In many cases, these tailings have been dispersed from impoundments and piles by natural forces and by humans for construction use in or around buildings or for roads. UMTRCA, which in 1978 amended the AEA, established two programmes to protect the public health, safety and the environment from uranium mill tailings. Title I of UMTRCA addresses 22 Congressionally designated sites (to which DOE added two more) that are now inactive (e.g., all milling has stopped and the site is not licensed by the NRC). A list of these sites include:

UMTRCA Title I Sites	
Salt Lake City, UT	Riverton, WY
Green River, UT	Converse County, WY
Mexican Hat, UT	Lakeview, OR
Durango, CO	Falls City, TX
Grand Junction, CO	Tuba City, AZ
Rifle, CO (two sites)	Monument Valley, AZ
Naturita, CO	Lowman, ID
Maybell, CO	Cannonsburg, PA
Slick Rock, CO (two sites)	Edgemont, SD
Shiprock, NM	Bowman/Belfield, SD
Ambrosia Lake, NM	

Title II of UMTRCA addresses active sites (those with NRC or Agreement State licenses) (48 FR 45926).

The milling process generated large volumes of tailings which were disposed of in tailings impoundments. ²²⁶Ra, ²³⁰Th, and ²²²Rn (gas) are the radionuclides present in uranium mill tailings that are of principal concern to human health and the environment and a principal controlling issue in the development of regulations for reclamation of mill tailings sites.

Title I defines tailings at inactive uranium milling sites as residual radioactive material. It requires the clean up of offsite tailings and the long-term control of tailings piles. DOE was charged with remediating these designated sites, with the full co-operation and participation of the states, to achieve compliance with standards prescribed by EPA. EPA has promulgated final health and environmental standards to govern stabilisation, control, and clean up of residual radioactive materials (primarily mill tailings) at inactive uranium processing sites.³² The DOE must meet these standards when remediating Title I sites.

EPA promulgated standards for two types of remedial actions: control and clean up. Control places tailings in a situation that will minimise their long-term risk to humans. Clean up reduces the potential health risks resulting from dispersed tailings. All remedial actions must be selected and performed with the concurrence of the NRC. Upon completion of the remedial action at the 24 designated sites, the NRC must issue a license to ensure that public health and the environment are protected. The license may require DOE to conduct monitoring, maintenance, or any other actions the NRC deems necessary.³³

The Uranium Mill Tailings Remedial Action Amendments Act of 1988 provided an extension of the UMTRCA Title I deadline for the DOE to finish remediating the 24 designated sites. It allowed DOE until Sept 30, 1994 (previously 1990) to perform remedial actions at designated sites. The authority to perform groundwater restoration was extended without limitation. In 1995, EPA issued final regulations to correct and prevent contamination of groundwater beneath and in the vicinity of inactive uranium processing sites by uranium tailings.³⁴ The regulations apply to tailings at 24 locations that qualify for remedial action. They provide that tailings must be stabilised and controlled in a manner that permanently eliminates or minimises contamination of groundwater beneath stabilised tailings, so as to protect human health and the environment. They also provide for clean up of contamination that occurred before the tailings are stabilised. The rule also establishes groundwater protection standards that include a list of specific hazardous constituents relevant to each waste management area, a concentration limit for each hazardous constituent, the point of compliance, and the compliance period.

EPA promulgated final standards for the control of residual radioactive material from non-operational uranium processing sites designated in Title I of UMTRCA in Subpart A of 40 C.F.R. 192. The purpose of Subpart A was to provide for long-term stabilisation and isolation in order to inhibit misuse and spreading of residual radioactive materials, control releases of radon to air, and protect water. These standards require that the remediation:

- Be designed to be effective for up to 1 000 years to the extent reasonably achievable, but at a minimum for 200 years.
- Provide reasonable assurance that releases of ²²²Rn from residual radioactive material to the atmosphere will not exceed an average release rate of 20 picocurie(pCi) /m²/s.
- Provide reasonable assurance that releases of ²²²Rn from residual radioactive material will not increase the annual average concentration of ²²²Rn in air by more than one-half picocurie per litre.

32. 40 CFR 192 (1992).

33. 55 Fed. Reg. 45,591 (1990).

34. 60 Fed. Reg. 2854 (1995).

Under Subpart B of 40 CFR 192, EPA promulgated final standards for the clean-up of land and buildings contaminated with residual radioactive materials at the 24 designated inactive uranium processing sites. EPA required that remedial actions be conducted to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site.³⁵

- The concentration of ²²⁶Ra in land, averaged over any area of 100 m² shall not exceed the background level by more than:
 - 5 picocurie per gram (pCi/g), averaged over the first 15 cm of soil below the surface.
 - 15 Pci/g averaged over 15 cm thick layers of soil more than 15 cm below the surface.
- In any occupied or habitable building:
 - The objective of the remedial action shall be, and reasonable effort shall be made to achieve, an annual average radon decay product concentration (including background) not to exceed 0.02 WL. Regardless, the radon decay product concentration, including background shall not exceed 0.03 WL.³⁶
 - The level of gamma radiation shall not exceed the background level by more than 20 microrentgen per hour.

Subpart C of 40 CFR 192 allows DOE, with NRC concurrence, to apply supplemental standards in lieu of the standards in Subparts A and B. Before using these supplemental standards, certain conditions must be present; for example, the remedial actions required to satisfy Subpart A or B pose a clear risk of injury to workers or to members of the public.

Additional guidance for the restoration of these mills included the following:

- A Standard Review Plan for UMTRCA Title I Mill Tailings Remedial Action Plans, U.S. NRC, 1985; A Staff Technical Position on Testing and Inspection Plans During Construction of DOE's Remedial Action at Inactive Uranium Mill Tailings Sites, Rev 2, U.S. NRC, 1989.
- A Standard Format and Content for Documentation of Remedial Action Selection at Title I Uranium Mill Tailings Sites, U.S.NRC, 1989; and A Technical Approach Document, Rev II, UMTRA-DOE/AL 050425.0002, U.S. DOE, 1989.

Title II Mills

Title II of UMTRCA applies to currently operating uranium mill tailings facilities licensed by the NRC or an Agreement State. Title II regulates uranium by-product materials such as mill tailings at operating sites. The Title II programme contains requirements for a final disposal of tailings, the control of effluents into groundwater, and radon emissions during and after milling operations. UMTRCA required EPA to establish standards for operating sites in a manner consistent with

35. 40 CFR 192(b) (1992).

36. WL (working level) is defined as, "Any combination of short-lived radon decay products in one litre of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts." (40 CFR 192).

standards established under Subtitle C of the Solid Waste Disposal Act, as amended.³⁷ However, the tailings as a substance are exempt from EPA's RCRA Subtitle C regulations.³⁸

The standard setting requirements are divided into two parts. The first part applies to the management of tailings during the active life of the pile and during the subsequent closure period, which begins after cessation of milling operations but prior to completion of final disposal. The second part specifies standards for after the piles are closed, which govern the design of disposal systems.³⁹ The site must be closed in a manner that meets applicable NRC standards before the NRC or Agreement State terminates the operating license and issues a long-term care license.⁴⁰ The NRC requires a detailed Long-Term Surveillance Plan (LTSP) from DOE or an appropriate State which addresses ownership (whether Federal or State), disposal site conditions, the surveillance programme, required follow-up inspections, and how and when emergency repairs and, if necessary planned maintenance, will be accomplished.⁴¹

In 1983, EPA proposed general environmental standards for uranium and thorium mill tailings sites licensed by NRC or one of its Agreement States.⁴² The NRC published amendments to 10 CFR 40 to conform its rules to EPA's general standards in 40 CFR 192, as it affected matters other than ground water protection.⁴³ EPA promulgated final rules in Subpart D of 40 CFR 192 to establish standards for the management of uranium by-product materials at Title II sites, pursuant to 1984 of the AEA, as amended.

Uranium by-product materials include the tailings or wastes produced by the extraction or concentration of uranium. The final standards address both uranium ore processing operations and closure and post-closure for uranium by-product management facilities. The uranium ore processing operation standards require:

- Impoundments containing uranium by-product material such as tailings to meet design criteria established by EPA for owners and operators of hazardous waste treatment, storage and disposal (TSD) facilities.⁴⁴
- Managing uranium by-product materials to conform to:
 - A combined ²²⁶Ra and ²²⁸Ra standard of 5 pCi/l.
 - A gross alpha-particle activity (excluding radon and uranium) standard of 15 pCi/l for groundwater.
 - The groundwater protection standards⁴⁵ and the monitoring requirements⁴⁶ that were established for owners and operators of hazardous waste TSD facilities.

37. 42 U.S.C. 6901-6992k.

38. There is no permit required by EPA for the disposal of by-product material. 42 U.S.C. 2022(b)(2). Additionally, uranium tailings are exempt from RCRA Subtitle C regulations (hazardous wastes) by 40 CFR 261.4(b)(7) (1992).

39. 58 Fed. Reg. 32,174 (1993).

40. 55 Fed. Reg. 45,591 (1990).

41. *Id.*

42. 48 Fed. Reg. 19,584 (1983). Final standards were published in 48 Fed. Reg. 45926 (1983) and codified in 40 CFR 192(D) and (E).

43. 50 Fed. Reg. 41,852 (1985).

44. 40 CFR 264.221 (1992).

45. 40 CFR 264.92 (1992).

- The Environmental Radiation Protection Standards for Nuclear Power Operations.⁴⁷
- The Ore Mining and Dressing Point Source Category: Effluent Limitations Guidelines and New Source Performance Standards, Subpart C, Uranium, Radium, and Vanadium Ores Subcategory.⁴⁸

Uranium by-product management facilities must meet the following closure and post-closure requirements:

- Closure and post-closure requirements for non-radiological hazards, which EPA promulgated for hazardous waste treatment storage and disposal facilities.⁴⁹
- The disposal areas must be designed to provide reasonable assurance of effective control of radiological hazards for at least 200 years.
- The disposal areas must be designed to limit releases of ²²²Rn from uranium by-product materials to the atmosphere so as not to exceed an average release rate of 20 pCi/m²/s (the same standard as for Title I sites). This requirement, however, is not applicable to any portion of a disposal site that contains a concentration of ²²⁶Ra that, as a result of uranium by-product material, does not exceed the background level by more than:
 - 5 pCi/g, averaged over the first 15 cm below the surface.
 - 15 pCi/g averaged over 15 cm thick layers more than 15 cm below the surface.

Additional rules covering these mills are found in:

- A Rulemaking Issue (Affirmation): Amendments to 10 CFR Part 40 for General Licenses for the Custody and Long Term Care of Uranium and Thorium Mill Tailings Disposal Sites, USNRC SECY-90-282, 1990.
- A Draft Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act, USNRC NUREG-1620, 1999.

All mills

Appropriate NRC rules on these operations include:

- A Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers, USNRC, Reg. Guide 3.64, 1989.
- A Design of Erosion Protection for Long-Term Stabilisation, USNRC NUREG-1623, 1999.
- A Uranium Mill Tailings Management Position, USNRC, 1989.

46. 40 CFR 264.98 (1992).

47. 40 CFR 190 (1992).

48. 40 CFR 440 (1992).

49. 40 CFR 264.111 (1992).

The US NRC has established numerous other Guidelines and Staff Technical Positions that address reclamation cost estimating and bonding as well as technical elements of by-product isolation, erosion protection, radiological surveys, and monitoring.

The US NRC is the regulatory agency for reclamation and environmental management of mills and mill sites in non-agreement states (i.e., New Mexico, Utah, Wyoming, North Dakota, South Dakota, Idaho, Oregon). The agreement states (Texas, Colorado and Washington) have that authority under the guidance and approval of the US NRC. The agreement states reclamation and environmental management requirements are essentially the same as those of the US NRC as cited above.

Conventional uranium mines

Background

Uranium mining and reclamation is regulated by the states rather than the federal government. Each state has its own laws and regulations, and these are different in each state. However, all uranium-production states except Arizona have established specific performance criteria or standards which mines must meet upon completion of reclamation work. Arizona's standards are more general and are based on protection of water resources. The existing regulations vary: some are specific, such as the State of Washington's maximum pit and waste pile heights and slope angles, and some are less specific, such as New Mexico's standards that require that reclamation designed for environmental protection be consistent with the designated post-mining land use. The following sources and references address each state's reclamation policies and regulations.

Waste rock volumes and restoration sites

The mining of uranium ores by both underground and surface methods produced large amounts of bulk waste material, including excavated top soil, barren overburden rock, weakly uranium-enriched waste rock, and subgrade ores (or protore). In open pit mining, top soil is the natural soil overlying the pit outline and the overburden includes material lying between the top soil and the uranium ore deposit. Open pit mining generally produced more waste products than underground mining, principally because of overburden removal. Protore contains significant amounts of uranium, but below levels justifying its immediate processing at the mill. Protore was often stockpiled on site for possible processing later. The amounts of such materials produced depend on several factors, including the price of uranium, uranium price forecasts, type of mining method, ore grades, recovery and processing costs, and other factors related to mining operations. These factors vary depending upon mine locations and demands for uranium. For example, ores mined from 1987 to 1996 have varied in uranium concentration (measured as U₃O₈% of ore) from a low of 0.198% to as high as 0.52%.⁵⁰ The concentration of uranium found in other materials that are processed like ores to recover uranium values, such as protores, mine and tailings water, and mill and mine restoration waste, is not reported by the industry.⁵¹

50. Energy Information Administration (1997), *Uranium Industry Annual 1996*, U.S. Department of Energy, DOE/EIA-0478 (96).

51. *Ibid.*

Reclamation status

The U.S. EPA⁵² found that mines subject to State reclamation requirements have been reclaimed, but they are still a small fraction of the total. EPA estimated the total overburden generated by open pit mines to range from 1 to 8 billion metric tons, with an average of 3 billion metric tons. For underground mines, the estimate ranges from 5 to 100 million metric tons, with an average of all estimates of 67 million metric tons. However, there are uncounted numbers of unreported or unlicensed mines, exploration pits and underground mine adits throughout the uranium producing states whose mine spoil wastes may be quite substantial and are not included in these estimates. Waste produced by open pit mining is a factor of 45 greater than for underground mining, based on their respective averages.

Two primary reclamation techniques are used, Class I and Class II.^{53,54} Class I reclamation is defined as complete backfilling of the mine followed by the application of topsoil, contouring, and revegetation. It is assumed that following Class I reclamation, the site is returned to its original or near original condition, and the potential for exposure of the public has virtually been eliminated. Class II reclamation generally consists of regrading, contouring, sloping, applying top soil and revegetation of waste piles and pits; while wastes are not necessarily returned to mined-out areas. The estimated unreclaimed overburden, generated from 1948 to 1988, is estimated to be 3.1 billion metric tons, and distributed as follows:

Mine Category	Unreclaimed Overburden (billion t)			
	Class I	Class II	Unreclaimed	Total
< 900 t	0	0	0.0031	0.0031
900 to 90 000 t	0	0.02	0.13	0.15
> 90 000 t	0	0.73	2.2	2.9
Total	0	0.75	2.3	3.1

The proportion of Class I reclamation to Class II reclamation for the number of mines probably has not changed with reclamation that has occurred since the 1989.

Colorado

Comprehensive compilations of radioactive mineral occurrences, prospects, and mines describing most uranium mines, their geology and early mining history, and production have been published for Colorado. Rim stripping was done in many areas of the Colorado Plateau. In this type of open-pit mining, the ore body occurred at or near the surface along the edge of a canyon. Miners would strip the shallow overburden from the deposit and generally drop the waste material down the adjacent canyon wall. Given the numbers of smaller prospects, but widespread occurrence of uranium in the state, approximately 1 200 mines (nearly one-third of uranium mines in the U.S.) were found in this

52. U.S. Environmental Protection Agency, in preparation, *Uranium Mining Technologically Enhanced Naturally Occurring Radioactive Materials*, Washington, DC.

53. Cohen S. and Associates, Inc., (1989), *Radiological Monitoring at Inactive Surface Mines*, report prepared for the U.S. Environmental Protection Agency, February 1989.

54. U.S. Environmental Protection Agency, *A Background Information Document – Proposed NESHAP's Regulations for Radionuclides*, draft, report prepared for U.S. EPA, 520/1-89-006, February 1989.

state. The EPA⁵⁵ estimated that one sixth of those mines were underground operations. Studies by that agency in 1989 found that for the 12 mines that produced between 900 and 90 000 metric tons of ore, only 3 had been reclaimed, while only 1 of 4 mines that produced over 90 000 tons had been reclaimed.

Generally only some currently abandoned properties which were active after the mid-1970s have been reclaimed or have ongoing reclamation activities. The Department of Energy in Grand Junction has a reclamation programme for abandoned properties on old Atomic Energy Commission lease tracts. An estimated 190 000 m³ of waste was inventoried on AEC lands and during 1994 about 27 000 m³ of waste was reclaimed.⁵⁶ This inventory does not include active company properties on those leases. Most waste piles range from 800-4 000 m³. The single largest producer in the Uravan mining district, has been reclaimed by UMETCO.

Typical reclamation at a mine site in the Uravan mineral belt consists of using elevated gamma-activity material (ore stockpiles, subore piles, ore storage pad soils) to backfill adits, shafts, pits, and decline trenches. Low-activity waste piles are recontoured. If a waste pile has significant regrowth of vegetation it is left undisturbed.

State control of reclamation activities is carried out by Department of Natural Resources, Division of Minerals and Geology, Mined Land Reclamation Board.

The relevant statute section is the Mined Land Reclamation Act as specified in Colorado Revised Statutes Section 34-32-102 – Hard Rock/Metal Mining, Rules and Regulations.

New Mexico

Uranium mining in New Mexico has principally been from moderate to extremely large open-pit mines and from moderate to extremely large underground mines. About 50% of uranium production (in pounds of uranium oxide) has come from each of these two sectors, but with slightly higher grades in the underground mines. More metric tons of ore were produced in the open-pit mines and a much higher proportion of waste was produced from the open-pit mines. About 50-75% of all uranium mine waste has been reclaimed in the State of New Mexico.⁵⁷ For example, the Jackpile-Paguate open-pit mine with its 364 million metric tons of waste has been completely reclaimed.

The state regulating agency is the Department of Energy, Minerals and Natural Resources; Mining and Minerals Division, Mining Act Reclamation Programme. Its activities are covered under the New Mexico Mining Act 19 NMAC 10.2; Rules Subpart 5, Sections 506 and 507.

Texas

According to the EPA,⁵⁸ the Texas Abandoned Mine Lands (AML) Section of the Surface Mining and Reclamation Division began an environmental inventory and prioritisation of abandoned uranium

55. U.S. Environmental Protection Agency, *A Potential Health and Environmental Concern of Uranium Mine Wastes*, Report to Congress, EPA 520/1-83-007, June 1983.

56. Cotter Ed, DOE, oral communication, 1998.

57. V. McLemore, oral communication to EPA, 1998.

58. U.S. Environmental Protection Agency, in preparation, *Uranium Mining Technologically Enhanced Naturally Occurring Radioactive Materials*, Washington, DC.

mine sites in Texas in 1988.⁵⁹ Mine sites investigated were those that were abandoned or became inactive prior to the enactment of Texas Uranium Mining and Reclamation Act of 1975 which requires reclamation of uranium mines. This survey studied 18 properties in three areas in Karnes, Atosca, and Live Oak Counties, south Texas which were inactive or abandoned. Reclamation was underway at one site already identified and surveyed. All open-pit mines, where companies were obligated to reclaim the sites, have been reclaimed. About 70% of reclamation work for company and AML open-pit operations has been completed in the State of Texas as of 1998.

In Texas the principal regulating agency is the Texas Railroad Commission, Surface Mining and Reclamation Division. The pertinent regulation title is - Uranium Mining Rules, Texas Admin. Code Title 16, Part 11.71 *et seq.*, Surface Mining and Reclamation Act, Texas Natural Resources Code Ann. Part 131 *et seq.*

Utah

Based on studies conducted by the EPA Utah operations would be mixed with open-pitting of the shallow parts of the ore body occurring first, then adits or declines would extend from the lower part of the pit to follow ore underground. Utah has conducted some mine reclamation work on abandoned uranium properties in the State. This effort has consisted mostly of inventory and mine opening closures (for physical safety). About 2 000 underground uranium mine openings have been counted. A rough estimate is that the average mine opening has a 1 000 m² waste pile associated with it. If the average pile were 2 m thick the total waste volume for all underground uranium mines in Utah would be 4.0 million m³ or 8.0 million metric tons. More precise waste volume estimates are possible for Utah as such data is present in state files, however no summary of this data has been published. Mine reclamation efforts for these generally small mines has not begun although sealing of openings and barrier placement to protect physical safety is underway.

Company reclamation work has occurred at some larger mines including the Yellow Cat and Mi-Veda mines and mines in the Lisbon Valley area.

The principal regulating agency is the Department of Natural Resources; Division of Oil, Gas, and Mining. It operates under the Mined Land Reclamation Act, Title 40-8, and General Rules and Rules of Practice and Procedure R 647-1 through R 647-5.

Washington

Only a small amount of mining has occurred in Washington with 3 mines recorded in the state. The largest mine of these, the Midnite Mine on Spokane Indian Tribal lands is now the subject of EPA enforcement activities for Superfund clean-up. In the state, the principal regulating agency is the Department of Ecology, whose relevant operating statute section is Ch. 78.44 RCW.

Wyoming

According to the EPA review,⁶⁰ an initial inventory of sites covering about 50-60% of all the known eligible sites for all types of mining was completed by the state in 1984. Eligibility for reclamation is determined by the time of abandonment or declaration of inactive status of the property.

59. Railroad Commission of Texas, *South Texas uranium district abandoned mine inventory*, Surface Mining and Reclamation Division, Railroad Commission of Texas, 171 p., 1994.

60. U.S. Environmental Protection Agency, in preparation, *Uranium Mining Technologically Enhanced Naturally Occurring Radioactive Materials*, Washington, DC.

Through the end of 1994, 3 200 acres of uranium mine sites have been reclaimed with 37.6 million m³ of waste moved at a total cost of USD 40.85 million. Reclamation consists of backfilling and grading to eliminate dangerous high walls, restore erosional stability, and to return the surface to livestock and wildlife grazing. Waste piles are surveyed for radioactivity by surface surveys and drilling.

Pits are backfilled with waste pile material, with low-radioactivity material used to fill the pit below the projected water table, higher radioactivity material from the water table to just below the graded surface, and low radioactivity material for the surface. Topsoil is placed on top of this for revegetation. Some low-activity waste piles may be left in place and graded to reduce slopes and permit revegetation.

The principal Regulating agency in Wyoming is the- Department of Environmental Quality, Land Quality Division and Abandoned Mines Division. Relevant statute section or regulation is the W.S. 35-11-406 (a-d); Guideline 12 (bond) and Chap. 2, 3, 4, 7; Environmental Protection Performance Standards, Non-coal Rules Chap. III and IX (b).

Arizona

According to the EPA⁶¹ uranium mining in Arizona has occurred primarily on Navajo lands in north-eastern Arizona and in underground breccia pipe mines north of and within the Grand Canyon National Park. Most production on Navajo lands occurred prior to 1980. Total pre-1980 production in Arizona is 3,295,846 metric tons of ore⁶² with slightly less than half of all production coming from four mines. It is estimated that approximately 1 100 mines are found on Navajo lands, the majority in Arizona, though many in New Mexico.

EPA found that the Navajo Nation has been conducting clean up of open-pit mines in various mining districts in north-eastern Arizona. Overall, perhaps 10% of uranium mine waste has been reclaimed in Arizona.

Licensing and permitting of uranium production facilities

It is notable that no new uranium mills have been licensed in the U.S. since 1981. Only one major uranium mine, Green Mountain, has been licensed in recent years. Essentially all recent permitting and licensing activities have been conducted for *in situ* leach projects. Examples of recent permitting and licensing processes are detailed in the following paragraphs.

NRC-state permitting agreement

“In order to process or refine ores containing by weight 0.05% or more uranium, after removal from their place of deposit in nature, an NRC Source Material License is required. An applicant for a new license or renewal of an existing license to receive, possess and use source material is required to provide, detailed information on his proposed facilities, equipment, experience and procedures. This information is used by the commission in determining whether the applicant's proposed activities will,

61. U.S. Environmental Protection Agency, in preparation, *Uranium Mining Technologically Enhanced Naturally Occurring Radioactive Materials*, Washington, DC.

62. Scarborough, R.B., *Radioactive occurrences and uranium production in Arizona*: U.S. Dept of Energy Report GJBX-143 (81), 297 p., 1981.

among other things, result in undue risk to the health and safety of the public. General guidance for filing an application is approved in 40.31 of 10 CFR Part 40.”⁶³

The NRC is mandated by Congress to regulate operations whose primary purpose is the recovery uranium, as defined in the Atomic Energy Act of 1954. Operations in which uranium is recovered as a secondary or by-product are not regulated by the NRC, but are regulated by state agencies as any other industrial activity. For example, by-product uranium recovery in Louisiana is regulated by the Department of Environmental Quality.

Under UMTRCA, the NRC also has the responsibility for regulating uranium mill tailings. Some states preferred to regulate mills within their borders, as this was a right of a state. In this way, state-level expertise could be employed in dealing with local environmental matters as well as any socio-economic impacts that might result from such operations. In the early 1960s, the NRC and so called “Agreement States” signed agreements whereby the state would provide permitting, regulating, and monitoring systems comparable to the NRC systems. In non-Agreement States, the NRC was the regulating agency. When regulating/monitoring requirements became more extensive and expensive, some states, New Mexico for one returned responsibility to the NRC. Only three states, Colorado, Texas, and Washington, are currently Agreement States for uranium mills and tailings completely within the State. All other states allow the NRC to provide the necessary controls.

ISL of uranium is considered a primary recovery or “milling” for uranium. Therefore, ISL is regulated by the NRC, or the agreement state involved.

Regulation by the NRC does not preclude state involvement in a uranium milling operation. States have different requirements for water quality permits, drinking water permits, etc., and the NRC works closely with the different state agencies which have an interest in the mill development. The Radiation Control Programme Director in each state helps to co-ordinate the State and NRC activities.

New Mexico – Crownpoint

Licensing activities for the Crownpoint *in situ* leaching project were initiated in 1988, but the necessary permits and licenses for project operations are yet to be issued. Major activities included preparation of a draft environmental impact statement which was published in early 1995 and completion of the changes necessary in that draft to publish a final environmental impact statement in February 1997. Principal approvals necessary for ISL operations in New Mexico include a source materials license from the NRC and an underground injection control permit from the New Mexico Environmental Department or the U.S. Environmental Protection Agency.

A complicating factor in the issuance of permits and approvals for this project is its relationship to the American Indian community and the political environment of that community. These relationships have pulled a variety of federal agencies into the licensing/permitting process.

Prior to 1986, New Mexico was an “Agreement State” and regulated all uranium production activities through state agencies. As of June 1, 1986, the NRC assumed the primary responsibility for regulating uranium mills and mill tailings in New Mexico. Because ISL operations are classed as primary uranium production facilities, they are also regulated by the NRC. The state of New Mexico regulates all other activities related to uranium, but is also deeply involved in the areas where the NRC is the primary regulator.

63 . U.S. Nuclear Regulatory Commission, Regulatory Guide 3.5.

Conventional uranium mining activities in New Mexico are regulated primarily by the Energy, Minerals and Natural Resources Department; the Environmental Improvement Division of the Health and Environment Department; and the State Engineer.

ISL activities at Crownpoint will be licensed and regulated primarily by the NRC, but many other agencies will also be involved as shown in the following list.

Permit/regulation authority	Review agency/granting
Well Drilling and Completion Permits	USGS, USBIA, USNPS, SEO
Pilot Test Mine Plant	USGS, USBIA
Notice of Intent to Discharge	EID (WPCB)
Groundwater Discharge Permit	EID (WPCB)
Underground injection	WQCC
Archaeological Clearance	USNPS, SHPD
Endangered Species Protection	NMNRD
Air Quality Control Permit	EID (AQB)
Solid Waste Disposal Registration	EID (CSSB)
Water Appropriation Permit	SEO
Mine Registration	EMD (MMD)

Note:

USBI Bureau of Indian Affairs

EID Environmental Improvement Division, New Mexico Health and Environment Department. Under the EID:

- AQB Air Quality Bureau, EID*
- CSSB Community Support Services Bureau, EID*
- RPB Radiation Protection Bureau, EID*
- WPCB Water Pollution Control Bureau, EID*

WQCC New Mexico Water Quality Control Commission

EMD New Mexico Energy and Minerals Department

MMD Mining and Minerals Division (State Mine Inspector)

SHPD New Mexico Historic Preservation Division, Office of Cultural Affairs

SEO New Mexico State Engineer Office

NRD New Mexico Natural Resources Department

USNPS National Park Service

USGS U.S. Geological Survey

Wyoming – Smith Ranch

The licensing of a commercial solution mining operation in the State of Wyoming has, in the past, required approximately 4.0 to 4.5 years. The principal requirement was a demonstration of aquifer restoration capability through a pilot plant test. Recently, however, the licensing process has been

streamlined and a demonstration of aquifer restoration may not be required. This streamlining is the result of a change in attitude by Wyoming regulatory authorities from adversarial to neutral or even accommodating. This change has occurred in response to an increasing awareness of the contribution of uranium production to the economy of the State as well as increasing familiarity with the technology of solution mining.

The following permits are required in order to conduct commercial solution mining operations in Wyoming:

- United States Nuclear Regulatory Commission (USNRC):
 - Source Materials License.
- Wyoming Department of Environmental Quality (WDEQ):
 - Land Quality Division and Water Quality Division.
Permit to Mine.
 - Water Quality Division.
Permit to Construct Evaporation Ponds.
Permit to Construct Wastewater Treatment Systems (Sanitary and Laboratory Waste).
- Groundwater Pollution Control Permit:
 - Land Quality Division.
Exploration by Drilling Permit.
 - Air Quality Division.
Permit to Construct and Operate Plant.
Permit to Construct and Operate Yellowcake Dryer.
State Engineer's Office.
Groundwater Appropriation permits for Potable Water Wells, Well fields, Monitor Wells and Hydrologic Test Wells.
Other.
Permit to Construct Evaporation Ponds.
Access and Use Agreements with Landowner.
County Planning Department Approvals.
Approval of Safety Training Plans by U.S. Mine Safety and Health Administration.

Rio Algom, and previously Kerr-McGee (Sequoyah), were involved in the permitting process at Smith Ranch for many years, with underground, surface and ISL exploitation. The NRC approved the transfer of the Kerr-McGee pilot plant source material license to Rio Algom on January 12, 1989. In mid-1989, Rio Algom submitted applications for commercial ISL licenses to the NRC and DEQ and in July 1990, filed an amendment to those applications to increase the design capacity to 2.0 million pounds U_3O_8 per year. The State of Wyoming issued a commercial mining permit in August of 1991, and the NRC issued a source material license in March 1992.

Texas

Texas remains one of the few states wherein commercial uranium production operations are regulated by State agencies. A Radioactive Materials Handling License is required in order to operate an *in situ* leach uranium production facility in Texas. Since January 1975, when the first commercial

operation for *in situ* leach mining of uranium began in Texas, about 25 such mines have been permitted.⁶⁴

Under the Texas Natural Resource Conservation Commission (TNRCC), the Underground Injection Control (UIC) program is guided by State regulations/statutes and Federal rules/statutes governing underground injection wells and the protection of groundwater in Texas. Injection wells used in Texas for *in situ* solution mining of uranium, Class III wells^{65,66}, are those which inject fluids for extraction of minerals (including extraction of uranium), exclusive of oil and gas and are regulated by the TNRCC as described below.

Jurisdiction over radioactive substances is handled by the Texas Low-Level Radioactive Waste Disposal Authority, the Bureau of Radiation Control (BRC) of the Texas Department of Health, and the TNRCC. The BRC, which has jurisdiction over all activities except the disposal of radioactive wastes and naturally occurring radioactive materials (NORM), was given in 1997 under S.B. 1857 responsibility for issuing radioactive material licenses for *in situ* uranium mining and processing and uranium by product disposal. The TNRCC, formed in 1993 from the merger of several State agencies to form a single environmental regulatory agency, issues permits for injection wells used for *in situ* mining, for underground injection of wastes, and for disposal of NORM not associated with oil and gas production.

Permit applications must be reviewed for comment by the following agencies:

- Bureau of Economic Geology.
- Railroad Commission of Texas.
- Texas Air Control Board.
- Texas Department of Agriculture.
- Texas Historical Commission.
- Texas Parks and Wildlife Department.
- Texas State Soil and Water Conservation Board.

Texas requires financial security to be established in order to provide for reclamation of all site operations. The amount of funds and the form of security must be acceptable to the State, and are subject to annual revision by the State.

License application fees amount to USD 68 000. The annual fee is USD 29 000. While it may be possible to operate two facilities under one license, such as a primary recovery facility and a satellite, some pressure exists for individual licensing of each facility.

64 Texas Natural Resource Conservation Commission. *Underground Injection Control: Rules* (Update: November 4, 1999).

65 *Ibid*, p.1.

66 Knapp, B.K., *Underground Injection Operations in Texas, A Classification and Assessment of Underground Injection Activities*, Texas Department of Water Resources Report 291, (December 1984), pp. 1-1, 1-6.

Nebraska – Crow Butte

The licensing process for the Crow Butte project began in 1983 when applications for Research and Development Pilot Plant Operations licenses were submitted to the NRC and the Nebraska Department of Environmental Control (NDEC). These licenses were approved in 1985, but limited the pilot plant flow rate to 100 gpm.

Applications for commercial licenses were submitted in late 1987 to both agencies. The NRC issued its approval in December 1989 and the NDEC approved the operation in April 1990. The Crow Butte (ISL) licenses approved by the NDEC were the first such licenses issued by that group.

Owners of the Crow Butte project have overcome a series of major difficulties during the licensing process including a possible foreign ownership restriction at the state level and difficulties in identifying an acceptable low-level waste disposal facility. All licenses and permits were actively opposed by a small but vocal group of local anti-nuclear activists.

Costs of environmental management at operating facilities

Of the 75 sites evaluated for operating status and costs, only one, Cotter Corporation's new Canon City Mill, was operating at the end of 1999. U.S. Energy's Shootaring Canyon mill, Quivira's Ambrosia Lake mill, and U.S. Energy/Kennecott's Sweetwater mill are in standby status. International Uranium Corporation's White Mesa mill is processing "alternate feed" materials. No current operating cost information could be obtained for these facilities.

Costs of environmental management after closure

Costs of environmental management after closure consist primarily of reclamation and monitoring costs. For uranium mills, these costs include mill decontamination and demolition, long-term tailings stabilisation, and ground water remediation. For mines, reclamation involved partial backfilling of pits, stabilisation of waste rock piles, recontouring of disturbed land surfaces, and revegetation. Monitoring is a post-closure cost of both mills and mines. In Tables 1-7, a summary is provided of the after-closure costs for the 75 production facilities, including mines and mills, that were included in this study.

Table 1. Title I Uranium mills – decommissioning study – quantity and cost

Title I Uranium mills	Owner/Operator	mt Ore (million)	mtU	Curies	Total USD (million)	USD/mt ore	USD/kgU	USD/lb U ₃ O ₈	USD/Curie	
Ambrosia Lake Mill	Phillips, United Nuclear Corp	2.8	5 077	1 850	33.80	12.07	10.95	6.75	2.60	
Belfield Plant	Union Carbide	<0.1	130	NA	4.00	91.36	82.88	30.92	11.89	
Bowman Plant	Kerr-Mcgee Nuclear	0.1	233	NA	2.70	36.30	32.93	11.37	4.37	
Canonsburg	Vitro Minerals	0.3	224	100	35.00	129.63	117.60	156.25	60.10	
Durango Mill	Vanadium Corp.	1.5	3 020	1 400	53.50	36.90	33.47	17.72	6.81	
Edgemont Mill	Tennessee Valley Authority	2.1	3 493	NA	35.30	16.83	15.27	10.12	3.89	
Falls City Mill	Susquehanna Western	2.3	3 077	1 277	41.60	18.08	16.40	13.52	5.20	
Grand Junction Mill	Climax	2.1	4 496	NA	450.50	214.52	194.61	100.20	38.54	
Green River Concentrator	Union Carbide	0.2	346	30	15.20	76.00	68.95	43.93	16.90	
Gunnison Mill	Gunnison Mining	0.5	623	175	40.30	80.69	73.21	64.76	24.91	
Lakeview Mill	Lakeview Mining	0.1	150	42	24.60	245.71	222.91	163.81	63.00	
Lowman Mill	Porter Brothers	0.2	140	12	11.50	57.49	52.15	82.14	31.59	
Maybell Mill	Umetco Minerals Corp	2.4	1 538	455	42.80	17.82	16.17	27.81	10.69	
Mexican Hat Mill	Atlas Minerals	2	4 385	1 800	44.00	22.00	19.95	10.03	3.86	
Monticello Mill	US Atomic Energy Commission	0.8	1 763	NA	256.20	320.25	290.53	145.32	55.89	
Monument #2 Upgrader	Vanadium Corp.	0.9	2 307	NA	17.50	19.44	17.63	7.58	2.92	
Naturita Mill	Vanadium Corp.	0.6	1 895	79	59.80	99.72	90.46	31.57	12.14	
Rifle Mill	Union Carbide	2.8	6 154	2 738	100.20	35.77	32.45	16.27	6.96	
Riverton Mill	Susquehanna Western	0.8	831	NA	39.10	48.83	44.29	47.00	18.08	
Salt Lake City Mill	Vitro Minerals	1.5	4 185	1 550	83.90	55.96	50.77	20.06	7.72	
Shiprock Mill	Footo Minerals	3.4	7 115	748	17.80	5.22	4.74	2.50	0.96	
Slick Rock Concentrator	Union Carbide	0.6	1 290	149	36.10	57.79	52.43	27.96	10.75	
Slick Rock Plant	North Continent Mining	-	-	-	-	-	-	-	-	
Spook Upgrader	Wyoming Mining	0.2	173	125	5.50	27.49	24.94	31.78	12.22	
Tuba City Mill	El Paso Natural Gas	0.7	1 806	940	25.70	36.69	33.28	14.22	5.47	
Total & averages		28.9	54 381	13 470	1 476.50	51.16	46.41	27.15	10.44	49 829

mt = Metric ton.
 NA = Not available.

Notes : Belfield Plant : The reported ore processed was 44 429 metric tons.
 Source : International Nuclear, Inc. "Support for Data Compilation and Analysis of Costs Relating to Environmental Restoration of U.S. Uranium Production Facilities." Unpublished firmal report, prepared for the Energy Information Administration, Golden, Colorado, U.S.A., March 2000.

st = Short ton.
 kgU = Kilogram of uranium.
 lbU₃O₈ = Pound of uranium concentrate as U₃O₈.

Table 2. Title II Uranium mills – decommissioning study – quantity and cost

Title II Uranium mills	Owner/Operator	mt Ore (million)	mtU	Total USD (million)	USD/mt ore	USD/st ore	USD/kgU	USD/lb U ₃ O ₈
Bear Creek Mill	Rocky Mountain Energy	4.3	2 529	4.90	1.14	1.03	1.94	0.75
Bluewater Mill	Anaconda Minerals Co	32.8	50 000	43.00	1.31	1.19	0.86	0.33
Church Rock Mill	United Nuclear Mining & Milling	3.2	3 091	16.40	5.13	4.65	5.31	2.04
Conquista Mill	Conoco Inc	8.0	6 154	8.00	1.00	0.91	1.30	0.50
Durita Heap Leach	Hecla Mining Corp.	0.6	147	3.00	5.00	4.55	20.41	7.85
Ford Mill	Dawn Mining Co	2.8	4 773	17.50	6.25	5.67	3.67	1.41
Gas Hills Mill	Umetco Minerals Corp	7.3	6 836	50.60	6.93	6.29	7.40	2.85
Gas Hills Mill	Federal-American Partners	5.2	10 263	7.40	1.42	1.29	0.72	0.28
Grand Junction Pilot Plants	U.S.Atomic Energy Cimmission	<0.1	50	33.30	–	–	–	–
Grants Mill	United Nuclear-Homestake	22.2	28 500	71.10	3.20	2.90	2.49	0.96
Grants Mill	Quivira Mining Co	37.9	48 360	41.20	1.09	0.99	0.85	0.33
Highland Mill	E Exxon Minerals Co	10.0	9 297	20.00	2.00	1.81	2.15	0.83
L-Bar Mill	Sohio Western Mining Co	1.5	1 736	17.00	11.33	10.28	9.79	3.77
Lisbon Mill	Rio Algom Corp	3.5	5 712	15.50	4.43	4.02	2.71	1.04
Lucky Mc Mill	Pathfinder Mines Corp	14.6	21 909	9.80	0.67	0.61	0.45	0.17
Maybell Heap Leach Facility	Umetco Minerals Corp	1.8	385	3.20	1.78	1.61	8.31	3.20
Moab Mill	Atlas Minerals	19.5	24 769	16.00	0.82	0.74	0.65	0.25
New Canon City Mill	Cotter Corp	1.9	6 847	12.80	6.74	6.11	1.87	0.72
Old Canon City Mill	Cotter Corp	–	–	–	–	–	–	–
Panna Maria Mill	Rio Grande Resources	5.9	5 846	21.00	3.56	3.23	3.59	1.38
Ray Point Mill	E Exxon Minerals Co	0.4	229	4.10	10.25	9.30	17.90	6.89
Sherwood Mill	Western Nuclear Inc	2.6	2 300	8.30	3.19	2.90	3.61	1.39
Shirley Basin Mill	Petrotomics Company	5.7	9 075	9.90	1.74	1.58	1.09	0.42
Shirley Basin Mill	Pathfinder Mines Corp	6.5	9 463	15.00	2.31	2.09	1.59	0.61
Shooting Canyon Mill	U.S. Energy	<0.1	10	7.00	–	–	–	–
Split Rock Mill	Western Nuclear Inc	7.0	7 190	25.00	3.57	3.24	3.48	1.34
Sweetwater Mill	Minerals Exploration Co	2.1	497	5.40	2.57	2.33	10.87	4.18
Uravan Mill	Umetco Minerals Corp	9.4	16 346	96.20	10.23	9.28	5.89	2.26
White Mesa Mill	International Uranium	4.0	10 923	11.50	2.87	2.60	1.05	0.40
Total & averages		220.2	293 297	594.10	2.69	2.44	2.03	0.78

mt = Metric ton. mtU = Metric ton of uranium. st = Short ton. kgU = Kilogram of uranium. lbU₃O₈ = Pound of uranium concentrate as U₃O₈. – = Not applicable.
 Notes : Grand Junction Pilot Plant : The reported ore processed was 30 000 metric tons ; reported uranium concentrate production includes concentrates received at the sample plant from other facilities. Data totals for the Old Canon City Mill are included under the New Canon City Mill. Shooting Canyon Mill : reported ore processed was 15 000 metric tons.
 Source : International Nuclear, Inc. "Support for Data Compilation and Analysis of Costs Relating to Environmental Restoration of U.S. Uranium Production Facilities." Unpublished final report, prepared for the Energy Information Administration, Golden, Colorado, U.S.A., March 2000.

Table 3. Uranium mines – decommissioning study – quantity and cost summary – uranium mines

Uranium mines	Owner/Operator	mt Ore (million)	mtU	ha	Total USD (million)	USD/mt ore	USD/st ore	USD/kgU	USD/lb U ₃ O ₈	USD/ha
Bear Creek O.P. Mine	Rocky Mountain Energy	4.3	2 615	765	6.20	1.44	1.31	2.37	0.91	8 105
Big Eagle O.P. & U.G. Mines	U.S. Energy	1.2	1 064	183	7.30	6.06	5.49	6.83	2.63	39 716
Conquistia O.P. Mines	Conoco Inc	5.2	2 875	1 160	5.20	1.00	0.91	0.71	0.70	4 483
Crooks Gap Mines	U.S. Energy	5.9	8 000	129	1.40	0.24	0.22	0.18	0.07	10 853
Day-Loma O.P. Mine	Energy Fuels Nuclear, Inc.	0.4	575	167	24.60	61.50	55.79	42.78	16.45	147 305
Felder O.P. Mine	Exxon Minerals Co	0.9	982	184	0.40	0.48	0.43	0.44	0.17	2 337
East Gas Hills O.P. Mine	Umetco Minerals Corp	7.3	6 836	780	16.60	2.27	2.06	2.42	0.93	21 219
Gas Hills O.P. Mines	Federal-American Partners	0.8	563	161	2.30	2.88	2.61	4.09	1.57	14 286
Highland O.P. Mine	Exxon Minerals Co	10.0	9 297	447	3.80	0.38	0.34	0.41	0.16	8 501
Jackpile/Paguate O.P. Mine	Anaconda Minerals Co	21.6	28 808	1 075	35.00	1.62	1.47	1.21	0.47	32 558
Lucky Mc O.P. Mine	Pathfinder Mines Corp	10.6	16 923	1 284	15.00	1.42	1.28	0.89	0.34	11 682
Midnite O.P. Mine	Dawn Mining Co	2.0	3 846	128	34.50	17.25	15.65	8.97	3.45	269 531
Panna Maria O.P. Mines	Chevron Resources Co	4.7	1 868	407	15.00	3.19	2.90	8.03	3.09	36 855
Pitch O.P. Mine	Homestake Mining Co	0.3	830	126	10.00	33.33	30.24	12.05	4.63	79 365
Powder River Basin O.P. Mines	Kerr-Mcgee Nuclear	0.5	384	118	1.90	3.80	3.45	4.95	1.90	16 102
Rhode Ranch O.P. Mine	Chevron Resources Co	1.1	3 036	183	4.00	3.81	3.46	1.32	0.51	21 858
Sherwood O.P. Mine	Western Nuclear Inc	2.6	2 300	205	3.50	1.35	1.22	1.52	0.59	17 073
Shirley Basin O.P. Mine	Pathfinder Mines Corp	6.5	9 463	1 369	59.30	9.12	8.28	6.27	2.41	43 316
Shirley Basin O.P. Mine	Petrotonics Company	5.7	9 075	399	32.00	5.61	5.09	3.53	1.36	80 201
St. Anthony O.P. Mine	United Nuclear Mining & Milling	0.6	568	175	2.00	3.33	3.02	3.52	1.35	11 429
Sweetwater O.P. Mine	Minerals Exploration Co	2.1	497	294	11.80	5.62	5.10	23.74	9.13	40 136
Total & averages		94.2	110 405	9 739	291.70	3.10	2.81	2.64	1.02	29 957

mt = Metric ton.
= Open pit (mine).

mtU = Metric ton of uranium.
U.G. = Underground (mine).

ha = Hectare.
st = Short ton.

kgU = Kilogram of uranium.
lbU₃O₈ = Pound of uranium concentrate as U₃O₈ O.P.

Source : International Nuclear, Inc. "Support for Data Compilation and Analysis of Costs Relating to Environmental Restoration of U.S. Uranium Production Facilities." Unpublished final report, prepared for the Energy Information Administration, Golden, Colorado, U.S.A., March 2000.

Cost-benefit analyses

Comparisons of reclamation costs to quantifiable benefits, or cost-benefit analyses, were performed for all 75 sites included in this survey. For Title I mill sites, total reclamation costs were compared to tons of ore processed, tons of U_3O_8 produced and curies of ^{226}Ra isolated from the environment. For Title II mill sites, total reclamation costs were compared to tons of ore processed and tons of U_3O_8 produced; no data were available to evaluate costs versus curies of ^{226}Ra isolated from the environment. For mines, total reclamation costs were compared to tons of ore processed and tons of U_3O_8 produced.

Title I sites (Table 4) were comparatively costly to reclaim, or stabilise, to required standards. Of the 26 Title I sites, the most costly by far was the Grand Junction mill at USD 450.5 million. Average costs of reclamation were USD 50.91/mT of ore and USD 29.22/kgU produced, but if the Grand Junction mill is excluded, the average cost per ton drops to USD 38.16/mT of ore and the average cost per kgU drops to USD 22.31. The averages without Grand Junction mill are considered to be more representative and meaningful, especially for comparison to costs for Title II mills. The cost per curie ^{226}Ra range from USD 5 000/curie to USD 958 000/curie and averaged USD 48 000/curie. The average cost of reclamation per Title I site was USD 56.9 million.

In terms of costs of reclamation per ton of ore, Title II sites (Table 5) were substantially less costly to reclaim to the same standards as the Title I mills. Average costs of reclamation of the 28 Title II sites were USD 2.66/mT of ore and USD 2.06/kgU produced. However, the Shootaring Canyon mill is an anomaly in that it had been operated only long enough to test the mill, processing only 13 500 metric tons of ore. If Shootaring Canyon cost figures are excluded, the Title II average costs drop to USD 2.62/mT of ore and USD 2.03/kgU produced. Costs of reclamation of these sites ranged from a low of USD 0.67/mT of ore and USD 0.65/kgU produced to a high of USD 11.33/mT of ore and USD 10.28/kgU produced, excluding Shootaring Canyon. The average cost of reclamation per Title II site was USD 20.9 million, or about 37% of the average cost of Title I sites. Table 6 compares total closure costs for Title I and Title II sites.

The benefit to public health and the environment of uranium mill reclamation includes many factors, in addition to curies contained, tons of ore and uranium produced, numbers and locations of receptors and exposure pathways. Those other factors could not be determined or quantified for this survey. Therefore, the only evaluation of benefits that can be made from data common to all mill sites is based on tons of ore and quantity of uranium produced, as described above. It is apparent from these costs that Title II site reclamation provided more benefit per unit cost than the Title I reclamation.

Costs of reclamation of the 21 mines (Table 7) included in this survey varied widely, by more than two orders of magnitude in terms of cost per ton of ore and kgU produced. Some of this range is attributable to differences in acreage land area disturbed per ton of ore, but much of it is due to the differences in methods of accounting for reclamation costs. Some mines performed contemporaneous reclamation during mining and some of those mines charged those costs against operations while others charged them separately as reclamation costs. Average costs of reclamation of the 21 mine sites included in this survey were USD 3.01/mT of ore mined, USD 2.54/kgU produced, and USD 29 969/hectare of land disturbed. However, the Day-Loma has exceptionally high costs and skews the averages disproportionately to its total production. If Day-Loma cost figures are excluded, the Title II average costs drop to USD 2.77/mT of ore, USD 2.34/kgU produced, and USD 27 900/hectare of disturbance. Costs of reclamation of these sites ranged from a low of USD 0.24/mT of ore, USD 0.18/kgU produced, and USD 2 337/hectare disturbance to a high of USD 33.33/mT of ore, USD 23.74/kgU produced excluding the Day-Loma mine, and USD 269 531/hectare disturbance for all 21 mines. The average total estimated cost is USD 13.9 million per mine.

Table 4. Uranium production and site closure cost for title I mills and related facilities

Items	Value
Sites (number)	25
Uranium Production	
Ore Processed (million metric tons ore)	28.90
U Produced (metric tons)	54 381.00
Closure Cost Experience	
Average Cost (USD/mt ore)	51.16
Lowest Cost (USD/mt ore)	5.22
Highest Cost (USD/mt ore)	320.25
Average Cost (USD/kgU)	27.15
Lowest Cost (USD/kgU)	2.50
Highest Cost (USD/kgU)	163.81
Average Cost (USD/Curie, ²²⁶ Ra)	50 000.00
Lowest Cost (USD/Curie, ²²⁶ Ra)	23 743.00
Highest Cost (USD/Curie, ²²⁶ Ra)	958 167.00
Average Closure Cost per Site (25 sites; million USD)	59.00
Total Closure Cost (25 sites; million USD)	1 477.00
Groundwater Restoration (25 sites; million USD)	215.00
Grand Total (25 sites; million USD)	1 692.00

Table 5. Uranium production and site closure cost for title II mills and related facilities

Items	Value
Sites (number)	29
Uranium Production	
Ore Processed (million metric tons ore)	220.80
U Produced (metric tons)	29 3237.00
Closure Cost Experience	
Average Cost (USD/mt ore)	2.69
Lowest Cost (USD/mt ore)	0.67
Highest Cost (USD/mt ore)	11.33
Average Cost (USD/kgU)	2.03
Lowest Cost (USD/kgU)	0.45
Highest Cost (USD/kgU)	20.41
Average Closure Cost per Site (29 sites; million USD)	21.00
Grand Total (29 sites; million USD)	594.00

mt ore = Metric ton of ore. kgU = Kilogram of uranium. Curie ²²⁶Ra = Unit of radioactivity from radium-226 isolated from the environment.

Notes: When costs for Shooting Canyon Mill are excluded, the value for Closure Cost Experience, Average Cost of Closure is USD 2.66 per metric ton ore and USD 2.00 per kilogram uranium. Values for Average Closure Cost per Site, Total Closure Cost, Groundwater Restoration and Grand Total are rounded to nearest million USD.

Source: International Nuclear, Inc. "Support for Data Compilation and Analysis of Costs Relating to Environmental Restoration of U.S. Uranium Production Facilities." Unpublished final report, prepared for the Energy Information Administration. Golden, Colorado, U.S.A., March 2000.

Table 6. Uranium production site closure cost for title I and title II mills and related facilities

Items	Value
Average Closure Cost per Site (54 sites; million USD)	42
Grand Total (54 sites; million USD)	2 286

Note: See Tables 4 and 5 for data relating to Title I and Title II uranium production sites and closure costs statistics. Values for Average Closure Cost per Site and Grand Total are rounded to nearest million USD.

Source: International Nuclear, Inc. “*Support for Data Compilation and Analysis of Costs Relating to Environmental Restoration of U.S. Uranium Production Facilities.*” Unpublished final report, prepared for the Energy Information Administration. Golden, Colorado, U.S.A., March 2000.

Table 7. Uranium production and site closure cost for mines

Items	Value
Sites (number)	21
Uranium Production	
Ore Processed (million metric tons ore)	94.20
U Produced (metric tons)	110 405.00
Closure Cost Experience	
Average Cost (USD/mt ore)	3.10
Lowest Cost (USD/mt ore)	0.24
Highest Cost (USD/mt ore)	33.33
Average Cost (USD/kgU)	2.64
Lowest Cost (USD/kgU)	0.18
Highest Cost (USD/kgU)	42.78
Average Cost (USD/ha disturbance)	29 957.00
Lowest Cost (USD/ ha disturbance)	2 337.00
Highest Cost (USD/ ha disturbance)	269 531.00
Average Closure Cost per Site (21 sites; million USD)	14.00

mt ore = Metric ton of ore. kgU = Kilogram of uranium. ha = hectare.

Note: See Table 3 data relating to uranium production and closure cost statistics for mines. Value for Average Closure Cost per Site is rounded to nearest million USD.

Source: International Nuclear, Inc. “*Support for Data Compilation and Analysis of Costs Relating to Environmental Restoration of U.S. Uranium Production Facilities.*” Unpublished final report, prepared for the Energy Information Administration. Golden, Colorado, U.S.A., March 2000.

• Uzbekistan •

State policy and regulations

As a Member State of the IAEA, Uzbekistan has followed IAEA recommendations, and prepared a Plan of Development of Radioactive Protection Infrastructure in Uzbekistan. Principle concepts

accepted in developed countries were used as a basis of the Plan. The same concepts have been reflected in the Law about Radiation Safety of Uzbekistan of August 31, 2000. The Law considers problems of state control in radiation safety. Under this Law, the Cabinet of Ministers, the Agency on Safety in Industry and Mining, the Ministry of Health, the State Committee of Conservation of Nature and the State Customs Committee are responsible for ensuring radiation protection.

History of uranium production facilities restoration

Territory of Uzbekistan can be divided into three geo-tectonic zones:

- Eastern and south-eastern, which is a mountainous area.
- Central (Central Kyzylkum) part, which was an active platform in Neogene-Quaternary time.
- North-eastern (Ustyurt plateau), which is a typical plateau.

All uranium deposits in Uzbekistan (there are about 50 of them) lie in the first and second zones.

Uranium deposits of Uzbekistan can be classified into three main groups: hydrothermal, hydrogenic and polygenic.

1. Hydrothermal deposits are connected with intrusive and volcanic rocks developed in Tashkent area and the Fergana Valley. These were under exploitation from the early 1950s for 30-35 years and are completely mined out. The Eastern Rare Metals Complex (Vostokredmet), formerly the Leninabad Mining and Chemical Complex, with its headquarters and processing plant are located at Chkalovsk, Tajikistan. All of Vostokredmet's activities related to exploitation of these uranium deposits have been stopped. The waste dumps, low-grade ore stockpiles, and other wastes, with increased radioactivity had been accumulated at the mined-out sites. All of these features with radioactive wastes contaminate the area and are hazardous for the population.
2. Hydrogenic uranium deposits are located in Central Kyzylkum. They occur in Cretaceous and Paleogene sandy-clay formations. These deposits have been exploited since the beginning of the 1960s, initially by underground and open pit mining. Later underground leaching was used as a more environmentally safe technique. This type of production technology is still in operation. Navoi Mining-Metallurgical Integrated Plant (NMMIP) is responsible for these mining operations. Some of the deposits have been mined out or mothballed.
3. Polygenic uranium deposits are connected with a carbonaceous-chert slate formation developed in Central Kyzylkum. The deposits of this type were never exploited. After exploration they had been mothballed.

Facilities where restoration is underway or planned

The tailing impoundment of the #1 Mining-Metallurgical Plant of NMMIP is the most environmentally hazardous due to its size and location in the Zarafshan River. This area has a dense population. The total amount of radionuclides accumulated at the site is 160×10^3 curies included in 60 million t of tailings at the site.

A set of measures is being undertaken in the tailing impoundment to improve the environmental situation:

- “A well curtain” of 24 pumped boreholes operate to recover solutions percolating from the impoundment and return them to the plant.
- 108 observation boreholes have been drilled in the area of the impoundment to monitor the underground waters.

Restoration work is at different stages of advancement at other sites under the administration of NMMIP:

- In the Northern Mining Administration, the volume of contaminated ground has been defined and a project for its burial has been prepared.
- In the Central Mining Administration, a radioactive waste disposal site has been prepared and the waste is being buried.
- In Mining Administration No. 5, a disposal site programme is being prepared.
- At the “Gunzhak” and “Kar’er” sites, wastes are being buried.
- A low-grade stockpile has been studied, it was found that no displacement should occur in Mining Administration No. 2.

The Yangiabad ore field is considered as the first priority area among mined out properties of Vostokredmet. A project for radioactive decontamination and restoration has been prepared for this area (30 km²) on the basis of a study done by “Kyzyltepageologiya”. The main concept of the project is to collect contaminated soil with total volume of about 500 m³, and to bury it in the existing low-grade stockpile area. The project did not previously provide protection to the local population living there (about 1 500 peoples) from increased radon concentration. The government of Uzbekistan made the decision to invest USD 250 000 per year for restoration of the area. The restoration has started.

The second Vostokredmet area includes the mined out Cherkesar-1 and Cherkesar-2 deposits and adjacent townships. An evaluation has been completed for this area, and the project of radioactive decontamination and restoration is being prepared.

There are also radioactive wastes at sites along the borders of the neighbouring territories of Tajikistan and Kyrgyzstan. The wastes could negatively affect the territory of Uzbekistan if the wastes from these sites are released into Uzbekistan. These sites are the: Degmai and Gafurov tailing impoundments along the Syrdarya River in the vicinity of the Vostokredmet mill at Chkalovski, and in the vicinity of Maili-suu Township, Kyrgyzstan, where a large amount of radioactive wastes are held in tailings impoundments and low grade stockpiles.

More active participation of international organisations in working out environmental protection measures would be desirable for these sites. First, site investigations using high-sensitivity modern instrumentation should be done.

Cost

In the past Vostokredmet and NMMIP, the subsidiaries of two integrated plants, conducted uranium mining in Uzbekistan.

All of Vostokredmet's uranium mining activities are now closed. There are several deposits located in Uzbekistan that were mined by Vostokredmet. The main deposits are: Alatanga, Kattasai, Dzhekindek and others (Mining Operations 1-2); Charkesar-I, Charkesar-II (Mining Operation 23); and other properties. Many contaminated areas were left at these properties for various reasons. They include low-grade stockpiles in the vicinity of mines and processing plants, ore transfer facilities, etc. Uzbekistan organizations are decontaminating these sites. The Uzbekistan government finances these works. Restoration of sites at Mining Operations 1-2 has been started. The annual cost of these works is USD 250 000. A plan and budget of restoration work has been prepared for Mining Operation 23. The estimated cost is USD 7 000 000. It is expected that the government of Uzbekistan will allocate the funds for this work.

NMMIP now exploits sandstone hosted uranium properties in the Central Kyzylkum area. Some of these properties, which were first exploited using conventional mining techniques, are Uchkuduk (Northern Mining Administration (MA), Sugrally (Central MA), Ketmenchi and Sabysai (Southern MA). As a result, low-grade waste stockpiles were formed. Some areas of these properties require restoration. ISL technology is now used at these sites. Spillage of the process liquor has also contaminated some sites. These sites also require cleanup and restoration.

Various organizations of NMMIP are dealing with radioactive decontamination and restoration works at its mined out facilities. NMMIP spends from 3.5% to 5% of its operating expenses for environmental activities every year, including about USD 6 000 000 for construction of environmental facilities.

The areas with radioactivity contamination in the mined out uranium facilities of Uzbekistan are characterised in following table.

Table 1. Uranium facilities of Uzbekistan with radioactive contamination

Name of property	NMMIP's properties						Tailing impoundment		Organisation financing restoration activities	Vostokredmet's properties			Organisation financing restoration activities
	Mining technique			Underground leaching			Contaminated area, 1 000 m ²	Volume of contaminated rock, 1 000 m ³		Name of property	Mining technique		
	Contaminated area, 1 000 m ²	Volume of contaminated rock, 1 000 m ³	Contaminated area, 1 000 m ²	Volume of contaminated rock, 1 000 m ³	Mining	Contaminated area, 1 000 m ²					Volume of contaminated rock, 1 000 m ³		
Northern MA, Uchkuduk deposit	347.2	1 448.0	1 784.0	569.0	-	-	-	-	NMMIP	Mining operation 1-2 Alatangai, Kattasai, Dzhekindek deposits	195	500	Government of Uzbekistan
Central MA, Sugraly deposit	1 060.2	956.6	61.0	13.4	-	-	-	-	-	Mining operation 23 Charakesar-I, Charakesar-II deposits	162	470	-
Southern MA, Sabyrsai and Ketmenchi deposits	500	253.4	1 300	377.8	-	-	-	-	-	-	-	-	-
MA No5, Bishkek, North and South Bukinai	-	-	1 740.0	1 923.0	-	-	-	-	-	-	-	-	-
MA No2, Chauli deposit	200	770	-	-	-	-	-	-	-	-	-	-	-
Hydrometallurgical Plant-1, tailings impoundment	-	-	-	-	6 000.0	-	30 000	-	-	-	-	-	-
Total	2 107.4	3 358.0	4 885.0	2 882.4	6 000.0	30 000	30 000	6 000.0	-	Total	357	970	-

• Viet Nam •

Relevant Legislation

- Ordinance on Radiation Safety and Control of June 26, 1996;
- Law on Environmental Protection of December 27, 1993.

Under the 1996 Ordinance, the Ministry of Science, Technology and Environment is the regulatory authority for radiation safety and control. It has under its supervision the Viet Nam Atomic Energy Commission and the Viet Nam Radiation Protection and Nuclear Safety Authority, responsible for licensing and inspection.

Treatment of the liquid and solid radioactive wastes in the units for processing monazite and uranium ores

The Institute for Technology of Radioactive and Rare Elements has two pilot units. The first one is the pilot plant for monazite processing with a capacity of 10 tonnes per year. It has been put into trial operation over the last four years. The major product of this pilot plant is total rare earth chloride. Since the typical radioactive composition of the monazite sand was determined to be 5% thorium and 0.25% uranium, both the liquid and solid radioactive wastes contain high radioactivity.

The second unit is the laboratory for treating uranium ore. Trials were carried out in this unit for collecting technological data on processing uranium ore.

The preliminary results relating to radioactive waste management from these pilot units are reported below.

Treatment of radioactive waste in the uranium laboratory

The average composition of Nongson uranium sandstone ore is shown in Table 1.

Table 1. Chemical composition of Nongson uranium sandstone

Composition	Content (%)
SiO ₂	73.56
CO ₂	0.62
V ₂ O ₅	0.085
BaO	0.014
P ₂ O ₅	0.003
U ₃ O ₈	0.14
Mo	0.0095

Table 1. **Chemical composition of Nongson uranium sandstone (contd)**

Composition	Content (%)
Pb	0.022
Ni	0.014
Cr	0.093
Co	0.026
Ga	0.0019
Cu	0.0018
Y ₂ O ₃	0.0002
Others	20.000

The radioactivity of elements in the liquid waste was determined by gamma-spectrometry and is given in Table 2.

Table 2. **Radioactivity of liquid waste before treatment**

Element	Radioactivity (Bq/l)	Allowable limit of radioactivity (Bq/l)
Th ²³⁰	10 000	<1
Pb ²¹⁰	1 000	<3
Ra ²²⁶	40	<2

The radioactivity of solid waste was determined to be 40 000-50 000 Bq/l by the same method. The process of treatment was conducted as follows. A volume of 2.5 litre of liquid waste was mixed with one litre of solid waste. It was agitated for 10 minutes.

CaO and BaCl₂ were used as additives. The former was employed to adjust the solution pH. When pH was raised to 7.5-10.0, most heavy metals such as Pb, U, Th were precipitated. The mass of lime consumed for one tonne of ore was 30-40 kg.

After finishing this stage, the liquid phase is still highly radioactive due to the presence of ²²⁸Ra. The second additive (BaCl₂) was used for precipitation of barium hydroxide. Co-precipitation of barium hydroxide and radium hydroxide occurred. The consumption of barium chloride was found to be 20-30 kg for one tonne of ore.

After finishing the second stage, the radioactivity in the liquid phase reached a limited value of less than 1 Bq/l. Therefore this treatment successfully removed the radioactivity to within allowable limits.

Treatment of radioactive waste from the monazite pilot plant.

The chemical composition of monazite is shown in Table 3.

Table 3. The chemical content of monazite

Composition	Content (%)
R ₂ O ₃	57.20
P ₂ O ₅	25.80
ThO ₂	5.30
U ₃ O ₈	0.26
Others	11.50

A pilot plant was developed to recover Rare Earth chloride. The treatment of the radioactive waste is discussed below.

Treatment of liquid waste

The mother liquor from the centrifuge may be collected and sent to effluent tank for neutralising. The proposed limits for treated effluents of liquid waste are shown in Table 4.

Table 4. The proposed limits for treated effluents

Characteristic	Tolerance limit
PH	To 9
Suspended solids	100mg/l
Phosphates	15mg/l
Fluorides	15mg/l
Gross alpha	10 ⁻⁷ μCi/ml
Ra-226	10 ⁻⁷ μCi/ml
Gross Beta	10 ⁻⁶ μCi/ml
Ra-228	3.10 ⁻⁷ μCi/ml
Pb	0.1 mg/l

Treatment of solid waste

The lead-barium cake is highly radioactive because of the ²²⁸Ra present in it and must be disposed of carefully. The lead-barium cake may be mixed with a cement-sand mixture and fixed in the matrix.

Composition of solid wastes are shown in Table 5.

Table 5. Composition of solid wastes

Type of solid waste	Composition	Content (%)
Thorium	ThO ₂	14.20
Uranium waste	U ₃ O ₈	0.71
(300kg waste/one tonne of ore)	R ₂ O ₃	11.20
	H ₂ O	20.00
	Others	35.50

Table 5. **Composition of solid wastes** (contd)

Type of solid waste	Composition	Content (%)
Lead-Radium waste (25 Kg-30 Kg waste/one tonne of ore)	PbO	6.70
	U ₃ O ₈	0.50
	ThO ₂	8.30
	R ₂ O ₃	14.50
	H ₂ O	15.00
	Others	55.00

Aggregate cost data for the monazite pilot plant and the laboratory for processing technology of uranium ores

- Type of site: Monazite Pilot Plant, and Laboratory for Processing Technology of Uranium Ores.
- Total amount of the monazite concentrate processed in 5 years: 50 t.
- Total amount of the technical uranium produced in 5 years: 200 Kg.
- Total amount of the tailings generated: 700 m³.
- Total amount of the waste rock generated: 70 t.
- Total restoration cost: USD 31 000.

Estimated total cost for specific items

No.	Item	Size	Cost (USD)
1.	Planning, Engineering and Licensing	–	6 000
2.	Tailing Ponds (m ³)	700	10 000
3.	Waste Rock Piles (Tonnes)	100	3 000
4.	Processing Plant Site (m ²)	2 000	7 000
5.	Laboratory for Processing Technology of Uranium Ores (m ²)	2 000	5 000
6.	Mining facilities	–	–
7.	Reclaimed Areas (m ²)	10 000	–
Total cost of restoration			31 000

Conclusion

Four tonnes of monazite sand have been treated at the pilot plant. About one tonne of thorium cake has been dried by opening compressed air to the press. The solid waste of thorium hydroxide was collected and stored. About 100 kg of lead-radium waste was mixed with cement and sand and fixed in the matrix. All of the liquid radioactive waste has been treated.

Annex 1

MEMBERS OF THE JOINT NEA/IAEA WORKING GROUP ON ENVIRONMENTAL RESTORATION OF WORLD URANIUM PRODUCTION FACILITIES

<i>Argentina</i>	Mrs. E.N. ACHEN† Mr. G. ÁVILA CADENA Mr. A. CASTILLO	Comisión Nacional de Energía Atómica Unidad de Proyectos Especiales de Suministros Nucleares, Buenos Aires
<i>Australia</i>	Mr. A. McKAY Mr. P. WAGGITT	Australian Geological Survey Organisation (AGSO), Canberra Office of the Supervising Scientist Darwin
<i>Brazil</i>	Mr. M. CAMARA DE MIRANDA FILHO Mr. D. AZEVEDO PY JUNIOR Mr. H.M. FERNANDES Ms. M. RAMALHO FRANKLIN	Indústrias Nucleares do Brasil (INB) S.A., Rio de Janeiro Institute of Radiation Protection and Dosimetry (IRD), Rio de Janeiro
<i>Canada</i>	Mr. P. DE	Low-Level Radioactive Waste, AECL, Gloucester, Ontario
<i>Czech Republic</i>	Mr. P. VOSTAREK	DIAMO s.p., Machova 201, 47127 Stráz pod Ralskem
<i>Egypt</i>	Mr. A.B. SALMAN	Nuclear Materials Authority (NMA), El Maadi
<i>Finland</i>	Dr. K. PUUSTINEN	Geological Survey of Finland, Espoo
<i>France</i>	Mr. H. CATZ Ms. V. MOULIN Ms. M-T. MÉNAGER	Commissariat à l'énergie atomique, Centre d'Études de Saclay (CEA) Commissariat à l'énergie atomique Direction de la stratégie et évaluation (DSE), Paris
	Mr. J-L. DAROUSSIN	Cogema DT/MQSE, Vélizy
<i>Gabon</i>	Mr. P. TOUNGUI	Ministère des Mines, de l'Énergie, du Pétrole et des Ressources hydrauliques, Libreville

Germany	Dr. F. BARTHEL	Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover
	Mr. J. BECKER	Uranerzbergbau GmbH, Cologne
	Mr. U. RIEGER	Federal Ministry of Economics and Technology, Berlin
Hungary	Mr. G. ÉRDI-KRAUSZ	Geo Faber Corporation, Pécs
Islamic Republic of Iran	Mr. S.H. HOSSEINI	Atomic Energy Organisation of Iran Tehran
India	MR. R. GUPTA	Uranium Corporation of India Singhnhum
Japan	Mr. H. MIYADA	Japan Nuclear Cycle Development Institute (JNC), Tokyo
Jordan	Dr. S. AL-BASHIR	Jordan Phosphate Mines Company (JPMC), Amman
	Mr. G. AL-KILANI	Ministry of Energy and Mineral Resources, Amman
Kazakhstan	Mr. G.V. FYODOROV	Atomic Energy Agency of the Republic of Kazakhstan, Almaty
Poland	Ms. Z. WACLAWEK	National Atomic Energy Agency Warsaw
Portugal	Mr. L.S. LEMOS	Direcção Regional do Centro do Ministério da Economia, Coimbra
	Mr. L. MARTINS	Instituto Geológico e Mineiro (IGM) Alfragide
	Dr. J.M. SANTOS OLIVEIRA	Instituto Geologico e Mineiro (IGM) San Mamede de Infesta
Romania	Mr. T. F. IUHAS	Uranium National Company, Bucharest
Russian Federation	Mr. A.V. BOITSOV	All-Russian Institute of Chemical Technology, Ministry of Atomic Energy Moscow
	Mr. A.V. TARKHANOV	
Spain	Mr. A. R. LOPEZ ROMERO	Empresa Nacional del Uranio S.A. (ENUSA), Madrid

<i>Sweden</i>	Dr. I. LINDHOLM†	Swedish Nuclear Fuel and Waste Management Company, Stockholm
	Mr. H. SVENSSON	AB SVAFO and Kemakta Konsult AB Stockholm
<i>Ukraine</i>	Mr. A.C. BAKARZHIYEV	The State Geological Company “Kirovgeology”, Kiev
	Mr. B.V. SUKHOVAROV-JORNOVYI	Scientific, Technological and Energy Centre, Kiev
<i>United States</i>	Mr. J. GEIDL (<i>Acting Chairman</i>)	Energy Information Administration, US Department of Energy, Washington U.S. Environmental Protection Agency (EPA), Washington
	Mr. L. SMITH (<i>Chairman</i>)	
	Mr. L. SETLOW	
<i>Uzbekistan</i>	Mr. R.I. GOLDSHTEIN	State Geological Enterprise “Kyzyltepageogogiya” Tashkent
	Mr. I.G. GORLOV	
	Mr. N. ERKAEV	
<i>Viet Nam</i>	Mr. DO NGOC LIEN	Institute for Technology of Radioactive and Rare Elements, Hanoi
	Dr. B. X. TRINH	Ministry of Industry, Dept. of Geology & Minerals, Hanoi
<i>European Commission</i>	Mr. J-M. HALLEMANS	Directorate General XVII (Energy) Nuclear Energy Brussels
	Mr. S. WEBSTER	
<i>IAEA</i>	Dr. D.H. UNDERHILL (<i>Scientific Secretary</i>)	Division of Nuclear Fuel Cycle and Waste Technology, Vienna, Austria
<i>OECD/NEA</i>	Dr. I. VERA (<i>Scientific Secretary</i>)	Nuclear Development Division Paris, France

Annex 2

LIST OF REPORTING ORGANISATIONS

Argentina	Comisión Nacional de Energía Atómica, Unidad de Proyectos Especiales de Suministros Nucleares, Avenida del Libertador 8250, 1429 Buenos Aires
Australia	Office of the Supervising Scientist, Science Group – Environment Australia, GPO Box 787, Canberra, ACT 2601
Brazil	Institute of Radiation Protection and Dosimetry (IRD), Av. Salvador Allende s/n, Jacarepagua, Rio de Janeiro CEP 22780-160
Canada	Low-Level Radioactive Waste Management Office, 1595 Telesat Court, Suite 700, Gloucester, Ontario K1B 5R3
Czech Republic	DIAMO s.p., Machova 201, 47127 Stráz pod Ralskem
Egypt	Nuclear Materials Authority (NMA), P.O. Box 530, El Maadi
Finland	Geological Survey of Finland, P.O. Box 96, FIN-02151 ESPOO
France	Cogema, DT/MQSE, Pôle Mines Chimie B.U. Mines, 2, rue Paul Dautier, BP 4, 78141 Vélizy Cédex
Gabon	Ministère des Mines, de l'Énergie, du Pétrole et des Ressources hydrauliques, B.P. 874 & 576, Libreville
Germany	Uranerzbergbau GmbH, Stüttgenweg 2, D-50935 Köln
Hungary	Geo Faber Corporation, Esztergar L.19, H-7633 Pécs
Japan	Japan Nuclear Cycle Development Institute (JNC), 4-49, Matsumura, Tokaimura, Naka-gun, Ibaragi, Japan 319-1184
Kazakhstan	Atomic Energy Agency of the Republic of Kazakhstan, 4, Chaikina str., Almaty, 480020
Portugal	Ministério da Indústria e Energia, Instituto Geológico e Mineiro, Rua Almirante Barroso, 38, P-1000 Lisbon
Romania	Uranium National Company S.A., 68 Dionisie Lupu Street, Sector 1, Bucharest

Russian Federation	All-Russian Institute of Chemical Technology, Ministry of Atomic Energy, 33 Kashirskoye Shosse, 115230 Moscow
Spain	ENUSA, Santiago Rusiñol 12, E-28040 Madrid
Sweden	AB SVAFO, P.O. Box 5898, S-102 40 Stockholm Kemakta Konsult AB, P.O. Box 12655, S-112 93 Stockholm
Ukraine	The State Geological Company “Kirovgeology”, 8 Kikvidze Str., Kiev 01103
United States	Energy Information Administration, Coal, Nuclear, Electric and Alternate Fuels (EI- 50), U.S. Department of Energy, Washington, D.C. 20585
Uzbekistan	The State Geological Enterprise “Kyzyltepageologia”, 7a, Navoi Street, 700000 Tashkent
Viet Nam	Institute of Technology of Radioactive and Rare Elements (ITRRE), 48 Lang Ha Street, Hanoi

Annex 3

GLOSSARY

The following is a glossary that may be used in describing environmental restoration activities for uranium production sites. Please note that the definitions are intended only as a guide and they may not represent legal or world-wide accepted definitions of these terms.

ALARA

An acronym for “as low as reasonably achievable”, a concept meaning that the design and use of nuclear facilities, and the practices associated with them, should be such as to ensure that exposures are kept as low as reasonably achievable, with technical, economic and social factors being taken into account.

Aquifer

A saturated permeable subsurface geologic unit that can contain and transmit significant quantities of water under ordinary hydraulic gradients.

Baseline study or survey

A study that documents all relevant information such as physical, chemical and biological data, as well as, the cultural and socio-economic conditions, and other relevant information prior to commencement of an industrial project.

Close-out

In the context of uranium mill tailings impoundments, the operational, regulatory and administrative actions required to place a tailings compoundment into long-term conditions such that little or no future surveillance and maintenance are required. A tailings facility is usually placed into permanent closure by covering the tailings, and termination and completion of activities in any associated structures. The same concept may apply to waste rock from mining (including barren and below ore grade waste rock), heap and in-stope leach residues and *in situ* leach sites.

Commissioning

The process during which systems and components of facilities and activities, having been constructed, are made operational and verified to be in accordance with the design and to have met the required performance criteria. Commissioning may include both non-nuclear/non-radioactive and nuclear/radioactive testing. The terms **siting, design, construction, commissioning, operation and decommissioning** are normally used to delineate the six major stages of the life of an authorized facility and of the associated licensing process. In the case of waste disposal facilities, **decommissioning** is replaced in this sequence by **closure**.

Contamination

The presence of radioactive and chemotoxic substances in or on a material or in the human body or other place where they are undesirable or could be harmful. Also the process giving rise to their presence in such places.

Cover

Artificial enclosure of the surface of a dump, tailing pond or other object. The objective of a cover is to seal off the object from the environment. The cover can eliminate or reduce to a prescribed level the object's detrimental impact on the environment, and/or the environment's detrimental effects on the object, e.g., to prevent surface water ingress and erosion by surface water and wind, reduce water seepage and radon emanation, and possibly, to allow for the utilisation of the surface area.

Decommissioning

Actions taken at the end of the operating life of a uranium mill or other nuclear facility in retiring it from service with adequate regard for the health and safety of workers and members of the public and protection of the environment. The ultimate goal of decommissioning is unrestricted release or use of the site. The time period to achieve this goal may range from a few to several hundred years. Subject to the legal and regulatory requirements of a Member State, a uranium mill or its remaining parts may also be considered decommissioned if it is incorporated into a new or existing facility, or even if the site in which it is located is still under regulatory or institutional control (i.e. restricted release or use.).

Decontamination

The complete or partial removal or reduction of radioactive or toxic chemical contamination by a deliberate physical, chemical, and/or biological process.

Dismantling

The disassembly and removal of any structure, system or component during decommissioning. Dismantling may be performed immediately after permanent retirement of a mill facility or may be deferred.

Disposal

The emplacement of waste in an approved, specified facility (for example, near surface or geological repository) without the intention of retrieval. Disposal may also include the approved direct discharge of effluents (for example, liquid and gaseous wastes) into the environment with subsequent dispersion.

Effluent

Any gas or liquid discharged as waste (including radioactive material) into the environment.

Environment

The physical, chemical and biological surroundings of a site. In addition to these natural components, the cultural and socio-economic conditions are also frequently included.

Environmental impact

The physical, ecological, cultural and socio-economic effects of an installation (planned, in operation, in decommissioning) or a technology.

Environmental impact statement

A set of documents recording the results of an evaluation of the physical, ecological, cultural and socio-economic effects of a planned installation, facility or a new technology.

Environmental remediation

Cleanup and restoration, according to predefined criteria, of sites contaminated with radioactive and/or hazardous substances during past uranium production activities.

Groundwater

Water which permeates the geological strata of the earth, excluding water of hydration.

Groundwater remediation. The process of returning affected groundwater to its baseline quality.

Heap leaching

The process whereby a leach agent percolates through a pile of ore previously mined by conventional methods in such a way that the leachate can be collected for recovery of the metal values.

In situ leaching (ISL)

In situ leach, or solution mining is the process of extracting uranium by injecting leaching solutions through wells into an underground, water-saturated ore body and recovering the solutions through other wells after they have passed through the host formation and dissolved the uranium ore. The uranium bearing solution is then pumped to a surface facility where the uranium is recovered from the solution.

Institutional control

Control of a waste site by an authority or institution designated under the laws of a country. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor in the design of a nuclear facility (e.g. near surface repository).

In stope (or block) leaching

The process whereby a leach agent percolates through a pile (or block) of ore located within an underground mine in such a way that the leachate can be collected for recovery of the metal values.

Mine

Installation for recovering ores from the earth containing uranium series or thorium series radionuclides. A mine processing radioactive ores is any mine that yields ores containing uranium series or thorium series radionuclides, either in sufficient quantities or concentrations to warrant exploitation or, when present in conjunction with other substances being mined, in quantities or concentrations that require radiation protection measures to be taken as determined by the Regulatory Authority.

Milling facility

Any facility for processing radioactive ores coming from mines as defined above to produce a physical or chemical concentrate.

Monitoring

Continuous or periodic measurement of radiological or other parameters for determination of the status of, or as the basis to take action to control, a system. Sampling may be involved as a preliminary step to measurement. Monitoring can be continuous or non- continuous.

Natural attenuation

The natural processes of biodegradation, dispersion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants occurring in soils and groundwater that effectively reduces contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

Plume

The three-dimensional spatial distribution of airborne or waterborne material as it disperses in the environment.

Regulatory body or authority

An authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing licenses or permits, and thereby for regulating the siting, design, construction, commissioning, operation, closure, close-out, decommissioning and, if required, subsequent institutional control of the nuclear facilities or specific aspects thereof..

Restricted use

The use of an area or of materials, subject to restrictions imposed for reasons of radiation protection and safety. Restrictions would typically be expressed in the form of prohibition of particular activities (e.g. house building, growing or harvesting particular foods) or prescription of particular procedures (e.g. materials may only be recycled or reused within a facility).

Ring dyke impoundment

A confinement basin for tailings formed by constructing a single self-closing embankment, normally used on relatively flat terrain. The impoundment could be square, rectangular, curved or irregular.

Riprap

A layer of large uncoursed stones, broken rock or precast blocks paced in random fashion on the upstream slope of an embankment dam or on the sides of a channel as a protection against wave and ice action.

Risk analysis (or assessment)

An analysis of the risks associated with an activity, process or technology wherein the possible events and their probabilities of occurrence are considered together with their potential consequences, the distribution of these consequences within the affected population(s), the time factor and the uncertainties of these estimates.

Safety assessment

A comparison of the results of safety analyses with acceptability criteria, its evaluation, and the resultant judgement made on the acceptability of the system assessed.

Shutdown

A permanent or temporary closing of an industrial plant.

Stabilisation

Actions taken to prevent or retard movement of tailing material away from an impoundment due to action of natural forces, such as gravity, wind or water erosion, and in a manner such that little or no surveillance and maintenance is required.

Tailings

The remaining portion of a metal-bearing ore consisting of finely ground rock and process liquid after some or all of the metal, such as uranium, has been extracted.

Tailings impoundment

A structure in which the tailings and tailings solution are deposited, including all its elements such as embankment walls, liners and over layers.

Unrestricted release or use

The use of an area or of materials without any radiologically based restrictions. There may be other restrictions on the use of the area or materials, such as planning restrictions on the use of an area of

land or restrictions related to the chemical properties of a material. In some situations, these restrictions could, in addition to their primary intended effect, have an incidental effect on radiation exposure, but the use is classified as unrestricted use unless the primary reason for the restrictions is radiological. Unrestricted use is contrasted with restricted use. A designation by the regulatory body in a country or state, that enables the release or use of formally or potentially contaminated equipment, materials, buildings, or the site without radiological restriction.

Waste characterisation

Determination of the physical, chemical and radiological properties of the waste (including radioactive waste) to establish the need for further adjustment treatment, conditioning, or its suitability for further handling, processing, storage or disposal.

Waste, radioactive

For legal and regulatory purposes, radioactive waste may be defined as material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body, and for which no use is foreseen. (It should be recognised that this definition is purely for regulatory purposes, and that material with activity concentrations equal to or less than clearance levels is radioactive from a physical viewpoint - although the associated radiological hazards are considered negligible.)

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