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Closeout of uranium mines and mills: A review of current practices

INTERNATIONAL ATOMIC ENERGY AGENCY

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FOREWORD

The International Atomic Energy Agency first introduced the subject of decommissioning of nuclear facilities into its programme in 1973, issuing publications which reflected the needs of its Member States in this area. These publications summarized the work carried out by various technical committees, advisory groups and international conferences, symposia and other meetings. Several of them were dedicated to the particular topic of decommissioning of uranium mines/mills and closeout/stabilization of the associated radioactive wastes.

In a number of countries, the commercial operation of uranium mines and mills started between 1950 and 1960. Although most of the facilities have now been closed, environmental monitoring around the sites has continued, and the monitoring networks, in some cases, have collected data for 30 to 40 years. In the earlier period of the uranium mining and milling industry, less consideration was given to matters of radiation safety than is generally done in the present-day approach. There has been a range of impacts on the natural environment in some places, but these mostly result from heavy metals or other toxicants in the waste rather than uranium or radiogenic materials.

In view of the potential longer term chronic impacts on human health and the worldwide developments in radioactive waste management practice, the need exists to collect information on the closeout practices at uranium mines and mills. In this context, a consultants meeting was convened in 1993 to prepare a working report on this subject. The scientific secretary was M. Laraia, Division of Nuclear Power and the Fuel Cycle. Following the completion of this initial draft report, an advisory group meeting (AGM) was held in Vienna in May 1995 to review and further refine the report. The AGM resulted in development of a questionnaire to be sent to Member States to collect data on the current practices employed in the closeout of uranium mines and mills around the world. These questionnaires were sent to 13 countries. The IAEA convened another consultants meeting in September 1995 to analyse and summarize the country responses, and to prepare the final technical report. D.E. Clark of the Division of Nuclear Power and the Fuel Cycle was the scientific secretary for both these meetings.

The present report is a first step in gathering information on the assessment and control of the long term (over a few centuries) impact of uranium mining and milling waste. Its intention is to outline several examples of worldwide experience. It contains summaries of current closeout practices which have not previously been presented in a single publication. Hopefully, it will provide necessary information to Member States to formulate meaningful decisions for adequately controlling impacts resulting from uranium mines and mills waste materials. The information contained herein may also be valuable as background material for developing relevant guidance in this subject area, for example within the IAEA Safety Standards Programme. This would serve interested Member States in preparing their own regulatory reports. The IAEA wishes to express its thanks to all the persons involved in the preparation of the present report.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. GENERAL

The overall uranium production of the world is shown in Table I (Ref. [1]) for each uranium producing country. Cumulatively through 1992, about 1 810 000 metric tons of uranium were extracted from ores and deposits of various grades. This production has resulted in a much larger volume of residues and materials containing trace concentrations of uranium and other extraction-related contaminants. It can be estimated that more than 2 billion metric tons of residues must be managed worldwide. The values given in Table I are graphically shown in Figure 1. To carry out the safe and environmentally acceptable closeout of the world's uranium production facilities within the economic and other constraints that apply to each situation represents a formidable challenge.

In recent years, considerable efforts have been devoted to developing an increased understanding of the long term impacts that uranium mining and milling facilities have, or will give rise to, on human health and the environment [2-5]. Some Member States have established legal requirements for dealing with the management of such facilities [2, 6-8] in order to ensure that the impacts are adequately controlled and that sites are rehabilitated. The approaches adopted by Member States, however, have not always been the same with respect to legal requirements, the setting of safety goals, or the actual rehabilitation practices. As one step to assist Member States in the development of these processes and to encourage a harmonized and systematic approach where possible to the management of mining and milling waste, this report on current practices has been developed.

This publication provides a review of current closeout practices in selected Member States. The information presented was gathered though a questionnaire which was distributed to about one-third of the countries shown in Table I. Although not all Member States which were contacted responded, a broad cross-section of States contributed input. Indeed, the 10 responses received did represent countries accounting for approximately 60 per cent of the world's production of uranium through 1992.

The material provided in this publication does not constitute technical guidance on measures to be taken for the closeout of uranium mines and mills. Such guidance is provided elsewhere [2].

Finally, the impacts of non-radioactive hazardous substances that are present in the wastes from uranium mines and mills are noted. It is also recognized that there is a need to address entire ecosystem effects in any assessment carried out to determine the adequacy of particular remedial actions. Comprehensive safety assessments addressing both human health and environmental hazards are seen as an integral part of the overall assessment of the potential impacts that remediated uranium mines and mills may have on the environment.

As used in this publication, the term 'management' refers to all activities that relate to the remediation of uranium mines and mills, including the planning and assessments that are carried out before the implementation of such activities.

The scope of this publication encompasses uranium production prior to enrichment as part of the nuclear fuel cycle. Pertinent facilities include mines, mills, heap leach ponds, in-situ leach plants, byproduct recovery and associated process residues.

TABLE I. WORLD URANIUM PRODUCTION BY COUNTRY

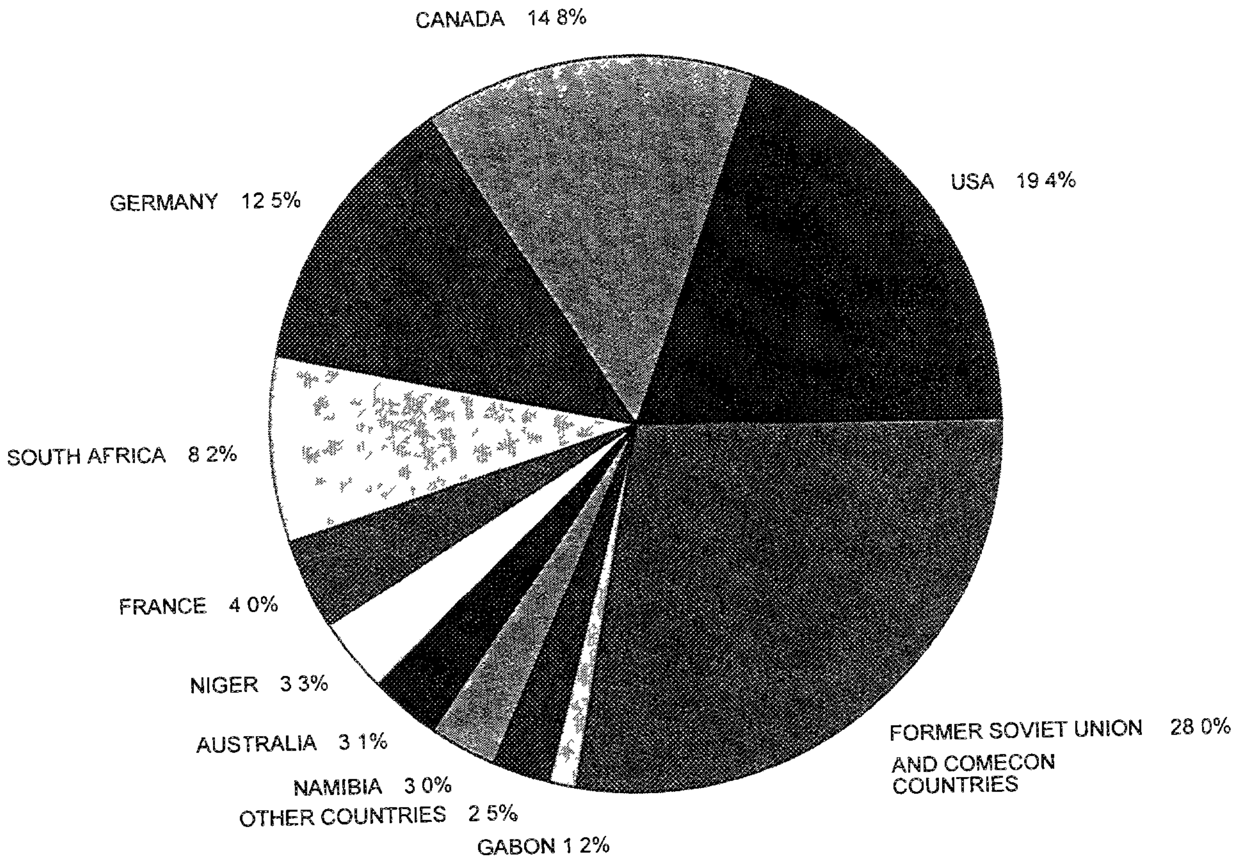
Cumulative production through 1992 in thousands of metric tons of uranium (from Ref. [1])

Rank	Country	U Production	Rank	Country	U Production
1	USA	339*	18	Tadschikistan	20.0
2	Canada	258*	19	Hungary	19.9*
3	Germany	218*	20	Romania	18.4
4	South Africa	143*	21	India	5.78
5	Czech Republic	102	22	Spain	3.78*
6	Russian Fed	101	23	Portugal	3.56
7	Kazakstan	81.7	24	Argentina	2.15
8	China	79.6	25	Poland	1.00
9	France	70.0*	26	Brazil	0.94
10	Uzbekistan	61.0	27	Madagascar	0.77
11	Niger	56.8	28	Pakistan	0.66
12	Australia	54.2*	29	Belgium	0.51
13	Namibia	53.1	30	Slovenia	0.38*
14	Ukraine	45.1	31	Sweden	0.20*
15	Zaire	26.6	32	Japan	0.09
16	Bulgaria	21.9	32	Mexico	0.04
17	Gabon	21.4	34	Finland	0.03
				Total:	1810

* Indicates one of the select countries which participated in the IAEA Questionnaire used to develop this current practices report. These respondents represent about 60% of the world's total uranium production.

An important feature of this publication is the presentation of waste practices and control of radiological impacts arising from the closeout of these facilities. These impacts are influenced by activities carried out during the operational phase of mining and milling and during the planning of such activities. As such, the information represents all phases of the lifetime of mines and mills.

It is recognized that uranium may be extracted as a byproduct from other mining and milling activities (e.g. gold mining in South Africa). The issues of both radiological and non-radiological impact for such facilities also require consideration similar to that for uranium production operations.



Total Production 1,810,000 Metric Tonnes U

FIG 1 Historical distribution of uranium production through 1992

1.2. PURPOSE AND ORGANIZATION OF THIS REPORT

The purpose of this publication is to (a) assist Member States in the development of closeout proposals by providing information on practices in various countries, (b) identify areas in which further efforts may be needed to ensure that the associated hazards are adequately controlled, and (c) assist in the harmonization of waste management practices in the area of uranium mining and milling.

In particular, the focus of this report is to present a review of current practices for the closeout of uranium mining and milling facilities in selected countries for which information has been obtained. The summarized results of the survey of current closeout practices are presented along with the analysis in Section 5.

Results on current practices presented in this report should be considered as complementary to other published studies [2, 7-9].

It is beyond the scope of this publication to address the safety of various practices in the uranium mining and milling industry. Also, the technical aspects of managing these wastes have been presented elsewhere [see, for example, Refs 2-3, 7-9]. The current publication, then, is simply intended to present an overview of factors commonly considered in the long term management of uranium mining and milling wastes and, most importantly, the results of a survey of current practices in a limited number of Member States.

This report is organized so that descriptions of important factors in determining the approaches taken by different countries in managing their uranium mining and milling wastes are presented prior to discussing the summary of questionnaire responses. In this way, the results can be considered in the context of each country's individual approach to the management of these wastes. These factors include human and environmental concerns, post-closeout goals and considerations, and facilities closeout planning, assessment and implementation. Discussion of the individual items is presented in Sections 2, 3 and 4, respectively.

Section 2, on human health and environmental considerations, includes discussion of the nature and characteristics of the impacts; risk concepts for radioactive as well as other hazardous substances (e.g. heavy metals); and human health and environmental concerns related to radioactive wastes such as are associated with uranium mining and milling. The intent is not to be prescriptive but simply to present these concepts and concerns as being important factors to which the questionnaire was directed.

In Section 3, the generally accepted post-closeout goals and considerations (i.e. for periods after operations have ceased) for uranium mines and mills are discussed. Again, the topics are presented in order to illustrate the associated development of the questionnaire.

The subjects of planning and assessment of closeout for uranium mining and milling facilities are presented in Section 4. Discussion concerns the general approaches that have been undertaken in some Member States. Once more, the content of this Section is intended to be illustrative but not at all prescriptive. Consideration of these factors was taken into account when formulating the questionnaire.

Section 5 presents a written summary of the questionnaire responses which were received from 10 countries concerning remediation goals and radiation considerations.

Section 6 contains the summary and recommendations of this report, including reference to the desirability of obtaining additional data in the future.

Annex A contains a copy of the questionnaire form which was developed for this report, a tabular representation of the responses, and illustrative, country-specific write-ups of practices for selected uranium mining and milling sites.

A sampling of published literature on the management of uranium mining and milling wastes and related subjects is given in the References.

2. HUMAN HEALTH AND ENVIRONMENTAL CONCERNS FOR CLOSEOUT OF URANIUM MINING AND MILLING SITES

This section presents a discussion of the common concerns regarding human health and the environment that are applicable for the closeout of uranium mining and milling facilities. It is not the intention here to be prescriptive in any way but rather to delineate these items as they relate to the contents of the questionnaire.

2.1. INTRODUCTION

In order to plan and implement the measures needed to close out mining and milling sites, it is important to characterize the local situation (e.g. radionuclide concentrations, nature of the residual materials, geologic and hydrologic conditions, etc.), including pre-operational conditions, and to carry out an assessment of the short term and long term impacts on human health and the environment. The current practice in many countries is generally restricted to estimating actual and potential radiation doses to persons resulting from migration of radionuclides from remediated sites or from human intrusion. It is, however, becoming increasingly accepted that there are potential impacts on the overall ecosystem which should also be taken into consideration. In addition, the hazards associated with non-radioactive substances from uranium production may be significant and need to be assessed accordingly. While this publication is concerned with current practices, some discussion of these other issues is included in anticipation of the need to address them in assessment guidelines that may be developed in the future. It is not the intent of this publication to discuss non-radiological impacts in detail. The discussion of the concerns for both human health and the environment is also not intended to be exhaustive. The intent is to simply introduce these issues for further consideration.

2.2. THE NATURE AND CHARACTERISTICS OF POSSIBLE IMPACTS

Apart from the impacts arising from physical changes to the environment caused by mining and milling processes, impacts on human health and the environment can arise due to both the radioactive and chemical properties of mining and milling spoils, residues and other wastes.

Radiation exposure to humans and the ecosystem can occur due to radioactive materials migrating from or being physically near or on the site, or from intrusion by humans or other species. Exposure to chemically hazardous substances may occur by the same mechanisms. Radiation exposure may result in health effects such as an increase in the risk of cancer for the exposed individual. In general, this risk is considered to increase with the radiation dose received. Regarding exposure to hazardous non-radioactive substances, often thresholds of intake or exposure must be exceeded before harmful effects arise. In some instances, these substances may be carcinogenic (e.g. arsenic), as well as toxic.

2.2.1. Types of release

In addition to dispersion by precipitation-induced water flow and related mechanisms, contaminants or hazardous substances may be released from closed out facilities in two distinct ways:

(a) The contaminant may be released slowly and at low concentrations over a long period of time, such as in seepages from the foot of dams into surface water, or seepage from impoundments into groundwater. This is referred to as a chronic release.

(b) The substances may be released in large quantities over a short period of time due to extreme events such as a dam failure. This is referred to as an acute release.

The type of release (chronic or acute) will affect the severity of the impact. Chronic releases may take some period of time to become manifest. However, their effects over time could be comparable in magnitude to an acute release. An acute (accidental) release resulting from a dam failure could, for example, contaminate a river system or a lake, and such a contaminated ecosystem could take a considerable time (e.g. decades) to recover from such an event. Of most importance is the effect of contaminant or hazardous substance release on the uptake, both chronic and acute, of such substances by human and animal populations.

2.2.2. Long-term integrity of engineered features

Regardless of the quality of design and construction of a rehabilitated site, all containment features have the potential to fail over the long term (e.g. centuries). This is because the integrity of engineered structures cannot be guaranteed over the very long time frames associated with the radioactive decay (i.e. long half-lives) of the materials contained.

Most engineered, near earth surface structures would at best have a design life of a few hundred years, and some could remain effective for perhaps a few thousand years. But none could be guaranteed to effectively contain all of the radioactive materials for centuries, let alone for tens or hundreds of thousands of years, unless active surveillance and repairs can be maintained by future generations.

Internal factors can act upon the containment structure to alter its physical and chemical properties (e.g. differential settling, digenesis, materials decomposition, root penetration, water table development and fluctuations). These effects are relatively unpredictable, but continue to gradually degrade the integrity of the structure over time. Nevertheless, it is often possible to design the structure to cope with these processes so that integrity can be maintained for a significant time period. The design can also be developed to take advantage of, in the most positive manner, the expected natural changes occurring in the local environment.

External factors which can place the rehabilitated structure at risk include seismic activity, extreme climatic conditions (e.g. severe rainfall, flooding); acid rain (which may kill the vegetative cover); climatic change; and human intrusion. These events are even less predictable than the internal factors, and could at some time bring about massive failure of any above-ground engineered containment structure.

Thus, the effective longer term performance of a rehabilitated site will be a function of the gradually destabilizing effects of internal processes, and of the less predictable external factors which have the potential to cause a failure. It is therefore prudent to design rehabilitated structures conservatively to mitigate the consequences of such failures when they occur.

2.2.3. Future exposures

Describing the environmental conditions in the future becomes more and more speculative when the periods considered are far into the future (e.g. several thousands of years). For example, glacial episodes have occurred in a cyclical fashion, and the next ice-age may appear within the next 10 000 years or so. Significant changes in the biosphere will undoubtedly also occur during these long future periods, probably linked to factors such as climatic change. The environmental conditions and human nutritional habits at a distant future date may be vastly different from those of today, and estimates of such factors are highly speculative.

Since neither the location nor the living habits of future human generations can be predicted, the dose and risk assessments are probably not realistic for periods as long as a few thousand years. This does not necessarily imply that the assessments for such long time scales should not be made (since the results could be instructive), but it indicates that other independent means may be needed to reinforce the conclusions of the dose and risk assessments. Moreover, the relative importance of protective measures to apply primarily for distant future situations may need to be carefully weighed against other (more immediate) concerns.

2.3. RISK CONCEPTS FOR RADIOACTIVE AND OTHER HAZARDOUS SUBSTANCES

The risks associated with exposure of humans to radiation have been quantified by scientific groups on the basis of epidemiological and focused studies carried out on exposed human and animal populations. Based on the quantification of such risks, recommendations have been made by the International Commission on Radiological Protection (ICRP) on the protection of humans from radiation. Their recommendations have taken into consideration other risks to which humans are exposed and which are largely accepted by society or, in some instances, simply tolerated [10]. These recommendations address separately occupationally exposed persons and members of the public. In the latter case, more restrictive limitations of exposure are recommended. In both instances, consideration is given to all modes and pathways of exposure (i.e. external and internal).

Risks from exposure to other hazardous substances, on the other hand, are often based on toxicological studies on laboratory animals using a number of conservative assumptions. No consideration is given for exposure to multiple hazardous substances. Thus, the risk factors used in the determination of exposure limits to such substances are necessarily conservative.

In order to account for risks from all sources, it would be desirable to have a comparable basis for the risk determinations for both radioactive and hazardous substances. This approach would permit the application of more cost-effective strategies when dealing with waste materials containing both radioactive and hazardous constituents.

2.3.1. Human health concerns

As with many human activities, there are potential health concerns associated with the mining and milling of uranium ores. The risks to human health should be considered for all phases of uranium mining and milling, including decommissioning and post-closeout of the site.

2.3.1.1. Radiological impacts to humans

The exposure of persons to radiation arising from mining and milling waste is influenced by the physical, chemical and radioactive properties of the waste materials. The radionuclides in undisturbed and unprocessed ores exist in conditions close to secular equilibrium, but following mining and processing of this material to extract uranium, the state of secular equilibrium will be altered. Of more importance, however, is the changed physical and chemical state in which the radionuclides exist after the extraction operations are completed. This changed state may enhance their ability to migrate into the human environment and it may increase their accessibility for entering into the bodies of humans.

Uranium mining and milling operations involve handling of materials containing several radionuclides, however, some are of more concern than others with respect to potential radiation exposure. These include:

- Thorium-230
- Radium-226
- Radon-222 and its short-lived progeny
- Longer lived radon progeny.

Wherever it is found, ^{230}Th, with a half life of 76 000 years, will continue to generate ^{226}Ra and thus will be a source of future loadings of radium. In the soil, radium and thorium migrate slowly, but can move via groundwater from the tailings management areas into sediments or surface waters. The ^{226}Ra will produce radon gas (^{222}Ra, with a half-life of 3.8 days) that can be released into the atmosphere at a rate influenced by the condition of the tailings and any cover system employed (e.g. the release rate is a function of the moisture content of the soil). ^{226}Ra and ^{230}Th can also be dispersed through the air pathway on dust particles, but in open systems this results in a dilution of their radiogenic effects.

Radon emanating from mines and mill tailings (and/or residues) is dispersed easily in the air as a radioactive noble gas with the possibility of contributing exposure to humans through inhalation and take up of the radionuclide. Nevertheless, the main pathway for human exposure comes from the inhalation of short-lived progeny attached to the aerosol particles in air very quickly after their sequential arising from radon. The dose from inhalation of radon itself is less important since its deposition in the lungs is much less than for particulate matter. Similarly, the radon decay products attached to fine particulate matter can be dispersed down wind, eventually settling out on the earth's surface.

These longer lived daughter products (^{210}Pb and ^{210}Po) are of potential concern since they may give rise to exposure to humans through a variety of pathways (e.g. lead can substitute for calcium in bone formation; polonium has a tendency to form radiocolloids and it can concentrate in aquatic foodchains, etc.).

There are many mechanisms by which radionuclides in uranium process residuals can enter or give rise to exposure pathways to humans. The principal ones with respect to uranium mining and milling are mentioned below.

- Erosion of the tailings area may occur due to precipitation, resuspension, wind or frost damage. Each of these occurrences can remove protective covers and expose the underlying waste materials to dispersion mechanisms by air or water.

- Seepage from the bottom of the tailings pile may entrain the radionuclides and other substances into groundwater and thus allow them to migrate to a discharge area where they can enter either the air pathway or the surface water pathway.

- Seepage at ground level may also allow the radionuclides and contaminated substances to enter the surface water and air pathways.

- Various human activities can intrude into sites where mining and milling residues may be present. This may come about by way of construction, agriculture, recreational or other activities. Several exposure pathways may be associated with such intrusions including the inhalation of suspended material, direct exposure, skin contact and ingestion due to uptake of contaminated water and foodstuffs.

- Contaminated materials may be removed intentionally from mining and milling sites and enter human exposure pathways. Historically, this has arisen from tailings material being used for land fill or in the manufacture of building materials and from waste rock being used for similar purposes. Similarly, contaminated materials such as steel or timber can give rise to a variety of exposure pathways depending on the use to which such materials are put.

- Extreme events such as earthquakes, floods and dam failures, which would generally be rare, may give rise to large releases over a short period of time. The severity of the impact in such cases could be significant. In general, human exposure to radiation above normal background levels is considered to be potentially hazardous to health and should be controlled where possible.

In many countries, the regulatory control of radiation hazards to the public is generally based on recommendations of the ICRP. The ICRP has formulated a system of radiation protection [10] for conducting proposed or continuing practices, which consists of the three following principles:

- The justification of practices;
- The optimization of protection, reducing exposures/doses to as low as reasonably achievable (ALARA);
- Individual dose and risk limits;

It should be noted that in demonstrating the optimization of protection, collective doses to the exposed population are sometimes taken into consideration. However, it is recognized that the use of collective dose estimates has some limitations and may lead to unsubstantiated conclusions, especially when dealing with very low individual doses to very large populations. Collective dose approaches are most defensible when used for comparing remedial action alternatives.

For existing sites which contain mining and milling wastes from past practices (where controls had not been put in place and where members of the public had been exposed), the principles of intervention recommended by the ICRP could be applied. In such instances, optimization of protective measures would be carried out, although it might not be possible to comply with specific dose limits.

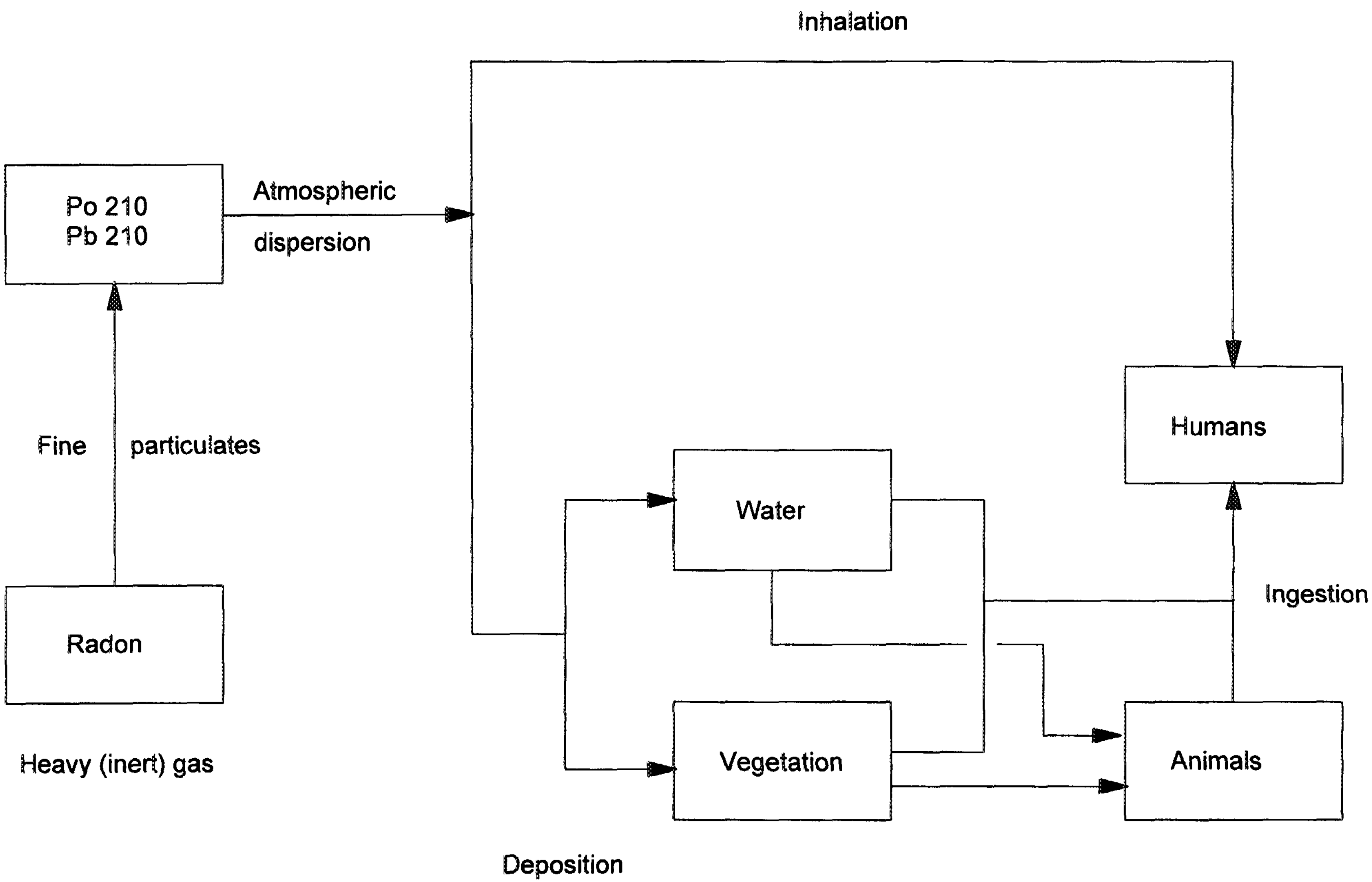


FIG. 2. Radon daughter pathways to humans.

2.3.1.2. Non-radiological impacts to human health

Uranium mining and milling activities give rise to tailings and other wastes that also contain several different non-radioactive hazardous substances. Heavy metals, process organics and acid generating residues amongst others are potential sources of impact on human health. It is important that the associated risks from these substances also be considered in the assessment and implementation of closeout plans.

One example of such a hazardous substance that could pose a risk to members of the public is seepage and release of arsenic from closed out tailings areas, or waste rock piles. Arsenic is recognized as a carcinogen, and manifests its carcinogenicity through exposure over the long term at sub-lethal concentrations. Other substances may also act in this manner. Closeout plans are expected to address the effects of possible chronic exposure to sub-lethal levels of these types of substances.

2.3.2. Environmental concerns

In recent years more attention has been directed to the impacts that the nuclear fuel cycle may have on the environment. When environmental media (soils, surface and groundwaters, and air) have increased in contaminant levels, biota may also take up and accumulate contaminants. Such uptake may pose a threat to ecosystem vitality in the shorter term and to the biological community structure in the longer term. As humans ultimately depend on the environmental media of soil, water and air for survival, and also occupy the top of the food chain, there is an inescapable link between human health and safety, and the health of the environment.

The health of the environment, both in the close proximity and further afield from a closed out uranium mine or mill, may be at some risk for a very long time. The level of risk relates to the probability over time that radioactive (and non-radioactive) materials are released into environmental pathways at concentrations or volumes which can be harmful to the environment. A well rehabilitated site can reduce this level of risk considerably by providing a structure designed to isolate these materials, or to restrict their release over time at such concentrations and rates that the effects can be tolerated and not significantly disturb the ecosystem.

2.3.2.1. Transfer of hazards to the environment

Acid drainage (from active or abandoned sites) can be a prime environmental concern. Low pH waters may dissolve minerals containing radioactive elements and heavy metals. Acidity combined with deposited salts and heavy metals can prevent plant growth. In addition, downstream surface water bodies may become contaminated and affect the health of the ecosystem. Stream banks may become destabilized as the vigour of vegetation supporting the banks is decreased. Dissolved uranium and daughter products can reach levels in water leaching from tailings and uranium waste rock piles which pose a direct chemical toxicity threat to ecosystems. These radionuclides can be bioaccumulated to pose a significant threat to higher life forms, including humans.

Contaminated near-surface groundwaters may present an environmental risk if they migrate to surface water bodies or springs. Deeper aquifers may also be contaminated as the pollution front expands. The transport of pollutants by groundwater may serve as a long term source of contamination well after the site has been decommissioned and rehabilitated, but the same mechanism also serves as a means of dilution. The positive effects of dispersion would have to be compared on a site-specific basis with the negative effects of transport of pollutants to aquifers, and so on.

Soil contamination may occur on lands adjacent to the site, due to atmospheric dispersion of radioactive materials, evaporation of contaminated waters transported by surface water, groundwater contamination or acid drainage.

Erosion and sedimentation by rainfall and wind may impact unstabilized and rehabilitated works, and may cause changes in slope, soil profile, degree of compaction and vegetation. Erosion may also affect the integrity of barriers designed to limit the release of radionuclides from the site.

The stability of rehabilitated land forms will decrease over time from internal natural processes, including ageing of the engineered structure, physical and chemical changes (e.g. digenesis), deterioration of equipment and effects of root penetration from a vegetative cover.

3. POST-CLOSEOUT GOALS AND CONSIDERATIONS FOR URANIUM MINING AND MILLING FACILITIES

This section presents a discussion of the generally accepted goals and considerations that are applicable for the closeout of uranium mines and mills. In no way are these meant to be prescriptive, but rather to be illustrative with regard to how the questionnaire was formulated.

3.1. GENERALLY ACCEPTED GOALS

The post-closeout (after operations have ceased) management is basically a proactive planned response to mitigate a potential chronic exposure situation to achieve protection for humans and the environment at levels which are acceptable to society and technically effective. This generally accepted goal applies both to current and future generations, and incorporates the principles of social responsibilities on ecological sustainability. Social responsibility includes working toward outcomes which are acceptable and beneficial to the general community, and decision making which is sensitive to the potential economic and other impacts of mine/mill decommissioning and closeout on the local community.

This section outlines certain optimum objectives for protecting human health and the environment. In some situations, the efforts required to achieve the best 'possible' outcome may exceed that which can be achieved within the available resources (funding/technology). In such cases, the closeout programme should be designed to achieve the highest level of protection with the available resources. Generally speaking, the more resources that are available, the better the chances are that the closeout programme will be effective in meeting its stated goals.

3.2. PROTECTING HUMAN HEALTH

The protection of human health is deemed to be an essential part of any plan for the closeout of a uranium mining or milling facility. In this regard, the potential health impacts on present day and future generations are considered.

3.2.1. Common goals for protection of human health

The common goal for protecting human health is to ensure that there are no unacceptable increases in risk as determined by current standards and recommendations [10]. The standards applied to protect the health of future generations are normally taken to be approximately the same as those used to protect the health of the present generation. The goal applies both to radiological risk (i.e. doses to individuals and groups) and to non-radiological risk (e.g. physical and chemical toxicological consequences).

3.2.2. Bases for protection of human health

The principles of radiation protection applied during the closeout programme should include justification, dose limitation and optimization. The principles applied in some countries in optimizing the level of protection achievable are ALARA, and best practicable technology (BPT); the best possible result for protection of human health, bearing in mind cost, available technology, and social attitudes and expectations.

3.2.3. Approach to protection of human health

In the commonly followed approach to protection of human health, the design of the closeout programme is based on analysis of risk pathways so as to optimize the protective features. The analysis can contain both radiological and non-radiological elements, and include an assessment of the levels of risk which would result from different rehabilitation designs (e.g. ranging from that risk resulting from a simple exclusion approach, where a fence and warning signs are erected around a feature which poses a significant hazard such as a mining void, to that from a complete landscape restoration where the pit is filled in and capped with a radon barrier and access is allowed). To help ensure that the dose limits are maintained, optimization procedures can be used which consider safety, hazards, costs, etc.

3.3. PROTECTING THE ENVIRONMENT

It is recognized that human health is clearly linked to maintaining a harmonized relationship with the environment. Likewise, the preservation of human health can only be ensured by protecting the environment from deleterious effects on the air, soil, water and biota (natural food chains) with which humans come into contact.

3.3.1. Common goals for protection of the environment

The common goal for protecting the environment is that there is no unacceptable increase in risk or no continuation of risk which could result in significant environmental damage. An effect which produces non-reversible environmental changes or which is deleterious to species diversity and ecosystem health may lead to significant damage to the environment. The measure of success for an effective closeout programme could be that the biological diversity of the environment around the site is not placed at risk at any time in the predictable future. In the ideal situation, one would strive to limit any deleterious effects on the environment to the extent possible, but restoration to original conditions is not an attainable goal.

3.3.2. Bases for protection of the environment

In many countries, an accepted principle which governs the goal of environmental protection is that any impact upon the ecosystem resulting from human activity should, as far as possible, generally fall within the range of natural variabilities (for example, pH levels in a river should not fall below the natural range for that river as a consequence of mine or mill discharges). It is expected that both during the operational life of a mine or mill, and during the post-closeout period, there will be impacts in the immediate vicinity of the site which cannot be kept within natural variability. It therefore becomes important to define the boundary between the mine or mill site (the project area), and the off site environment while different levels of impact might be acceptable, an idealistic goal could be to bring the environmental parameters of the project area as close as practicable to those in the less disturbed or undisturbed off site environment.

Another principle sometimes applied is that after closeout, the project area should be available for beneficial land use. Thus, land use may be optimized in the context of the surrounding environment and community/society needs and preferences. Options available for subsequent land use are related to characteristics of the site, as illustrated below:

Site characteristics	Some possible optional land uses
• undeveloped landscape	revert to natural landscape and vegetation
• agricultural land	rangeland grazing
• semi-urban	rubbish dump (domestic land fill); industrial site
• urban	recreation/parkland

A third principle that may be adopted is the application of BPT, aiming for the best possible result for the level of environmental protection in the long term, taking into consideration costs, available technology and community attitudes and expectations. A BPT analysis can be a powerful decision making tool to help in determining the optimum land use, particularly when the analysis involves, or at least takes into account, the views of all the affected parties (e.g. mine/mill operator, regulator(s), community, special interest groups etc.).

A fourth principle is the application of a surveillance programme to monitor performance, indicate where and when any other interventions are required if the integrity of the site is threatened, and to determine the success of the closeout programme.

3.3.3. Approach to protection of the environment

The issues outlined in this section are applicable to the general environment and have relevance to human health, as well. The commonly followed approach to protection of the environment is discussed below.

To minimize environmental impact and optimize the cost, the design of the closeout programme should as much as possible be firmly based on local, site-specific environmental data of high quality, and including climatic, geological, etc. variations and uncertainties. Information collected before and during the operational phase should be used to determine the key parameters by which environmental impact can be predicted and monitored. Additional data may need to be gathered in preparation for closeout, because the environmental parameters appropriate to the post-closeout period may be different for those which were appropriate during the operational phase.

All mine/mill components are usually included when deciding upon the post-closure strategy, e.g. mine voids, building foundations and services, underground tanks, embankments, waste rock heaps, camp sites, etc.

Different elements of the site may have different time frames and different end points for rehabilitation. Therefore, different milestones can be set to accurately represent this diversity, against which progress can be assessed.

A BPT analysis can be undertaken to determine the optimum land use for the site. On larger sites, a range of different land uses might be appropriate to cope with different risk factors, stability, available materials, etc. for the different areas of the site.

A time frame is determined which is reasonable in providing sufficient time for works to be completed and for the success of the programme to be assessed from an environmental point of view.

The design has to aim for an outcome which requires as little ongoing maintenance work as possible. Intensive management systems such as water treatment facilities should be incorporated with a clear end point in mind. For example, the water treatment can be discontinued and the facility dismantled once a target water quality consistent with long term environmental protection is met. As far as possible, 'passive' management systems are incorporated, although it may be difficult to establish the long term effectiveness of such systems. Examples may include the provision for a self-sustaining vegetative cover, silt traps to manage escape of suspended matter in water, and wetland filters to cope with suspended matter and contaminants in solution.

A clearly stated set of goals should be established which represent the endpoints for the closeout programme. These goals can be determined through consultation with the various stakeholders to ensure that they attract general support and do not lead to major dissatisfaction when the programme is completed.

An agreed upon process for measuring success is important, particularly where funds are held in trust to pay for the remediation programme. The process could be the basis upon which, if remediation is judged to be successful, the operator is freed of any further obligations or responsibilities for the site. The operator could then be given any remaining money from the trust fund, and further responsibility for the site would subsequently rest wholly with the state or the new land/lease holder.

A process is necessary for determining when the goals have been achieved. The process can be prescriptive - e.g. radon levels must be below a pre-determined figure; similar restrictions could apply to chemically hazardous substances; vegetation diversity or cover must reach a certain level; etc. However, as mine site rehabilitation is a relatively new activity and as site-specific characteristics make comparisons with other sites uncertain, in many cases a less prescriptive approach could be more appropriate. In some cases, stepwise planning and control procedures may be effectively used. For example, the design might be performed so as to facilitate monitoring for the early detection of chronic releases.

The period of assessment of the remediation success, i.e. the time between closeout and 'walk away', in some cases may be specified by legislation or regulation. However, as the purpose is to ensure that remediation success occurs, it may be advisable to regard any such specified period only as a minimal period.

After the walk away point is reached, some level of surveillance may still be needed. The frequency and intensity of surveillance will differ depending on the land use(s) achieved as a result of remediation, and the degree to which the objective of incorporating self-managing or 'passive' systems was met. In cases where the end land use provides for beneficial use of the site, the responsibility for surveillance can rest with the new operator (e.g. a municipal authority for rubbish dumps, parks, etc.; a private company if a commercial enterprise operates on the site, etc.). The surveillance programme can be specified by the regulatory authority which supervised the remediation programme, and the details should be incorporated in the land title/lease agreement. Similarly, any restrictions on activities which could threaten the integrity of the site can be incorporated in the land title/lease agreement and/or signposted by permanent markers on the site.

4. PLANNING AND ASSESSMENT OF CLOSEOUT OF URANIUM MINING AND MILLING FACILITIES

4.1. INTRODUCTION

For the purposes of this publication, the term 'management' has been used to include activities such as planning and assessment as well as the activities undertaken to remediate mines, mills and their respective associated overburdened waste rock and tailings areas. Thus, the term management as used in this publication refers to the overall process.

In the approach commonly followed, the goals for the remediation plan are first identified (see Section 3), then measurable criteria are established for determining if the goals have been met. Subsequently, a tentative decommissioning plan is proposed. This process may be applied to a facility already in operation (in the case of a new facility, a conceptual decommissioning plan could be developed at early stage), only the duration of the pre-implementation phase will change.

In the case of new mines and mills, it is possible that certain remedial activities may occur during the operational and design phases in preparation for decommissioning. In addition, the operators can gather data and carry out studies to improve certain aspects of the conceptual decommissioning plan to reduce uncertainty in future model predictions. Other aspects such as the effectiveness of mitigative measures may also be tested in this phase. Thus, the new mine operator has an advantage over the remediator of an idle mine site in that the process of planning for future remedial action assessment and implementation will be ongoing throughout the life cycle of the facility. The advantage is really that the process is evolving and can be done during the conceptual design phase in order to avoid problems later on.

In other cases where there is a need to construct a remedial plan for an idle mine or mill facility, the time available for the planning, assessment and implementation phase may be limited. In this case, the development and refinement of the plan will have to be fitted into the time and resources available. However, the basic process remains the same, comprising three major phases:

1. Planning/assessment
2. Implementation (not covered in this report)
3. Follow-up.

4.2. PLANNING AND ASSESSMENT

The planning and assessment phase establishes a credible basis for the effective closeout of uranium mining and milling facilities. Early development of such plans and assessments in the operational or pre-operational period of a facility can serve to make the overall process more efficient and effective.

4.2.1. Planning

This is the initial phase of the overall management process for formulating a realistic plan of action. Goals and criteria are established and a tentative plan proposed. Then the plan is assessed to determine if it can meet the goal(s). The outcome of this phase is a plan of remedial activities, a set of predicted or modeled behaviours, and a plan of follow-up.

4.2.2. Assessment

Assessment is a process that examines a situation in terms of desired goals and in the context of certain limitations such as physical resources, available technologies or funding, and results in the identification of one or more approaches. The final determination as to the course of action, being taken in a larger social context, is often made by a regulatory body.

In some Member States, the regulatory bodies require that an environmental assessment be carried out as a planning and decision making tool before any irrevocable steps are taken.

Safety assessment is a part of the environmental assessment process [2]. However, the assessments differ in that the main objectives are human safety and environmental protection, respectively. The process of assessment in both instances is essentially the same. Responsible authorities establish their specific requirements and determine the nature and extent of assessments to be done prior to the making of key decisions.

4.2.3. Approach

The long term safety of any hazardous system, whether a planned future activity or an existing situation, must be shown prior to the commencement of any remedial work . For uranium mining and milling facilities, safety and environmental assessments over time-scales far beyond the horizon of the normal technical planning stage have already been conducted in some countries. The principal aim of these investigations is to quantify and provide for the long term safety of a given site.

A safety or environmental assessment often consists of a number of interrelated steps, which can be summarized as follows [11]:

- Establishment of long-term safety goals (see Section 3);
- Collection and review of data to identify hazardous constituents and characterize the site (site characterization);
- Assessment and evaluation of adverse radiological impacts of the present site conditions;
- Broad identification of the future evolution of the site conditions based on the selection of various procedures for either conducting a new activity, or remediating/controlling site hazards (scenario development);
- Development of appropriate models to assess fate and transport of hazardous constituents (model development);

- Assessment and evaluation of the reduction of impacts resulting from the implementation of the remediation plan;

- Uncertainty and sensitivity analysis;

- Validation (if possible) and review of all components of the safety assessment;

- Comparison of mitigated impacts of selected action with long-term safety and environmental goals.

Although wide international consensus exists on this general approach, it should be noted that individual techniques may differ depending upon the objectives of the assessment and the types of safety and environmental protection criteria to be met. In addition, differences in the site-specific conditions and the type of facility may result in a range of approaches to the subject [12].

4.2.3.1. Baseline monitoring and site characterization

As part of the assessment, the area in which the facility is located must be characterized. Some of the parameters that may be considered in the site characterization are discussed below. The information obtained establishes a baseline against which to judge the effectiveness of remedial measures, and provides data for refining the assessment models and designing a monitoring plan. It is important for the assessment to also consider the site conditions and characteristics that were existent prior to the startup of mining and milling operations.

The following is a list of areas in which baseline monitoring and site characterization is typically done. This is not an exhaustive list; the actual parameters monitored or surveyed will depend on the specific site:

(a) Geology
(b) Hydrogeology
(c) Geochemistry
(d) Tectonics and seismicity
(e) Geomorphology
(f) Surface processes (river/stream flows, flooding, fires, landslides, erosion/deposition)
(g) Meteorology/climatology
(h) Ecology (species diversity, toxicological sensitivity).

4.2.3.2. Scenario development

As mentioned earlier, safety assessments of uranium mining and milling facilities may be required to consider long periods of time (i.e. over centuries or even thousands of years). Over such a timeframe, changes due to natural processes and in various human activities are expected to occur at the site and its surrounding environment. Since it is impossible to reliably predict the future, uncertainties must be allowed for in the safety assessment process; scenario development is a commonly used technique to predict and account for uncertainties about the future consequences of a particular action [13].

Scenario development is a central part of safety assessment for several reasons. First of all, the assumed scenarios provide a context in which safety analyses can be performed. This ensures that an analysis of the long term safety of a system is conducted with due consideration for future conditions at the site which arise in accordance with given scenarios. Secondly, the scenarios are expected to identify which conditions require examination and what information and data should be collected. Finally, scenario development requires wide communication and consultation among all those parties with an interest in the safety of the system, including the public.

Scenario development can be expanded to environmental assessment by the addition of impact identification on natural systems and the inclusion of ecological goals.

4.2.3.3. Model development

The necessity of using predictive models to assess potential radiological consequences in safety assessment is well recognized. Predictive models for various aspects of uranium mining and milling sites have been used to evaluate and quantify the effects of the operation on the environment. Further modelling development is required in some areas to reduce the uncertainties to meaningful proportions. A sound basic understanding of the relevant physical, chemical, geochemical and biological properties of the system's constituents and their evolution remains a main prerequisite for successful modelling.

The ultimate objective of safety/environmental assessments is to provide the bases upon which decisions can be made about the present and long term behaviour of the system with a known degree of confidence. Such confidence can be reached through the model validation process which is intended to show that the models adequately represent real system behaviour. There is no absolute way to validate system performance for predictions made over long periods of time; however, various aspects of modelling may be supported through additional laboratory, field and natural analogue studies. For some situations, partial validation can be obtained from the results of monitoring and surveillance programmes implemented at uranium mining and milling sites in connection with their closeout or rehabilitation plans.

Another means of increasing confidence in model predictions is to carry out sensitivity studies. These studies can provide information on which areas of uncertainty most need to be reduced by the collection of additional data. In these studies, the parameters which have the largest impact on the model output are determined. The greatest effort can then be directed towards reducing the uncertainty in those parameters [14].

Nevertheless, uncertainties resulting from a limited understanding of the process governing the behaviour of the system in the far future will still remain. For these reasons, probabilistic modelling is done in addition to deterministic modelling as another tool to increase confidence in results.

As long as the modelling has followed accepted practices, the results may be used as reliable relative indicators of future behaviour of the remediated site. The results must not be taken as absolute. Their value is for relative ranking, that is, in comparing one closeout option with another. Projections of dose or some other impact over time should show no sudden changes or deviations. The objective of the modelling is to aid in choosing an option, as well as to increase confidence in the chosen option.

4.2.3.4. Evaluation of positive agreement

The modelling, site characterization and monitoring activities may be carried out in parallel. At some stage, the results are compared to the previously developed safety and environmental goals and related criteria; thus the positive agreement among the activities can be evaluated. In this fashion, the effectiveness of proposed remedial works can be assessed. Since this is an iterative process, several intermediate steps may occur before the planned works can be shown to meet the safety and environmental goals.

The proposed remedial activities should not only meet the safety goals, but they should also fall within established limits of certainty. The degree of certainty considered acceptable will depend on factors such as the availability of resources and social values. Hence this criterion will vary from country to country.

4.3. PRODUCTS OF SAFETY/ENVIRONMENTAL ASSESSMENTS

An effective assessment phase and the associated evaluation process will produce the following:

(1) A measure of the reliability of the predicted results.

(2) A remedial action or decommissioning plan.

(3) A set of predictions of post-implementation behaviours.

(4) A set (or sets) of criteria for identifying when closeout has been successfully accomplished.

(5) A follow-up monitoring plan for:
   (a) enhancing the effectiveness of the decommissioning activities;
   (b) increasing confidence in the predicted long term, post-closeout behaviours;
   (c) determining (where possible) if the goals of the plan have been met;
   (d) providing surveillance and maintenance where and when necessary.

The implementation phase is not discussed here as it is outside the scope of the publication and has been dealt with elsewhere [2].

4.4. FOLLOW-UP AND FEEDBACK

Generally before the closeout of a uranium mining and milling facility and after decommissioning is completed, a monitoring and surveillance period is established. The length of this period is variable, depending on the country legislation, characteristics of the site, and so on. During this period, the site, its surroundings and the results of the engineered remedial actions are allowed to equilibrate. This period allows for an assessment of the performance of the remedial action with respect to the objectives which were previously established in the remediation plan. Monitoring techniques and principles are described elsewhere [2-3, 15-16]. Monitoring of the site can provide a measure of the actual values of the parameters that are predicted or used in the impact calculations for the selected and remedial action scenarios, and the data can be used to improve (or reduce) confidence in the modelling predictions. Monitoring may even identify processes not taken into account in the initial modelling effort, and it may suggest modifications and additions to remedial actions.

The monitoring and surveillance phase is continued as long as necessary to obtain a good level of confidence in the predicted behaviour of the remedial works. Surveillance involves visual inspection of the remedial works to determine the need for maintenance and ensuring that the site is being adequately maintained and to increase the level of confidence in the stability and long term viability of the remedial works. Thus, the goals of monitoring, surveillance and maintenance are to ensure that the safety objectives are achieved and continue to be maintained; to perform timely and required modifications to the previously performed remedial action activities; and to increase the confidence in the long term viability of the remedial works.

Surveillance inspections would, among other things, discover signs of erosion, subsidence, seepage, changes in patterns of vegetation, evidence of flooding, changes in on-site and nearby streams. Environmental media would be monitored to gain confidence that the remedial works are effective and to determine that long term safety and environmental goals are attained.

Any necessary maintenance can be performed in accordance with the needs identified by the inspection team. However, it might be pointed out that, if a properly designed closeout plan has been implemented, the requirements for maintenance would be minimal, consisting only of minor repairs. More extensive maintenance may be required in the event of extreme events, such as major flooding. Monitoring can facilitate early identification of any deficiencies or unforeseen circumstances affecting the site, and hence the choice of appropriate remedial maintenance. The monitoring and surveillance programme following closeout may cover:

- erosion and sedimentation management;
- water quality;
- emissions of radon;
- stability and visual impact of the site;
- maintenance of a vegetative or rock cover;
- the integrity of the tailings;
- seepage from the disposal area;
- rainwater infiltration rates; and
- moisture content.

In some cases, objectives may have been set for certain levels to be maintained or achieved before or during the monitoring phase. These may include, for example, minimum species diversity or density of vegetation; introduction and sustainability of fauna; erosion below certain levels; flow of particulates, radioactive solids or gases in air or water below levels which could pose a human health or environmental risk.

Development, approval and implementation of a monitoring and surveillance programme, including post-closeout monitoring, may encompass both areal and personnel radiation monitoring, direct and remote sampling, and site inspection. Through such programmes, the appropriate authority should be able to evaluate compliance by the operator with stated requirements for the particular site, and determine how the monitoring programme should be continued for such period of time as required by the appropriate authority to enable demonstration of a successful transfer from active to passive management.

The objective of the monitoring and surveillance phase is to determine when the site meets all of the requirements of the closeout plan. When this is achieved, the mine/mill operator may be absolved of further responsibility for the site and any outstanding trust funds which may have been put aside to cover closeout costs would be refunded. At this point of walkaway, the mine/mill operator might be presented with a certificate or other report by the regulator recognizing that the required standards for closeout have been met. On this basis, the government authorities may decide to proceed with an alternate land use for this site, and they could enter into appropriate arrangements with the new owner/occupier for any necessary ongoing monitoring and surveillance.

5. SUMMARY OF QUESTIONNAIRE RESPONSES

5.1. INTRODUCTION

This section compiles the responses to a questionnaire on current practices from the Member States (see Annex A). The questionnaire was sent to a selected group of Member States known to have mined and milled uranium ores. Ten responses were received, mostly from North American or Western European countries. This biased response does not include some significant uranium producing countries, such as the Newly Independent States (NIS) of the former Soviet Union. The responding countries represent about 60% of the world's uranium production through 1992.

The questionnaire was structured in three parts. Part A (Goals) was intended to determine the goals for remedial action within each country. Part B (Radiological Considerations) was to obtain quantitative criteria on radiological protection employed in each country. Part B also was intended to compile each country's approach to the broader subject of ecological protection. Part C (Site Specific Considerations/Data) asked for a detailed description of a representative uranium production facility which had undergone remedial action.

This section summarizes the questionnaire responses, which are tabulated in Annex B. The detailed descriptions of each country's representative remediated project are given in Annex C.

5.2. REMEDIATION GOALS

Question 1a asked "How many operating, non-operating, unremediated, and closed-out uranium mine/mill facilities do you have in your country?". As can be seen in the accompanying table in Annex B, the interpretation of what constitutes a mine was quite variable. In view of the broad range of mining practices (ranging from small single adit one-man operations to large mines, both open pit and multi-shaft underground mines with hundreds of kilometres of galleries), the number and types of mines in each country varies considerably. Another observation made is that in most countries, the number of non-operating uranium mines and mills greatly exceeds the number of operating facilities.

Question 1b asked "Do you have close-out plans"? The accompanying table in Annex B shows that the majority of responding countries do have (or intend to have) close-out plans for both operating and non-operating mines and mills.

Question 1c asked "Are these plans subject to revision, and if yes, how often are they revised"? The respondents generally indicated that such plans are subject to revision. In most instances the frequency of revision is driven by local, site specific issues. Question 1d asked "On what basis are revisions made"? Most revisions are based on site specific issues and regulatory revisions; the development of new technology can also be a factor. It can be noted that in three Member States, public opinion plays a role in revision of close-out plans. It is possible that public opinion may become increasingly influential in these matters.

Question 2a asked "Are funds set aside to cover the closeout costs"? The responses contained many caveats and fall into three sub-categories: 1) funds set aside by owners for new operations, 2) set aside for past operations, 3) government funds will be made available on closeout for facilities for which funds had not been set aside previously. For new operations, the vast majority indicated that new owners would be required to set aside funds for closeout. For past operations, set-aside requirements were much more varied. Given the magnitude of the cost associated with closeout, this is not surprising. For some Member States, Government funding has been made available for closeout of past operations. This funding has been influenced by public sentiment. Question 2b asked "On what basis are closeout costs estimated"? The methods employed for cost estimates seem to be equally divided among technical assessment, rough estimates, and availability of resources. It is clear that there has been a change from past practices where funds had not been set aside to an acknowledgement by all respondents of the importance of financial planning for closeout operations before production begins.

Question 3 asked "What are your goals for site remediation"? Respondents were given three categories to choose from: (1) Exclusion (restricted access), (2) Restoration to protect human health, and (3) Restoration to beneficial/natural environmental conditions. These three choices represent three points on a continuous scale of increasing degree of protection, with clearly increasing cost implications. For closeout of mills, the majority of respondents indicated relatively high restoration goals. For tailings, the response was equally split between high and medium level goals, possibly reflecting the need for achieving a protective goal for tailings associated with high grade ores and the volume of tailings associated with lower grade tailings, where complete isolation of tailings from the environment may not be physically possible. The goals for mines were also split equally, again reflecting the diverse nature of mining operations and the feasible options available. The responses would seem to indicate the need to recognize that long term institutional controls will have to be exercised over some remediated mining and milling facilities.

Question 4 was "how are or will mills, tailings and mines be remediated?" No respondents indicated that mills would be abandoned. There was a mix of responses regarding intentions to decontaminate and re-use mills and in respect of intentions to demolish and bury on site or bury elsewhere. These decisions are most likely influenced by site location. Again there was no intention to abandon tailings and it would appear that the majority of tailings would be stabilized and capped in-situ. Some respondents indicated that tailings would be disposed of underground, mostly for those associated with high grade (i.e. high uranium content) ores. Remediation of mines would appear to be influenced very much by the nature of the mine and its location. Responses were accordingly somewhat mixed.

Question 5 requested information on planned or executed environmental monitoring. The question addressed both radiological and non-radiological monitoring for both pre and post-closeout periods in all relevant environmental media. Generally, such monitoring is or will be performed for radiological and to a lesser extent for non-radiological parameters.

Question 6 requested information on the time period after closeout over which environmental monitoring would be carried out. Both radiation and non-radiological monitoring programmes were generally proposed for periods ranging from a few to tens of years. Exceptions were much longer periods (beyond 1000 years in the case of the USA) and periods to be determined on the basis of prevailing circumstances. For non-radiological programmes, less environmental media were included in the monitoring programmes although water was generally included.

Question 7 asked what methods would be used to estimate whether proposed plans would meet goals. All the methods named in the questionnaire were used including probabilistic and deterministic modelling, comparison with similar sites, scientific and engineering judgement and in many instances actual testing was carried out. Countries generally use more than one method, often up to three or four, depending on the nature of the parameter under consideration.

Question 8 requested information regarding quality assurance associated with remediation. Most countries require such assurance mechanisms, often employing international recommendations and national requirements.

Question 9 asked what were the main problems encountered in the planning and execution of remediation plans citing regulatory, financial, social, expertise and technical problems as possibilities. All respondents indicated that regulatory problems had been encountered. These had been overcome in half of the cases, clearly indicating that problems remain in this area. Many respondents indicated that financial problems exist but only one indicated satisfactory resolution. Again, this is an area of continuing concern. Social problems appear to be a concern to 70% of respondents with few being resolved. The availability of expertise appeared to be less of a problem, although it remained an issue for two countries. Technical problems seemed to be of least concern.

Question 10 concerned the key environmental parameters used to decide whether environmental goals had been achieved. In respect of radiological parameters most respondents indicated that all important environmental media were monitored and the results used in such decisions. For non-radiological contaminants, fewer environment media were sampled, although again the monitoring of water was predominant.

5.3. RADIATION CONSIDERATIONS

Radiation Dose Limits

Dose limits for workers in the majority of respondents were 50 mSv per year with three exceptions (at 20 mSv per year). For members of the public, the majority of respondents have an annual limit of 5 mSv with 50% having an time integrated average of 1 mSv per year. Two exceptions were indicated, with facility specific annual limits of 0.25 mSv and 0.1 mSv.

Natural Background Levels

The levels reported indicated that differing interpretations had been placed on the question by respondents. However, no unexpected or exceptional data were reported.

Remediation Standards

Generally remediation standards were compatible with public dose limits being set at or below 1 mSv per year, the dose being in addition to background. In some instances, levels were set at a fraction of 1 mSv per year. The structuring of the question was perhaps too limiting to enable remediation standards to be addressed in detail, particularly in respect of instances were intervention was deemed to be appropriate. Sites which have been remediated were reported to exhibit radiation levels reduced by factors of 2 to 4 times, or, in the case of one respondent, up to 50 times. Collective dose did not appear to be a parameter that is used by the majority of respondents. It was not clear from the responses how optimization is factored into assessments although it is recognized that problems arise in this regard because of the long time-scales involved and the conceptual problems associated with truncating such collective doses.

Ecosystem Effects

Ecosystem effects are addressed by most respondents; however, it would appear that such considerations are limited at this stage.

5.4. COUNTRY SPECIFIC REMEDIATION PROJECTS

From the examples provided by respondents (Annex C), it is clear that Member States have considerably different approaches to remediation and closeout of mining and milling facilities. This no doubt arises from the great difference in mining and facilities, the overall environmental impact posed by such diverse facilities and the prevailing socio-economic circumstances in different Member States.

6. SUMMARY AND RECOMMENDATIONS

Worldwide, there is considerable variability in the regulatory approaches to the management of uranium mining and milling wastes. However, the current situation is such that requirements on

- Conventional safety, in particular for underground mines, and
- Operational radiation protection, both occupational and for the public,

are generally met for the existing situation. In countries where few or inadequate radiation and environmental protection criteria were applied in the past, remediation and restoration activities are underway or being planned.

For the long term effects on human health and the environment, it was generally hoped in the past that further studies, during and possibly after uranium mining and milling operations, would show that protection was maintained. Currently, active institutional control is maintained at most sites even after closeout to ensure compliance with license conditions, and effective protection of the workers, the public and the environment. Under these conditions, there appear to be no major problems.

In the long term, typical scenarios or occurrences needing attention are intrusion and erosion (i.e. human or natural-caused degradation of engineered barriers, etc.). Intrusion is particularly relevant for the resulting individual effects (e.g. radiation exposures) which may exceed normal limits.

Due to the very long half-lives of some radionuclides in uranium mining and milling wastes, it may be desirable to maintain institutional controls (or other means of preventing intrusion) for relatively long periods. However, predictive models of the physico-chemical behaviour of near-surface waste repositories (of which the disposed uranium mining and milling wastes can be considered to be an example) become increasingly uncertain after a time span of, say, a few centuries.

The approach to management of uranium mining and milling wastes varies between countries although it is generally accepted that goals must be established and quantitative assessments carried out to demonstrate that control measures to environmentally isolate these wastes do attain the established goals. The costs associated with remediating such facilities can be substantial and it is vital that such projects are planned and carried out in a manner that will achieve their set objectives.

The following aspects may be considered in assessing long term solutions for the disposal of uranium mining and milling wastes:

- Maintaining institutional control for long time periods. 'Historical memory' may play an important role in this regard.

- Upgrading long-term confinement systems. This may include options such as upgraded near-surface barriers, disposal into a lake or by backfill into an underground mine.

- Implementing advanced solutions where practicable and economically feasible, such as extracting selected radioisotopes from the tailings.

- Selecting dispersion instead of containment if a safety assessment case allows it.

- Comparing 'enhanced activity' conditions with site or local 'natural activity' conditions (this may be particularly relevant for open pit operations).

- Adopting less conservative or probabilistic scenarios or assumed occurrences.

Also, a clear distinction is often made between new and existing facilities. For the latter, cost/benefit analyses may dictate realistic solutions.

The long term aspects of uranium mining and milling wastes are still be debated by the international community. In deciding upon upgrading of practices for the long term, the following items may be considered:

- flexible, gradual application;
- probabilistic approach;
- new versus existing practices; and
- advanced technical solutions.

This publication provides a snapshot of current waste management practices in a selection of Member States and identifies that several problem areas exist, which are of concern to Member States. Of the problem areas identified, regulatory and financial aspects appear to be predominant. It appears that the establishment of international consensus regarding standards of remediation and the regulatory mechanisms which will demonstrate compliance with such standards is perceived to be a priority. Regulatory aspects to be emphasized include the guidance concerning the conduct of quantitative impact assessments and performance monitoring programmes. Their establishment will assist Member States in confirming the adequacy of existing programmes or establishing new or additional programmes.

The recognition that ecosystems may be significantly affected indicates the need for further work to be carried out in such areas as ecological risk assessment. In addition to consideration of ecosystem effects, both radioactive and non-radioactive substances should be considered, with equal attention to both based on risk assessments. It would appear that there is a current emphasis on radioactive considerations and that further work may need to be carried out by Member States to address non-radioactive aspects.

While the information gathered during development of this current practice report resulted in a useful snapshot of the practices employed in the major part of the world, some limitations are apparent. The main limitation is that the original questionnaire did not allow an interpretation of the reasons why each country's respective closeout practices were adopted. With only 10 respondents and with limited information gathered, there is a need to compile a more complete database which inventories the entire world's uranium production facility closeout practices. It is envisaged that this work could be continued with development of a much more detailed questionnaire, and information solicited from all uranium producing countries shown in Table I. A less ambitious approach would be to develop an enhanced questionnaire which would only focus on the rationale employed by each Member State in formulating its closeout plans. Other information gathering approaches, such as the use of fact-finding missions, might also be considered. In any case, it would be useful and informative to poll all of the uranium producing countries concerning their closeout practices.

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Annex A

URANIUM MINES AND MILLS QUESTIONNAIRE:
Current Closeout Plans and Practices

Name and address of respondent:

....

....

Telephone no.: .... Fax no.: ....

Date completed: ....

A. GOALS

1a. How many operating, non-operating, unremediated, and closed-out uranium mine/mill facilities do you have in your country?

		Mills	Mines
A.	Operating		
B.	Non-operating/unremediated		
C.	Closed-out		

1b. Do you have closeout plans?

		Mills		Mines	
A.	Operating	Yes	No	Yes	No
B.	Non-operating/unremediated	Yes	No	Yes	No

1c. Are these plans subject to revision?

Yes	No

If yes, how frequently are they revised?

Every .... years

On what basis are revisions made?

(Please check √)

Basis	
Site specific studies	
Revised standards/regulations	
Public opinion	
Other (please specify)	

2a. Are funds set aside to cover the closeout costs?

Yes	No

2b. On what basis are the closeout costs estimated?

(Please check √)

Basis	
Technical assessment	
Rough estimates/other	
Availability of resources	

3. What are your goals for site remediation?

(Please check √)

	Mills	Tailings	Mines
Exclusion (restricted access)			
Restoration to protect human health			
Restoration to beneficial/natural environmental conditions			

4a. How are/will the mill sites be remediated?

(Please check √)

Method	
Abandoned	
Decontaminate/alternative use	
Demolish; on site burial	
Demolish; off site burial	

4b How are/will the tailings sites be remediated?

(Please check √)

Abandoned	
In-situ containment and capping	
Below ground disposal; on site	
Below ground disposal; off site	

4c. How are/will mine sites be remediated?

(Please check √)

	Open pit	Underground
Abandoned		
Flooding		
Collapse/subsidence		
Backfill		

5. Is environmental monitoring planned/executed?

(Please check √)

	Radiological		Non-radiological	
	Pre-closeout	Post-closeout	Pre-closeout	Post-closeout
Air				
Water				
Soil				
Biota				
Humans				

6. For how long after closeout will monitoring be done?

	Radiological	Non-radiological
Air		
Water		
Soil		
Biota		
Humans		

(Put in your best estimate in years or comment)

7. What method(s) are/were used to estimate whether proposed remedial plans will meet post close-out goals?

	(Please check √)
Modeling: Probabilistic	
Deterministic	
Comparing with similar site(s)	
Scientific/engineering judgment	
Other (please specify)	

8. What methods do you use to provide quality assurance in site remediation, planning, and implementation?

	(Please check √)
Regulatory/legislated requirements	
International guidelines and practices	
Scientific/engineering standards	
Auditing and independent reviews	
Other (please specify)	

9a. What are the main problems you have experienced in remediation planning/execution?

	(Please check √)	Brief description
Regulatory		
Financial		
Social		
Expertise		
Technical		
Site-specific problems		
Others		

9b. How did you overcome these problems? What lessons can be learnt?

Issue	Response

10. State the key environmental parameters you use to decide when/whether you achieved your remediation goals.

	Radiological	Non-radiological
Air		
Water		
Soil		
Biota		
Humans		

B. RADIOLOGICAL CONSIDERATIONS

1. What radiation dose standards apply in your country for workers and the general public?

	mSv/a
Permissible dose to workers	
Permissible dose to the public	

2. What are the mean natural background radiation levels (i.e. readings at 1m above ground)?

	mSv/a
Mine/mill vicinity	
National average (range)	

3a. What radiation standards (if any) do you apply in remediation planning?

(Please specify, e.g. incremental dose for maximum exposed person)

mSv/a

3b. What are the mean radiation levels (i.e. readings taken at 1 m above ground) at the sites you have already remediated in your country?

Before remediation (mSv/a)	After remediation (mSv/a)

3c. Is collective dose used as a means of assessment?

Yes	No

3d. If so, what limits do you apply (e.g. as result of truncation)?

person-Sv

4a. Do you assess ecosystem effects in remediation planning?

Yes	No

4b. If so, what approaches do you use?

	Radiological	Non-radiological
Air		
Water		
Soil		
Biota		

5. Briefly describe the expected environmental impacts and conditions of the closed out uranium mine/mill facilities in your country over the medium and long term (i.e. over at least a few centuries of time).

C. SITE SPECIFIC CONSIDERATIONS/DATA

In order to supplement the foregoing information, please provide a narrative description of your approach for the remediation of representative mine and mill site(s). In this narrative, please include the information requested below in the format given.

In addition, it would be of use to include a discussion of your remediation goals, the criteria by which you identify the point at which your goals have been reached, and a brief description of the remedial measures.

A discussion of the regulatory requirements that affected either the formulation of the plans or their implementation would also be of use in understanding the external factors influencing your plans.

Finally, it would be of use to discuss what lessons were learned in implementing your plans.

Please be brief, a maximum of about five pages per representative site, and include any illustrations you feel would be of help to clarify your narrative.

Finally, to aid our analysis, please also summarize the information in the attached table.

Name of facility	
Operator	
Location	
Country	
Approximate size	
Age (a) of operation (from start up, through closedown or remediation complete, if applicable)	
Climate	
Nearby population (Size and distribution relative to the site, distance, land use in the near-by vicinity, etc.)	
Ore body type: Unconformity-related/ sandstone/vein/etc. Monometallic/poly metallic (list other metals mined)	

OPERATIONAL DATA

	Waste rock types		Mill tailings		Heap leached waste	
Quantity (metric ton)						
Acid generating	Yes	No	Yes	No	Yes	No
Remediation technique for acid wastes						
Size						
Use						

Topography and altitude (m)	
Hydrogeology: Aquifer Type (e.g. localized, regional, etc.)	
Hydrology: Distance to nearest significant drainage channel (m or km) Water flowrate volumes (m^3) /continuity Water quality, level/pH upstream Water quality, upstream/downstream impacts	
Description of remedial measures:	
Techniques used	

Regulations	
Objectives	
Criteria for success	
Lessons learned	

Discuss how any of the above features have strongly impacted or constrained the remediation programme.

Annex B
SUMMARY OF QUESTIONNAIRE RESPONSES

Part A - Goals

This annex presents a summary of the responses to the Questionnaire across all respondents (the countries which responded are listed at the end of this Annex). Each country's response varied in its interpretation of many of the questions. Therefore, it was necessary to subjectively judge many of the answers.

While the IAEA and its experts who evaluated the responses made every attempt to ensure that each country's response was an honest presentation of that country's practice, misinterpretations may have been made. Therefore, the summaries presented herein may not reflect the actual practices. In addition, the questionnaires were answered by a variety of practioners across the countries (represented by regulatory agencies, facility owners, government officials, and consultants) and does not necessarily represent the official position on current practices set by the individual Member States.

1a. How many operating, non-operating, unremediated, and closed-out uranium mine mill facilities do you have in your country?

		Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Operating	Mills	2	4	2	0	1	5	0	1	0	0
	Mines	2	4	2	0	2	4	0	1	0	3 [3)]
Non-operating	Mills	1	1	2	3	0	15	1	1	0	18
(unre-mediated)	Mines	1	2	100	7 [1)]	3 [1)]	35 [2)]	1	24	0	>200
Closed-out	Mills	2	6	4	0	0	0	0	1	1	30
	Mines	12	6	100	0	0	0	0	2	1	50

1) These mines are primarily in 'districts' with multiple access adits and shafts and extensive mine workings. The small numbers many not reflect the magnitude of remediation.
2) Mines are currently not producing uranium (gold mines) and could resume operation.
3) In-situ leach facilities only.

1b. Do you have close-out plans?

		Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Operating	Mills	Y	Y	Y	N/A	Y	N	N/A	Y	N/A	Y
	Mines	Y	Y	Y	N/A	N	N	N/A	Y	N/A	Y
Non-operating	Mills	Y	Y	Y	Y	N/A	N	Y	Y	N/A	Y
(Unre-mediated)	Mines	Y	Y	Y	Y	Y	N	Y	N/A	N/A	N

1c. Are closeout plans subject to revision?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Revision	Y	Y	Y	Y	Y	Y	N	Y	N/A	Y
Frequency (years)	1	V	1	V	2	V	N/A	2	N/A	N/A

V indicates revision is not periodically required but that revisions are performed variably due to many reasons.

1d. On what basis are revisions made?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Site Specific studies	X	X	X	X	X	X		X		X
Revised standards/regulations	X	X	X	X		X		X		X
Public opinion	X				X					X
Other										X[1]

[1] Revisions may also be necessary as the financial posture of the facility owner changes.

2a. Are funds set aside [1] to cover the closeout costs? (Y=yes, N = no, P= partial)

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Set aside for new operations?	Y[2]	Y	Y	Y	Y	Y	?	Y	Y	Y
Set aside in past operations?	P	P	P	N	N	P	N	N	N	P
Government funds available?	Y	?[3]	?[3]	Y	Y	N	N	Y	N/A	Y

[1] This question was answered by responding countries with many caveats. The question was modified to include 3 sub-categories (set aside by owners for mew operations, set aside in past operations, and will government funds be made available for closeout of facilities for which funds were not set aside previously).

[2] Depends on different state requirements.

[3] These countries currently have no provisions for funding closeout efforts, but may develop them in the future depending on public input.

2b. On what basis are the closeout costs estimated?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Swe	USA	
Technical assessment	X	X	X	X	X			X		X
Rough Estimates		X	X	X		X	X		X	X
Availability of resources		X			X	X		X		X

3. What are your goals for site remediation?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Mills	H	H[1)]	M	H[1)]	M	H	H	H	H	H
Tailings	H	H[1)]	M	H[1)]	M	M	M	M	H	H
Mines	H	M	M	H[1)]	M	H	R	H	H	R[1)]

H = High (restoration to beneficial / natural environmental condition)
M = Medium (restoration to protect human health)
R = Restrict Access / Exclusion

[1)] Not consistently applied across the country due to differences between production and/or mining laws and environmental/ radiation protection laws. Differences may also arise due to differing regulations imposed on operations by different states within the same country.

4.

	abandoned	Decontaminate: alternate use	Demolish: on site burial	Demolish: off site burial
(a) How are / will mill sites be remediated?	none	√√√√√√[1)]	√√√√√√√√√	√√√

	abandoned	In situ contain and capping	Relocation and capping	Below ground disposal on site	Below ground disposal off site
(b) How are / will tailings sites be remediated?	none	√√√√√√√√√	√	√√√	√

	abandoned	Controlled flooding	controlled collapse	Backfill
(c) How are / will mine sites be remediated?	√√√	√√√√√√√√√√√ √	√√√√√√	√√√√√√√√√√

[1)] Each mark indicates one affirmative response.

5. Is the environment monitoring planned/executed?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Radiological pre-closeout	AWS B	AWS B	AWS B	AWS B	AWS B	AWS B	AW SB	AW SB	AW SB	AW SB
Radiological post-closeout	AWS B	AWS B	AWS B	AWS	AWS B	AWS B[1]		AWS B	AW SB	[2]
Non-radiological pre-closeout	AWS B	AWS B	AW	AWS	WS	W			WB	AW SB
Non-radiological post-closeout	AWS B	AWS B	W[3]	W	WS	AWS B[1]		AWS B	WB	[2]

A = air, W= water, S = soil, B = biota

[1] As regulated (can be site to site differences).

[2] The USA monitors the physical integrity of the completed (closeout) structure.

[3] Only base metals.

6. For how long after closeout will the monitoring be done (years)?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Radiological media	AWS B	AWS B	AWS B	AWS B	AWSB	AWS B	AWS	AWS B	AW B	W
Duration (years)	>5	10	2-30	5-20	30-40	[1]	5-10	5	[1]	>1000
Non-radiological media	WSB	AWS B	W	W	WS	AWS B	W	AWS B	WB	W
Duration (years)	>5	10	2-30	20	30-40	[1]	10	5	1)	>1000

A = air, W= water, S = soil, B = biota

[1] As regulated (can be site to site differences)

7. What methods were used to estimate whether proposed remedial plans will meet post-closeout goals?

Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
PDCJ	PDCJ	DCJT	PDCJT	DJT	(1)	J	DJ	DCJT	PDJT

P= Probabilistic modeling, C = comparing to similar sites,
D = Deterministic modeling, J = scientific/ engineering judgement,
T = tests: A category described as 'other' was also available to the respondents and in all cases when this was selected, the method described was the use of tests on physical or chemical attributes of the closeout system.

8. What methods do you use to provide quality assurance in site remediation, planning and implementation?

Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
RGSA	RGSA	RGSA	GSA	GA	RG	G	RGSA		RGSA

R = regulatory/legislated requirements, S = scientific/engineering Standards
G = international guidelines & practices A = auditing and independent reviews
O = other

9a/b. (a) What are the main problems you have experienced in remediation planning and execution, and (b) how did you overcome these problems?

Problem classification	No. of Responses	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Sw e	USA
Regulatory	√√√√√√√ √√√	N	N	Y	Y	Y	?	Y	Y	?	?
Financial	√√√√√√√ √	N	?	?		?	?	N	Y		?
Social	√√√√√√√	Y	?	Y	Y				?	?	?
Expertise	√√√	Y		?			?				
Technical	√√√√			Y	Y		?			Y	

Y = Yes Identification of a problem and reported solution.
N = No Identification of a problem.
? = Unknown Identification of a problem but silent on the resolution.

10. Key environmental parameters you use to decide when/whether you achieved your environmental goals.

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Radiological	AWS BH	AWS BH	AW H	AW SBH	AW SBH		AW	AW SBH	W	AWS B
Non-radiological	AWB	AWS B	W	AWS	W		W	AWSB	W	AWS B

A = air, W= water, S = soil, B = biota, H = calculated parameters for humans

1. What radiation Standards apply in your country for workers/ public (mSv/a)?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
permissible dose to workers	20	50	50	50	50	50	20	50	50	20
permissible dose to public	1	5	5	5/1	5/1	0.25[1)]	1	5	0.1	1

1) Possible misinterpretation of the question by the respondent.

2. What are the mean natural background levels (i.e. readings at 1 m above ground) mSv/a?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
mine mill vicinity	2.5	10[(1)]	4[(1)]	0.9	0.9	1.2	5[(1)]	3.5[(1)]	0.7	1.4
national average (range)	2	1	2[(1)]	0.7	0.8	1.2	2[(1)]	2.4[(1)]	NR	1.2

1) Possible misinterpretation of the question by the respondent.
NR = Not reported

3a. What radiation standards (if any) do you apply in remediation planning (incremental dose for maximum exposed person mSv/a)?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
	1	1	5	1	1	none	0.3	0.3	0.7	none

3b. What are the mean radiation levels at the sites that you have already remediated (mSv/a)?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Before remediation	NR	25-50	2-6	3	4	NR	NR	6-13	6-12	50
After remediation	NR	<10	2-4	0.9	1.2	NR	NR	4	0.5-0.9	1

3c. Is collective dose used as a means of assessment?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
	N	N	N	Y[(3)]	N	N	N	Y	N	Y

N = no, Y = yes

3d. If Collective dose is used, what limits do you apply? (person-Sv)

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
	N/A	N/A	N/A	NR	N/A	N/A	N/A	0.9-3	N/A	none

N/A = Not applicable, NR = Not reported

4a. Are ecosystem effects assessed in remediation planning?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
	Y	N	Y	Y	N	N	N	Y	Y	Y

N = no, Y = yes

4b. If ecosystem effects are assessed, what approaches do you use?

	Aus	Can	Fra	Ger	Hun	RSA	Slo	Spa	Swe	USA
Radiological	AWS B		AW S					NR	W	W
Non-radiological	W SB			W SB				NR	W	W

A = air, W = water, S = soil, B=biota

LIST OF COUNTRIES WHICH RESPONDED TO THE QUESTIONNAIRE:

Australia (Aus); Canada (Can); France (Fra); Germany (Ger); Hungary (Hun); Republic of South Africa (RSA); Slovenia (Slo); Spain (Spa); Sweden (Swe); and the United States of America (USA).

5. Briefly describe the expected environmental impacts and conditions of the closed out uranium mine/mill facilities in your country over the medium and long term (i.e. over at least a few centuries of time).

Each responding country's response is presented in alphabetical order below:

Australia

Tailings placed below grade are expected to have minimal impact for at least 1000 years. Some groundwater contamination can be expected, but owing to the remoteness of most sites this is not likely to pose a significant problem for the foreseeable future, during which time it is highly unlikely they will be required for potable water; also the quality of the natural groundwater in some areas is very poor (saline) and unpotable for human or stock use.

Above grade containments represent some risk of breaching by erosion, particularly in the wet/dry tropics. Therefore, some risk of contamination exists through exposure of radioactive material and/or dispersal of material along creeks with radiological, chemical and physical consequences. Whilst efforts are being made to minimize the need for maintenance, it is likely that above-grade deposition of tailings will require some level of maintenance. No significant medium to long term impacts are anticipated from the mill sites.

Canada

Generally, all conditions downstream of the facilities will return to normal (i.e. pre-mining) conditions quickly. However, radium levels will initially tend to increase before returning to background in approximately 200 years, though never exceeding amount acceptable criteria.

France

The remediation objective is to isolate all radioactive materials from the environment to limit exposure and to prevent any radionuclide migration. Sites will be revegetated and water treatment is planned until water quality has improved due to flushing of contaminated pore water. Environmental monitoring (on and around the site) are planned until equilibrium is reached and stabilization of the actual impact is confirmed.

Germany

Tailings:	Covered; reduced water and radon release; no dust emission; seepage water treatment for perhaps 50 years; restrictions regarding use of remediated tailings ponds;
Mines:	Flooded; water treatment for 10 to 20 years, thereafter tolerable contaminant emissions into receiving waters;
Waste rockpiles:	Stabilized; covered, vegetated; reduced water and radon release; no dust;
Pits:	Backfilled; partly flooded; covered, little emission into ground and receiving surface waters (primarily salts).

Hungary

Owing to migration upward of radionuclides in cover layer above restored waste rock, future impacts were calculated:

Food contamination after	10 years	1000 years
Root vegetables	7.3 Bq/kg	57 Bq/kg
Cereals	0.19 Bq/kg	1.9 Bq/kg

External dose (cover layer 1 m):

after 200 years	<1 μ Sv/a
after 1000 years	1.1 μ Sv/a
after 2000 years	8 μ Sv/a

Internal dose after 500 years:

1 year old children	2.4 mSv/a
10 year old children	1.4 mSv/a
adults	0.8 mSv/a

Republic of South Africa

'Too early to describe'.

Slovenia

Expected environmental impact of the only uranium mine and mill facility in the country over the medium and long term:

Effective dose commitment below 0.3 mSv/a. Run off mine water uranium and radium-226 concentrations below 300 μgU/ℓ, 50 Bq Ra/m^3, respectively. Other long-term sources, mill tailing and mine waste disposal site contribution, will be negligible. All surface waters will be in the range of today's potable water limits. Radon-222 release rate below 0.7 Bq/s-m^2.

Spain

After the closure it must be similar to the radiation background of the zone. It must remain stable for at least 200 years and for 1000 years to the extent reasonably achievable.

Sweden

Lake Tranebärssjön, formed from a former open-pit mine, has increased levels of e.g. Ni and U. However, this is in the long run anticipated to decrease to near background levels.

The sealing of the mill tailings has after two years already resulted in a major decrease of heavy metal and U transport from the tailings. It is anticipated that in a few years cleanup of the leachate will no longer be required.

Some of the facilities have been dismantled. The remaining building will be taken care of by the present owner.

United States of America

Uranium mines: The closeout of uranium mines in the USA is not regulated under the auspices of radiation protection by state or federal governments. All mines are considered to be regulated by the federal Surface Mining Reclamation Act of 1977 or its state counterpart. All uranium mines which have been reclaimed have been done to remove physical hazards such as high wall instability and revegetated. Underground mines have simply been sealed. The expected long-term environmental impacts from closed out uranium mines is minimal.

Uranium mills: With dozens of uranium facilities already successfully closed out through the construction of robust disposal cells engineered to last 200-1000 years, the expected environmental impacts from them are minimal. The land on which these disposal cells are placed is controlled by the federal government. Routine (at first, annual) inspections of the disposal cells have begun and the only (small) concern is that those cells armoured against erosion by rock in some locations have shown a tendency to promote vegetation invasion. It is intended that this vegetation will be controlled (by the government) such that the performance of the isolation covers is not compromised.

Annex C
SITE SPECIFIC CONSIDERATIONS/DATA WORLDWIDE PRACTICES: DESCRIPTION OF REPRESENTATIVE CLOSEOUT ACTIONS BY SELECTED MEMBER STATES

This annex provides additional descriptions of specific closeout actions undertaken by each country for final remedial action at uranium mine and mill facilities. Each description is intended to be representative of the types of efforts each country typically employs in its administration of closeout requirements for uranium production facilities. Besides the descriptions provided in this Annex, related information for various other countries can be found in recent publications [2, 7-9].

Some of the descriptions given here have followed a format prescribed by the IAEA in the questionnaire sent to Member States. Others have also been included to present a sampling of the many current practices employed around the globe.

Because the various respondents to the IAEA request for this information represent a broad cross-section (e.g. regulatory agencies, facility owners, government officials and consultants) of each country's practioners, the information provided in Annex C does not necessarily represent the official position on current practices set by the individual Member States. Contributions to this Annex were received from cognizant persons for Australia, France, Germany, Spain and the United States of America.

AUSTRALIA

NABARLEK URANIUM MINE

This is an Australian example of a uranium mine remediation project.

NAME
Nabarlek Uranium Mine

LOCATION
West Arnhem Land, Northern Territory

CLIMATE
Wet dry tropics; average rainfall 1400 mm/a between October and April; temperatures 10°C minimum to 35°C max

NEARBY POPULATION

Distribution:	Township of Oenpelli/Gunbalanya, approx 900 persons
Distance:	40 km by road, west of the minesite
Land use in vicinity:	Natural bushland, traditional hunting and gathering

ORE BODY TYPE
Monometallic; shear zone to an unconformity; massive and sisseminated uraninite mineralization in altered (ferromagnesian chlorite/sericite) amphibolite-grade metamorphics.

OPERATIONAL DATA

Dates:	Mining/stockpiling took 143 days in May-October 1979, milling May 1980 to June 1988, heap leaching continued until late 1989
Ore production:	606 890 tons
Tailings production:	670 000 tons
Waste rock Production:	317 820 tons
Production of U_3O_8:	10 860 tons
Acid rock drainage potential:	nil

TOPOGRAPHY AND ALTITUDE
Sandy lowlands, peneplain; 69 metres ASL

HYDROLOGY AND HYDOGEOLOGY
Two major aquifers in the area; localized surface perched in weathered dolerite and surficial soils approximately 2 metres; underlying regional fractured rock aquifer; water table fluctluations seasonally 3 metres approx.; hydraulic conductivity is less than 10^{-8} m/s. Portable supplies taken from several borefields in the area providing up to 5 LPs. Surface drainage of the area is by a network of seasonal creeks.

REMEDIATION OF THE MINE

How:

The site is to be returned to a woodland condition suitable for pursuit of a traditional Aboriginal lifestyle involving hunting and gathering. The mill has been dismantled and much of the equipment sold. Parts to be removed from site have been decontaminated in accordance with existing regulations, and a code of practice developed specifically for the operation by the mine operator in conjunction with the regulating authorities. Equipment which was unsold or could not be decontaminated has been placed in the pit. The pit is also the final repository for tailings which were deposited throughout the eight-year milling phase. Upon completion of tailings deposition, drainage wicks were inserted into the tailings mass to assist settlement and internal drainage.

Site cleanup involves placing arisings from the mill and general mine area on top of the tailings mass in the mine pit; e.g. unsold mill components, concrete foundations, evaporation pond embankments. After site cleanup, waste rock will be used to fill up the pit and earthmoving will landscape the site to an approximation of pre-mining contours, apart from a raised cover over the pit area. A seeding programme will establish a wide range of native plants including shrubs, forbs and tree species on a prepared cap, which will incorporate stockpiled topsoil in the seed bed.

Closeout was due to be completed by 31 December 1995. The final **walkaway** schedule is still being discussed between the regulating authorities, the mine operators and the traditional land owners.

Work has been carried out under a series of small contracts overseen by a consulting engineer appointed by the mining company.

Why:

The Commonwealth Government has a responsibility for environmental protection in the Alligator Rivers Region through the provisions of the Environment Protection (Alligator Rivers Region) Act 1978. Specifically, the Supervising Scientist is responsible for planning and developing measures for the protection and restoration of the environment from the effects of uranium mining. The environmental requirements (ERs) which relate to rehabilitation are as follows:

ER 27 (a) The sites of mining excavations, the tailings retention system and other areas where ground has been disturbed shall be rehabilitated and revegetated to the satisfaction of the Supervising Authority. (The Supervising Authority is the NT Minister for Mines and Energy).

ER 27 (b) In revegetation, Queensland Mines shall establish appropriate ground cover plants in accordance with the directions of the Supervising Authority and shall fence, protect and, if necessary renew the establishing vegetation as may be necessary to bring about the rapid restoration of stable vegetation native to the region. This is also set out in UMEC sections 11 and 14(k). (The Supervising Authority is the NT Minister for Mines and Energy).

ER 27 (c) The obligations of Queensland Mines Limited under (a) and (b) above shall cease upon issue of a certificate of revegetation by the Supervising Authority.

The Northern Territory Government, under the Uranium Mining Environment Control Act, is also legally obliged to ensure satisfactory rehabilitation of the site. The two Governments have agreed that the general objectives for rehabilitation are:

- long term surface stabilization
- maintenance of an appropriate water balance in the area
- establishment of woodland communities which will blend with the surrounding countryside.

More specific objectives or standards against which a satisfactory outcome could be measured have not yet been developed.

The Northern Land Council, representing the traditional owners of the land, and the mining company, have developed an agreed set of objectives for rehabilitation based upon traditional Aboriginal land use of the area:

- The revegetated areas will consist of woodland communities of natural species that will blend with plant communities adjoining the Nabarlek mine site over which they will forage as per their current practice in adjoining plant communities.

- Foraging will involve:
  (a) day trips for plant foods and fauna across the revegetated areas,
  (b) occasional overnight camping.

This agreement is being used as a basis for Government to determine an agreed set of rehabilitation objectives and a method for determining rehabilitation success which will be acceptable to all of the stakeholders.

Outcomes:

To date the mine has been successfully decommissioned to the point of **cleanup.** The rehabilitation earthworks are in progress and will be completed by 31 December 1995. The results of research undertaken by the Commonwealth Government into stability of containment covers has been incorporated into the landscape design to minimize the risks of erosion. It has recently been agreed that the success of rehabilitation (including revegetation) will be judged by an independent expert acceptable to the Commonwealth and Northern Territory Governments, the Northern Land Council and the mining company, who will advise on the success and likelihood of self-sustainability of revegetation. It is anticipated that it will not be possible to realistically determine success for at least five years and possibly ten years after the rehabilitation works are completed, owing to the growth rates of native vegetation.

Lessons learned:

The planning of remediation should begin with the original mine plan. A comprehensive remediation plan which has been modified annually, more or less, in response to changes in operations, technology and end use requirements has enabled the remediation programme to proceed as well as could reasonably have been expected.

Assessment of revegetation has been difficult to agree upon. The process now agreed should ensure that an objective assessment is made which will be acceptable to all stakeholders (miners, regulators, traditional owners).

The pristine characteristics of the mine area prior to development, and the only land use in the region being traditional Aboriginal foraging practices, limited acceptable rehabilitation options to only one. In essence, the Aboriginal traditional owners want the area to be restored as closely as possible to its original condition. Placement of the tailings and all other disturbed materials back into the mine pit has been critical in achieving an outcome which is acceptable to the traditional owners.

GLOSSARY OF TERMS USED IN THE AUSTRALIAN EXAMPLE (NABARLEK URANIUM MINE)

Capping: Covering of contaminated/contained material with a layer or layers of rock, clay, soil or other materials designed to reduce the health risks to humans and to the environment (e.g. radon flux, alpha emitting dust etc.) and the risk of exposure to contained materials (e.g. against damage by erosion or from root and burrowing animal penetration).

Closedown: Permanent cessation of mining and milling activities.

Closeout: Completion of the decommissioning and rehabilitation works to the satisfaction of supervising authorities.

Decommissioning: Decontamination of the site and/or removal of facilities, materials and equipment so as to leave the facility and surrounding site in a safe state ready for rehabilitation.

Rehabilitation: Moving and shaping rock, soil and (for mill sites) tailings materials using normal earth moving and landscaping methods and machinery to develop the final landform; also initial establishment of vegetation by ground preparation, seeding/planning with or without fertilizer and use of support services such as irrigation.

Remediation: The period from closedown/beginning of decommissioning through to the point where post-rehabilitation monitoring indicates that the site has been successfully brought to a state consistent with the proposed future land use; also all applicable standards and associated regulations have been achieved or are assured (i.e. the walkaway point).

Walkaway: The point at which the regulating authorities determine that the goals of closeout have been met or are assured, and that the appropriate regulations and standards have been met and the site is suitable for the intended future land use. Often a certificate would be issued by the regulating authority to the mine/mill operator absolving them from any further liability/responsibility from this point on in respect of the site.

Institutional controls: Any measures, conditions or actions regulatory authorities may put in place to ensure that the effectiveness of the remediation programme is not lessened through any activity on the restored site; this applies primarily to the post-remediation land use.

Example of the phases and associated actions for closeout of a uranium mining/milling facility as followed by Australian authorities.

		<-----------------------	**REMEDIATION**	----------------------->	
PHASE	**OPERATIONAL**	**DECOMMISSIONING**	**REHABILITATION 1. Work programme**	**REHABILITATION 2. Post-work monitoring**	**NEW LAND USE**
DECISION POINT	CLOSEDOWN ---->	CLEANUP ------>	CLOSEOUT ------>	WALKAWAY ------->	
ACTION	Finalise rehabilitation objectives and agree indicators of success for all components	Assess completed cleanup works in relation to required objectives for decommissioning and walkaway. Commence rehabilitation/revegeta-tion works and associated assessment	Assess completed works in relation to progress towards desired objectives for walkaway; commence monitoring	Continue iterative monitoring and assessment until objectives for walkaway have been agreed as being achieved. Absolve operator of responsibility; issue revegetation/rehabili-tation certificate; refund bond money or balance of trust funds as appropriate	Continue long term surveillance monitoring if requires; commence new land use subject to any local conditions or controls

FRANCE

ECARPIERE URANIUM TAILINGS POND (COGEMA)

I. INTRODUCTION

Uranium Mining Division of Vendée was operated by COGEMA from 1954 to 1991. The main site is named ECARPIERE where were operated mines, mill and heap leaching facilities.

This site is located at Gétigné (Loire-Atlantique) in the west of France, 30 km from Nantes.

It is on a granite plateau 80 m high, dominating the valley of the river Moine, 400 m from a village (1300 people). The use of the land in the vicinity is agriculture, cattle breeding and viticulture. The climate is oceanic with an annual rainfall of 800 mm and an average temperature of 16°C.

On this site, there were:

- An underground mine (1953-1990), with maximum extension of 3 km long and 500 m deep - total production 3600 t U.
- Three open pits (maximum depth 50 m - total production 475 t U) lined up along the mineralized structures.
- A mill (1957-1991) - acid pulp leaching - maximum capacity 450 000 t/a treated 9000 kt ores containing 15 000 t U.
- Heap leaching facilities (1967-1991) dedicated to low grade ore (grade <600 ppm, 4000 kt) - total production 6 million cubic metres of uranium bearing solutions containing more than 1200 t U.

II. DESCRIPTION

Total area is 240 ha divided in units.

Location	area (ha)	Tonnage kt	Activity TBq Ra-226
open pit mining	115		
underground mining installations	12		
heap leaching facilities	25	4000	16
Mill	6		
tailings impoundment	73	7575	170
waste water collecting zone	9		

The mill tailings impoundment is a large settling pond built in two main steps for a total area of 73 ha.

The wastes were pumped and cycloned, the coarse fraction (150 μ) being used to build the dykes and the fine fraction settling behind them.

Main characteristics of the tailings dyke:

material used		sand
construction		vertical + upward
basement		granite
height		15-50 m
crest	length	3000 m
	width	10 m
slope		30-45%

There is a drainage network in the foot of the dykes. The monitoring equipment of the dykes include piezometric boxes, piezometers and shafts.

III. STUDIES

Studies provide a better understanding of the residues to be dealt with, of the materials which are used for the required cover and of the environment of the impoundment.

III.1 Petrography of the wastes and leaching tests

A complete study of the tailings by drilling through the complete pile down to the underlying granite gave valuable information:

- the deepest samples have the greatest proportion of argilous minerals (smectite) which is proof a real diagenesis comparable to any natural rock evolution.
- of course gypsum, linked to neutralization, is observed,
- radioactivity is linked to smectite and gypsum,
- 60% of the radium is located in the fine fraction (<30 μ) and is not removed by laboratory leaching tests,
- no radium migration is observed in the overlaid granite.

One can conclude that radium is fixed in the pile and that natural evolution leads to an even more stable chemical containment.

III.2 Hydrogeology

Water balance of the impoundment, of the underground mine (feeding by deep granitic circulation) and its environment, show that the impoundment is watertight. Moreover,

- altered surface granite give very low permeability measures : 10^{-10} m.s^{-1},
- this layer has been kept at the bottom of the impoundment, and drilling shows that it is now compacted by weight of the overburden,
- bottom residues are not yet consolidated and the piezometric level is ten meters above the original topography.

III.3 Settlement

- Lab measurements show variation of the density and cohesion with depth. The first three meters are consolidated with cohesion over 2 t m^{-2}.

- The natural settlement of the tailings under their own weight is not finished. Calculations conclude that in 25 to 30 years time, total reduction of the height will reach 5 to 12%, which corresponds to up to 5 metres for the thickest part of the impoundment.

- The final settlement is taken into account for determination of the thickness of the cover.

III.4 Tests plots: compaction and the final cover

The aim of the test plots was to test the efficiency of the cover as regard to:

- decrease of the radiological impact;
- decrease of permeability in order to limit the seepage of rain water and radon diffusion;
- reduction of gullying and prevention of intrusion.

The plots were 50 meters long and 10 metres wide built on a naturally dried part of the impoundment:

- a first metric layer of compacted heap leaching wastes,
- a second cover of different thickness of compacted and non compacted gabbros.

Radioactivity and radon flux measurements give the following results:

RADIOLOGICAL IMPACT	UNCOVERED TAILINGS	COVER*	BACKGROUND
Gamma SPP2 c/s**	910	135	100 - 200
Radon flux (10^5 at.m^{-2}.s^{-1})	40	0,6	0.6
Running water	(heap leaching waste)		
Ra-226 (Bq.l^{-1})	0.30	0.02	
U-238 (mg.l^{-1})	< 0.10	< 0.10	

* 1 meter heap leaching waste + 0.3 m compacted gabbro.
** focussed measures.

Compaction measurements show a considerable decrease in permeability and more than 50% increase in density. Radioactivity and radon fluxes are reduced to values comparable to the background.

For the typical cover, derived evaluation of the annual rate of exposure (ATAER - see § V.4) give 0.12 (on site) which is much less than the prescribed limit for the population in the environment.

III.5 Stability

During operation, behaviour of the dykes was always good with security factor of 2. After resloping, stability calculations show that under normal conditions the security factor is 2.6.

- in case water would rise to the maximum possible level, it is still 2.3,

- the historical seism, with a horizontal acceleration of 0.15g reduce the coefficient to 2.: all values being much higher than the usual 1.5 value recommended for such dykes.

IV. REMEDIATION

The framework of the remediation operations is set in the updated operating license issued in 1983:
- drying of the pond
- covering and reshaping of the site with good drainage of meteoric waters, limit water seepage and a radiological impact below 5 mSv
- seeding
- monitoring of radioactivity and stability.

First, the dykes are resloped down to 20-30% to achieve long term stability, to make easier implementation of the cover, reduce surface gullying and to improve integration in the landscape. The sand is relocated inside the naturally dried out pond.

The cover is a combination of heap leaching wastes and a layer of altered compacted gabbro to decrease the radiological impact. This layer is covered by top soil for vegetation. Total thickness is, at minimum, 1 metre.

Dismantling of the mill

Part of the equipment could be reused or sold according surface contamination limits. Over limits, products (scraps and concrete) were cut in pieces or compacted and disposed on two areas on the tailings, and covered. The buildings of the mill were demolished, and only offices, store and workshops have been kept, which will be used for new industrial activities.

Management of water

There are three kinds of water, according to their quality

- seepage waters coming from the tailings collected by ditches around the pound are treated for radioactivity and pH;

- underground mine water, over flowing in a special pond, is treated;
- meteoric waters are collected by a surface network and drainage tracks on the dykes then, after quality control allowed, to discharge in the river.

ORIGIN	FLOW RATE $m^3.h^{-1}$	pH	Ra-226 $Bq.l^{-1}$	Uranium $mg.l^{-1}$
Mine water	50	5.4	2	0.8
Seepage water	18	6.2	1.5	0.5
Surface running water	0-60	6.2	0.0 -0.4	< 0.1
River MOINE	9000	7.0	0.03	< 0.1

Waste waters are collected to adapt pH (objective 5.5 to 8.5) and reduce Ra-226 (objective <0.37 to 0.74 $Bq.l^{-1}$) and U-238 (objective <1.8 $mg.l^{-1}$) content before discharge in the river. Sludges shall be disposed of on special pond built on the tailings pond.

V. FRENCH REGULATION

In France, exploration, mining and remediation are controlled by the regional authority (Direction Régionale de l'Industrie, de la Recherche et de l'Environnement - DRIRE) within the framework of the French Mining Code. Since 1976, an environmental impact study covering the initial radiological state and the broad remediation concepts is required. Technical reports of impact studies are prepared and submitted to DRIRE and open to public inquiry before operation is allowed to start. The mining licence is issued by the prefect of the department. The remediation project is also submitted to the authorities.

Radiation protection of the environment during and after mining is the purpose of Decree No 90-222 dated 9 March 1990.

This decree was drawn up on the basis of the French mining code, Euratom directives and the French decree concerning the general principles of protection against ionizing radiations itself based on the recommendations of the ICRP (International Commission on Radiological Protection) and the directives of the European Union. It was submitted for approval to the Central Service for Protection against Ionizing Radiations (Ministry of Health) and the General Council of Mines.

It forms the 'ionizing radiation' section of the RGIE (General Instructions for the Mining Industry).

V.1 Applicability

"The provisions of this section are applicable to workings, surface installations and legal ancillaries of facilities where radioactive substances are used" (Art. 2).

Concerning uranium, the decree only applies to products with a uranium content greater than 0.03% (Art. 8).

"A deposit must be the subject of surveillance by the operator throughout the duration of the work and afterwards until it is proved that its radiological impact on the environment is acceptable" (monitoring must last during one year minimum after closure of the site).

V.2 Criteria for radiological protection of the population

"Work must be carried out in such a manner that its radiological impact on the environment is as low as reasonably achievable, both while the facility is open and after its final closure" (Art. 3).

The annual individual dose to members of the public, must be less than 5 mSv.a-1, in addition to natural exposure (Art. 6 and 7). Therefore, mine operators must :

- identify the main radionuclides or forms of radiation liable to be released by the sources,
- identify the main pathways of transfer liable to lead to members of the critical group (in the immediate vicinity and/or on the site),
- continuously take readings by means of fixed stations in the transfer pathways and the surrounding region (to assess the natural levels),
- establish a reasonable exposure scenario,
- for internal exposure:
    - a rough estimate can be made by assuming that drinking water represents the only transfer pathway by ingestion and that most exposed individuals drink 2.2 liters of water per day, taken from the receiving water course immediately after dilution of releases (appendix Art. 7).
    - as for inhalation, an individual from the public is assumed to inhale 0.8 m^3 of air per hour (appendix Art. 6).

V.3 Release verification and environmental monitoring after closure of uranium mining sites

Administrative constraints are introduced concerning discharges. A monitoring network is prescribed to ascertain any possible environmental contamination.

After site closure, the following procedure must be carried out:

- Identify the transfer pathways which remain.
- Identify the characteristic parameters to be monitored.
- If water contaminated with radium-226 continues to be released (Art. 9):
    - the release of less than 740 Bq m^{-3} is authorized without treatment,
    - between 740 and 3700 Bq.m^{-3} no treatment is required in situ but there must be a dilution factor of at least 5 in the receiving waterway,
    - with more than 3700 Bq.m^{-3} treatment is compulsory.

- Measurements must be implemented to monitor the environment at frequencies corresponding to the size of the site and the results obtained (the main monitoring requirements are related to radium-226 and uranium in water, alpha energy potential and gamma dose in air).

"The radiological impact on the environment is acceptable if the annual exposure limits prescribed in the Article 6 (following) are not exceeded" (Appendix Art. 8).

According to Article 6, annual limits for added exposure are :

- 5 mSv for external exposure,

- 170 Bq for long lived alpha radionuclides coming from U-238 as suspended matter in the air,

- 2 mJ of alpha potential energy for short life decay products of radon-222 in the air which might be inhaled,

- 6 mJ of alpha potential energy for short lived decay products of radon-220 in air,

- 7 kBq for ingested radium-226,

- 2 g for ingested uranium; the daily quantity of ingested hexavalent components should not exceed 150 mg.

"The added total annual exposure rate (Taux Annuel d'Exposition Totale Ajoutée TAETA) of anybody among the public must be less than 1" (Art. 7).

V.4 The Added Total Annual Exposure Rate ATAER [or TAETA] is determined from the measurements in the neigbourhood of the site (with substraction of the natural background exposure) and from a realistic exposure scenario which is established for the population. This means that:

TAER (station):	Total annual exposure rate of a station near the site
TAER (B):	Total (natural) annual exposure rate measured in the general region or established from analogous sites.

ATAER = TAER (station) - TAER (B)
must be less than 1 (the value of 1 corresponds to an exposure of 5 mSv/a).

TAER is calculated using the following formula:

TAER = Gamma + PAE Rn-222 + PAE Rn-220 + IE dust + IE Ra-226 + IE U-238

[Respective values: 5mSv; 2 mJ; 6 mJ; 170 Bq alpha; 7000 Bq; 2 g]

where:

gamma	=	external exposure through gamma irradiation in mSv
PAE Rn-222	=	potential annual inhaled alpha energy from short lived decay
PAE Rn-220	=	products of Rn-220 and Rn-222 in mJ

IE dust	=	total activity of long lived alpha-emitters of the U-chain, present in the air in the form of dust or in suspension, inhaled annually, in Bq.
IE Ra-226	=	internal annual exposure by ingestion of Ra-226 (through water) in Bq.
IE U-238	=	internal annual exposure by ingestion of U-238 (through water) in grams.

VI. MONITORING

Geotechnical monitoring

During remediation, all the equipment necessary to assess the water level inside the residues and specially in the dykes is preserved. Measurements go on after remediation in order to ensure the normal evolution of the settlement and global stability.

Radiological monitoring

On site, measurements are made to assess the evolution of the quality of running water, seepage water from the tailings pile, underground and open pit waters as well as air quality.

Around the site, a network of stations give the measurements necessary to:

- give an evaluation of the exposure due to natural environment (background - this is necessary in the case of Ecarpière as no evaluation on site has been made before beginning of operations),

- give an evaluation of the added exposure due to the past industrial activity and the remediated storage,

- evaluate the impact of the site on the critical population for which a scenario is applied.

The network used during operation and remediation is usually kept for a while after the end of remediation.

According to the results, the license may later allow a reduction in the number of sampling site.

The network in the environment of the site comprises:

- 6 alpha integrated dosimeters to measure alpha potential energy due to long lived alpha emitters associated to a TLD, thermoluminescent detector, for gamma radiation. They are located in each village around the site.
- water sampling station upstream and downstream as well as on the final effluent,

Also, well water (twice a year), sediments in the river, soils in gardens and the associated plants, milk, wine, fish... (food chain) are sampled once a year.

The main contribution to the added exposure is linked to air and water pathways which measures are given below. In this case, the exposure and ATAER (Added Total Annual Exposure Rate) of the critical group is evaluated with the following parameters:

- annual residence time: 7000 hours,
- standard breathing rate: 0.8 $m^3.h^{-1}$
- daily amount of ingested water: 2.2 liters of the downstream water.

This figure includes water ingested through food consumption.

	AIR PATHWAY				WATER PATHWAY			
	EXT. EXP	INTERNAL EXPOSURE						
	Gamma ray $nGy.h^{-1}$	Rn-220 $nJ.m^{-3}$	Rn-222 $nJ.m^{-3}$	Dust $Bq.m^{-3}$	Ra-226 $Bq.l^{-1}$	U-238 $mg.l^{-1}$	ATER	ATAER
Average 6 st 1994	170	16	44	1	0.07	0.1	0.46	0.12
Background	120	13	29	1	0.05	0.1	0.34	

According to evaluation of the exposure due to the background, the ATAER is 0.12, well below the limit prescribed by French regulation.

The first results of radiological monitoring on the remediated pond are:

External exposure: 120 $nGy.h^{-1}$
P A E Rn-222: 20-40 $nJ.m^{-3}$
P A E Rn-220: 16-20 $nJ.m^{-3}$
Dust: <1 $Bq.m^{-3}$
Water Ra-226: 0.05 $Bq.l^{-1}$
U-238: <0.1 $mg.1^{-1}$

ATER = 0.35, the exposure on the site is equivalent to the background.

VII. CONCLUSION

Ecarpière has been an important mill operated by COGEMA; its remediation has been under way since the end of operation in 1991.

The main conclusions of the studies are:

- Hydrological studies demonstrate the impoundment is isolated from the environment.

- Leaching tests show that radium is confined in the tailings pile.

- Petrographic observations concluded that a real diagenesis is already underway: mill tailings are not fixed entities and natural evolution enhance chemical confinement.

The cover on the impoundment protects from erosion and infiltration. The resulting radiological impact is very close to that of background condition.

The drying of tailings is continuing and seepage waters are collected for treatment. The site around the impoundment is clean and can be used for new activities without liabilities.

GERMANY

BERGBAUBETRIEB KÖNIGSTEIN, SAXONY

NAME
Bergbaubetrieb Konigstein

OPERATOR
The owner and operator of the 1964 built facility was the SDAG WISMUT, the Soviet/East-German Uranium Mining and Milling Company. Uranium production ceased in 1990. Since then the government owned WISMUT GmbH has performed environmental remedial activities.

LOCATION
The mine is located in the State of Saxony at latitude of 51° North and longitude of 14° East, 10 km to the Southeast of the town of Pirna (see Figure 1).

APPROXIMATE SIZE
Total area of the site: 144 ha; area of plant plus mine facilities: 118 ha, waste dump 24 ha; water and sludge ponds 2.3 ha. The mined area (underground) is about 4.5 km × 1.5 km down to a depth of about 300 m. The maximum thickness of the ore body is 20 m.

AGE OF OPERATION
Conventional underground mining started in 1964. From the beginning of the 1970s, in situ leaching experiments were conducted. Since 1984, uranium has been produced only by in situ leaching. Uranium production stopped in 1990. Now environmental remediation is conducted.

CLIMATE
The mean annual precipitation is 66 cm and the mean temperature 8° C.

DEMOGRAPHICS
Within a distance of 10 km from the mining facility there are villages with a total population of about 25 000 inhabitants and the town of Pirna with a population of about 50 000.

ORE BODY TYPE
The sandstone/type ore body had an average ore grade of about 530 ppm.

OPERATIONAL DATA
The Königstein mine produced a total of 18 000 t U, about 12 000 t U by conventional underground mining and 6000 t U by in situ leaching.

TOPOGRAPHY AND ALTITUDE
The mine site is located at an elevation of about 300 m above sea level at the margins of a the National Park 'Sächsiche Schweiz', about 2.5 km to the southwest of the river Elbe (0.6 km shortest underground distance to the river).

HYDROGEOLOGY
In the area around Königstein there are four aquifers (see Figure 2). All aquifers are used for drinking water supply, the fourth aquifer, however, only at some distance to the mine site.

The main drinking water resource is the third aquifer. Due to mine dewatering there is no aquifer contamination now. Groundwater contamination will occur as a result of flooding of the mine.

HYDROLOGY

Mine water and part of the neutralized and treated acidic leaching solution is released to the river Elbe and is diluted by an average Elbe flow of about 320 m^3/s. Both the third and fourth aquifer are in contact with the river Elbe.

DESCRIPTION OF REMEDIAL ACTIONS

With respect to groundwater protection the in situ leaching operation has been reduced stepwise, controlled by the water treatment capacity to guarantee the release water quality. The remedial actions are focused on about $1.9 \times 10^{+6}$ m^3 of acidic leaching solution that is still contained in the leaching circuit and in the rock pore volume within the ore body. In order to prepare the strictly controlled stepwise mine flooding, mine openings cross-cutting the third and fourth aquifer have to be sealed. These measures should protect the third aquifer (major drinking water supply) from contamination. The remedial actions also include demolition of the mine facility, remediation of land used by mining activities and covering the rock pile that also contains water treatment residues (sludge).

TECHNIQUES USED

The stepwise controlled flooding of the mine in conjunction with an effective water treatment (in order to reduce the concentration of groundwater contaminants) should restore the fourth groundwater aquifer, avoiding unacceptable contamination of the third aquifer. The pile cover will reduce the radon exhalation and water infiltration.

REGULATIONS AND OBJECTIVES

The legal framework for the decommissioning and rehabilitation work is defined in a number of laws and regulations. One of them is the Wismut Act, through which the legislature has charged WISMUT GmbH to shut down the former mines and to rehabilitate the associated sites. Other regulations concerning the Wismut project include The Federal Mining Law, The Atomic Energy Act, The Federal Emission Protection Law, The Environmental Liability Act, Legislation for radiation protection in the former GDR (carried over by reunification agreement for uranium mine rehabilitation in Eastern Germany) and The Radiological Protection Ordinance. In addition, the German Commission on Radiological Protection has issued a number of recommendations on radiological protection principles to be used for release of contaminated areas, waste rock piles, structures and materials originating from uranium mining. The main idea of these recommendations is to limit the additional individual effective dose of the population. This should not exceed natural background doses by more than 1 mSv/a. The parameters, used in the calculation of radiation doses have to be chosen as realistic as possible, but still conservative enough to cover the actual situations that are expected to occur in reality.

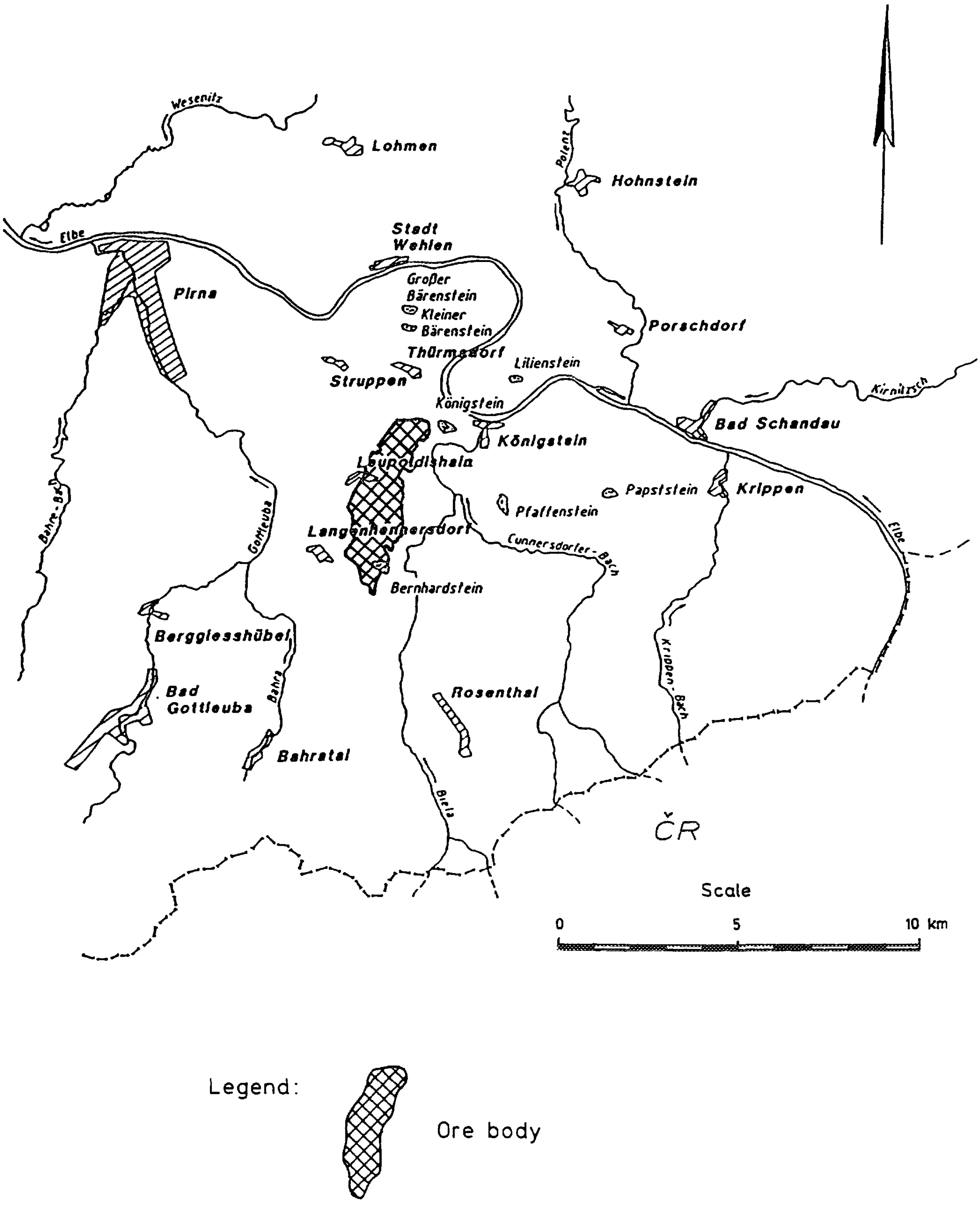

FIG. 1. Location of the Königstein deposit (10 km southeast of Pirna in the State of Saxony).

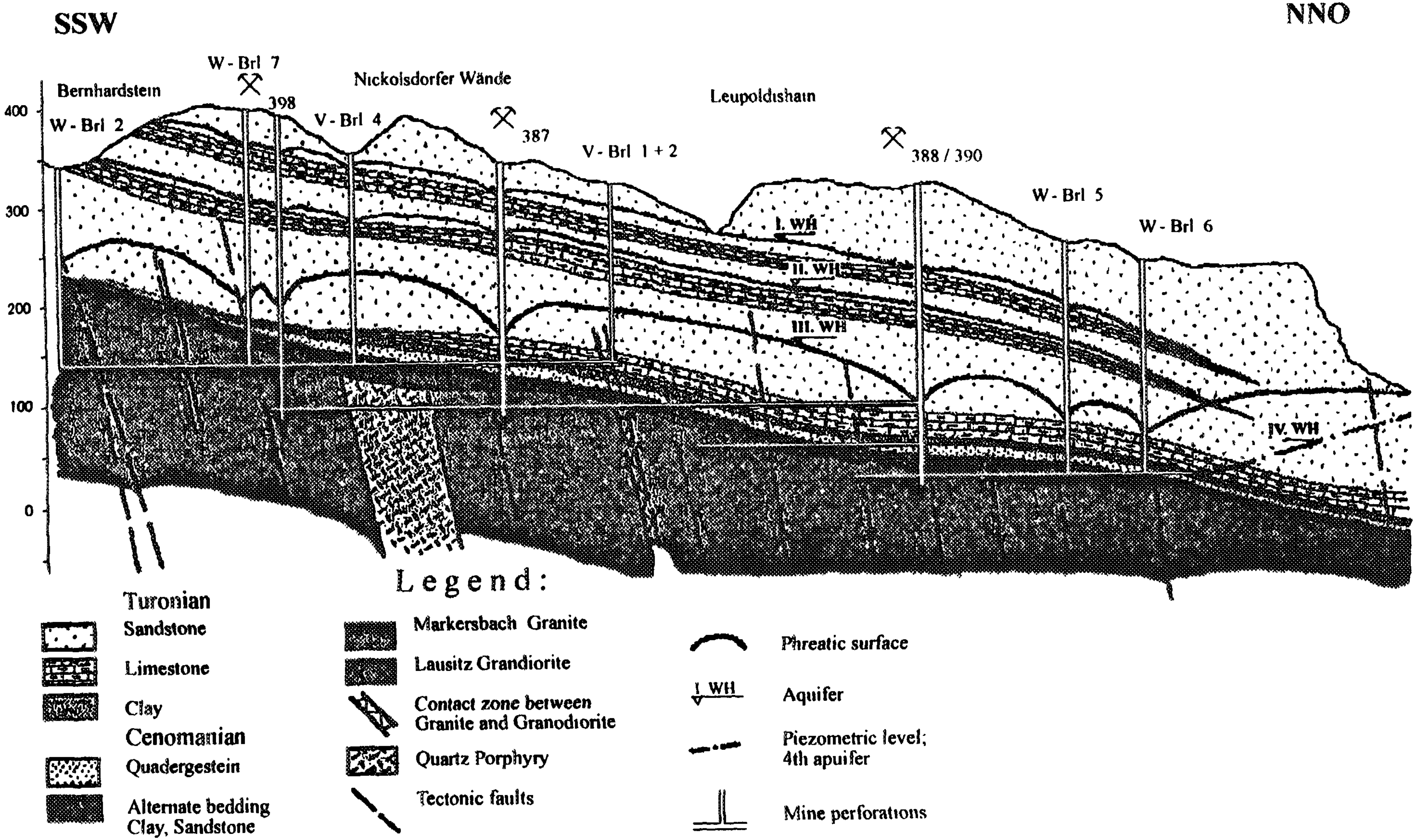

FIG. 2. Geological profile of the Königstein deposit.

SPAIN

PART 1. ANDUJAR URANIUM MILL

TYPE

The Andujar Uranium Mill Plant was operated from 1959 to 1981, producing uranium concentrate (yellow cake) from ore extracted from 24 mines within a 400-kilometers distance from the site. The Andujar Plant was designed for processing low grade uranium ore (0.15% U_3O_8) and produced 80% concentrate of U_3O_8 in form of sodium and ammonium uranate at a rate of 60-80 t/a. A total of 1.2 $\times$ 10^6 t of uranium ore was processed to produce 1350 t of U_3O_8 with a fineness of 80-85%.

STATUS

The mill site has been remediated by the Empresa Nacional de Residuos Radiactivos, S.A. (ENRESA).

The characteristics of the remediated site are as follows:

Site:	25.4 hectares
Pile:	14.3 hectares
Off-pile:	11.1 hectares
Tailings:	980 000 m^3
Demolitions debris:	22 000 m^3
Dismantling metal products:	180 m^3
Container cages:	400
Concrete slabs:	1240 m^3
Cover system:	445 000 m^3

Restoration of the site consists of planting native plant species in the area of pile and 1710 trees and shrubs on the rest of the site.

DESCRIPTION

The Andujar Uranium Milling Site is in the province of Jaen (Andalucia) on the southern flood plain of the Guadalquivir river 1500 km south from the urban center of Andujar (36 000 inhabitants). The site was trapezoidal in shape, covered an area of approximately 17.5 hectares and was contained within a peripheral wall, which was about 150 m from the course of the river. The Andujar mill site included the following areas: the tailings pile, the processing plant, the waste water treatment area, the auxiliary and administrative buildings and the housing area. All solid waste generated during the operation of the plant was contained in a tailings pile, which covered an area of 9.4 hectares and had a total volume of about one million cubic metres. The pile was constructed to a height of 20 m in the central and eastern parts and to a height of 10 m in the western part.

ENGINEERING FEATURES

The final pile configuration has been designed to minimize the movement of tailings and the size of the restricted disposal area. The pile was constructed with 4% top slopes and 20% side slopes, providing sufficient static and dynamic slope stability without requiring excessively large rocks to resist erosion. Protection against upland watershed runoff was provided by channelling runoff and away from the pile via drainage diversions walls along the perimeter of the pile. Protection against floods associated with the Guadalquivir river was provided by a rock apron around the perimeter of the pile and riprap layers on the sideslopes. The pile was covered with a multilayer system to meet the three simultaneous demands of erosion control, infiltration and radon control. The top slope cover consists of, from top down, a 500 mm vegetation growth and desiccation protection zone of random soil; a 250 mm filters of clean sand; a 300 mm biointrusion barrier of coarse rock; a 250 mm drawn of clean sand; and a 600 mm radon an infiltration barrier of silty clay. The most significant benefits of this cover are its ability to deal effectively with vegetation and to reduce infiltration to the cell because of effective evapotranspiration. From top down, the sideslope covers consist of 30 mm of soil to migrate into the rock and help support vegetation; a 300 mm erosion barrier of coarse rock-soil matrix; a 500 mm vegetation growth and desiccation protection zone of random soil; a 250 mm filter of clean sand; a 300 mm biointrusion barrier of large rocks; a 250 mm drain of clean sand; and a 600 mm radon and infiltration barrier of silty clay. The advantages of this cover include protection of the radon infiltration barrier from desiccation and the existence of a controlled zone (the random soil) for vegetation that might establish through the riprap and help reduce the visual impact of the remediated pile.

Decommissioning of mill facilities and buildings involved the dismantling of the equipment and process facilities, the demolition of the buildings, the reduction of metal wastes and demolition debris to manageable pieces, the cementation of the metal wastes and the disposal of dismantling and demolition wastes in the tailings pile. The major activities involved were decontamination/cleanup, dismounting and cutting of the equipment, demolition of structures, transportation of debris to the tailings pile and confinement in a cement matrix. Special containers were used to facilitate handling, transportation and cementation of the metal wastes. Cementation proved to be a cost-effective operation and provided a more stable structure to the wastes than the conventional alternative of mixing and compacting with the tailings.

The remedial action activities started in February 1991 and were completed in June 1994.

RADIONUCLIDE CONTENT

The total activated contained in the tailings is estimated at 2×10^{14} Bq (5400 Ci) and radium measurements indicate and average radium concentration of 10.8 Bq/g (292 ρCi/g). The average radon flux through bare tailings was 271.8 $\rho Ci/m^2/s$. Gamma exposures over the pile before remedial action ranged from 2.5 μSv/h to 5.2 μSv/h. In contrast, radiological characteristics at background locations near the site are 0.15 μSv/h. Average uranium activity in the tailing is 2Bq/g.

GEOLOGY/HYDROLOGY

The site overlies and alluvial aquifer of small thickness (less than 10 m thick) and great horizontal lithological variations, underlain by impervious marl. It is composed by a layer of gravel and sand of up to 5 m thicknesses at the bottom and a 1 to 3 m thick silt layers at the top. Permeabilities vary from 500 to 50 m/day.

Water levels range from 4 to more than 8 m below surface. The main source of recharge to the aquifer comes from rainfall infiltration in winter and surface water irrigation in the summer time. The highest groundwater levels occur in August, September and December. Saturated thickness varies from a few cm near the site to 6 m in the western part.

The main groundwater flow direction is to the northwest, towards the River Guadalquivir. However, locally, flow direction may be diverted from the main direction by buried stream channels and the topography of the impervious basement. Hydraulic gradients vary from 0.004 to 0.0004.

CLIMATOLOGY

The area enjoys a Mediterranean climate, with mild winters and hot summers. It is located at an altitude of 200 m above sea level. Most of the precipitation falls between October and April. From 1983 to 1992, the average rainfall was 465 mm/a with a standard deviation of 109 mm/a. The average temperature has been 16°C.

LAND AND WATER USE

The site is surrounded by an industrial area to the north and northwest and agricultural land to the south and west. Most of the water used in the industries comes from the public water supply system. Most of the agricultural land is dedicated to cotton, sunflowers, beets and orchards. They are irrigated with surface water from the River Guadalquivir by means of an irrigation system that crisscrosses the area.

LEGISLATION (OBJECTIVES AND DESIGN CRITERIA)

Primary objectives for the Andujar mill site were the following:

- Dispersion and stabilization control, to ensure confinement and long-term stability of tailings and contaminated materials.

- Erosion control to prevent surface water contamination and ensure long-term integrity of the closed out facility.

- Radon control to reduce radon emissions.

- Groundwater protection to prevent groundwater contamination by rainfall waters infiltrating into the tailings.

Design criteria used for the remediation activities were as follows:

- Dispersion control: Prevent inadvertent human intrusion and dispersion of contaminated materials by wind and water erosion.

- Long term radiation protection: Achieve an effective equivalent dose to the individual in the critical group below 0.1 mSv/a.

- Design life: Remain stable for 1000 years to the extent reasonably achievable and in any case for at least 200 years.

- Soil cleanup: Reduce the residual concentration of radium-226 in land, averaged over an area of 100 m^2, so that the background level is not exceeded by more than 185 mBq/g (5 ρCi/g) (averaged over the first 15 cm soil) and is less than 555 Bq/g (15 ρCi/g) (averaged over 15 cm thick layers of soil more than 15 cm below the surface).

- Radon control: Reduce radon flux over the surface of the final pile to an average release rate of less than 740 mBq/m^2/s (20 ρCi/m^2/s).

- Groundwater quality protection: Control groundwater contamination so that backgroundwater quality or maximum concentration levels (in accordance with Spanish regulations and CSN guidelines for radioactive constituents) are achieved in the long term. These maximum levels are: combined radium-226 and radium-228 0.18 Bq/L (4.86 ρCi/L), combined uranium-234 and uranium-238 1.2 Bq/L (32.4 ρCi/L) and gross alpha activity, excluding radon and uranium, 0.5 Bq/L (13.5 pCi/L).

- Long term maintenance: Minimize the need for long term maintenance.

- Construction works: Minimize hazards to the workers and the environment.

- Regulations: Comply with other applicable and relevant Spanish regulations governing air and water quality in non radiological aspects.

With regard to groundwater quality protection, it is also required that for short-term conditions the cover system be designed to limit infiltration to ensure that, at the end of the compliance period (minimum 10 years), the combined uranium-234 and uranium-238 concentration in groundwater complies with the two following conditions:

- Be less than 6.15 Bq/L (166 ρCi/L) at the point of compliance, at the downgradient boundary of the disposal site.
- Be less than 3.5 Bq/L (94.5 ρCi/L) at the wells in the vicinity of the site.

In addition to the above design standards, a performance standard has been established for Andujar: groundwater quality must be monitored during the compliance period (minimum 10 years) to confirm adequate performance of the cover and compliance with the maximum concentration limits established for short term conditions.

Name of facility	Fabrica de Uranio de Andújar
Operator	Junta de Enegía Nuclear
Location	Andújar (province of Jaen)
Country	SPAIN
Approximate size	The Andujar Plant was designed for processing low grade uranium ore (0.15% U_3O_8) and produced 80% concentrated at a rate of 60-80 t/a
Age (a) of operation (from start up, through closedown or remediation complete, if applicable)	Period of Operation: 1959-1981 Period of remedial activities: 1991-1994
Climate	Mediterranean climate. Mild winters and hot summers. Average rainfall: 465 mm/a Average temperature: 16°C
Nearby population (Size and distribution relative to the site, distance, land use in the near-by vicinity, etc.)	At 1500 m south from the urban center of Andujar (36 000 inhabitants). The site is surrounded by an industrial area (north and northwest) and agricultural land (south and west). Most of the water used in the industries comes from the public water supply system. Most of the agricultural land is dedicated to cotton sunflowers beets and orchards. They are irrigated with surface waters from the Guadalquivir river by means of an irrigation system that crisscrosses the area.
Ore body type: Unconformity-related/sandstone/vein/etc Monometallic/poly metallic (list other metals mined)	Granitic or metamorphic rocks From 1962 to 1967, 4214 t of copper were produced also

OPERATIONAL DATA

	Waste rock types		Mill tailings		Heap leached waste	
Quantity (metric ton)			1 220 000 t			
Acid generating	Yes	No	Yes	No	Yes	No
Remediation technique for acid wastes						
Size	1 220 000 t of ore produced 1350 t U_3O_8					
Use	Fuel element for NPP					

Topography and altitude (m)	Flat plain 200 m above sea level
Hydrogeology: **Aquifer:** **Type (e.g. localized, regional, etc)**	The site overlies an alluvial aquifer (localized) of small thickness (less than 10 m thick) and great horizontal lithological variations underlain by impervious marl

Hydrology:	
Distance to nearest significant drainage channel (m or km)	150 m (Guadalquivir river)
Water flowrate volumes (m^3)/continuity	Average flowrate in Guadalquivir river: 50 m^3/s
Water quality, level/pH upstream	
Water quality, upstream/downstream impacts	No impacts
Description of remedial measures	Stabilizing and consolidating the uranium mill tailings and contaminated materials on site by flattening the sideslopes to improve stability. Mill equipment, buildings and process facilities were dismantled and demolished and placed in the tailings pile. The pile was covered with a multilayer system.

Techniques used	STABILIZATION OF TAILINGS PILE Excavation of the tailings was performed using a backhole which loaded into a dump truck. Because of their wet nature, tailings were then taken to moisture-conditioning areas where they were spread and disced until a specified moisture content was achieved. Tailings were then taken back to the pile and compacted to a minimum of 90% of the standard Proctor density at a moisture content below optimum. During tailings relocation, pockets of sand tailings adjacent to the sideslopes were mixed with slimes and compacted to produce a more homogeneous material less susceptible to liquefaction. Demolition debris were placed in the lower part of the pile, compacted to a minimum of 90% of the standard Proctor density and surrounded with compacted tailings.
	Dust generated by excavation, earth movement, vehicle use, stockpiling and similar activities were controlled and minimized by the use of water and water-based surfactants sprayed from hoses or trucks. Sources of dust suppression water included water from the wastewater retention basic, runoff and uncontaminated water. DECOMMISSIONING OF MILL FACILITIES In order to avoid contamination to the workers in charge of the works of dismantling, a decontamination and cleaning phase was achieved using pressurized-water jetting to remove the loose contamination from equipment and materials. Ducts and tanks were emptied of contents and inside crusts and residues were removed with pneumatic hammers and manual scrapers to the extent required to permit removal and dismantling. Rubber liners were eliminated from the tanks prior cutting in order to prevent fire risks. All effluents from the cleaning phase were collected and taken to the treatment system prior to their discharge to the river. Pipes and ducks were cut by a shuttle saw, tanks and vessels were cut by torch and flattened. Light equipment and tin plates were compacted and reduced in volume using a truck-mounted mobile press. The dismantling wastes were placed in cages which were constructed out of structural steel from roofing demolition. The cages were filled manually with cement. DEMOLITION Demolitions works were performed by mechanical methods (impact, thrust, pressure) with the exception of an elevated water tank which was demolished by control blasting. Dust control was achieved by spraying water over buildings during the demolition works.
Regulations	USAEPA criteria and specific spanish regulations

Objectives	- Ensure confinement and long-term stabilizing - Erosion control to prevent surface water contamination - Reduce radon emissions - Groundwater protection to prevent groundwater contamination by rainfall waters infiltrating into the tailings
Criteria for success	See RADIOLOGICAL CONSIDERATIONS
Lessons learned	Development of technologies for remediation of contaminated sites

SPAIN

PART 2. PREVIOUSLY OPERATED URANIUM MINES

TYPE

The 24 abandoned uranium mines were developed by underground mining with the exception two sites which were operated by open-pit mining. Mining operations started around 1950 and were shutdown in 1976. Over that period about one million tons of mineral were extracted with an ore grade between 0.6‰ and 2.3‰. There is a great diversity among the mines, in terms of site conditions, mining methods and magnitude of operations. Whereas in some sites there is little trace of the mining works, in other sites large excavations, mining debris piles, abandoned shaft and galleries, and remainings of surface structures and equipment are encountered.

STATUS

The abandoned uranium mines are located in the southwest of Spain (provinces of Badajoz, Córdoba and Jaen) within 400 km from the Andujar mill. For those sites associated with underground mining, the primary disturbed areas include mining debris and waste rock piles, mine openings (shafts and galleries) and depressed areas, and left over surface structures or equipment which were used during the mining operations. For those sites associated with open-pit mining, the following disturbed areas are in place: open-pits (in some cases holding contaminated water), waste rock piles and foundation (construction debris).

DESCRIPTION

For a description of old mines see 'STATUS'.

ENGINEERING FEATURES

To achieve the design objectives and criteria, remediation plans were developed for the underground as well as the open pit mines. Basic closeout activities for the underground mines included: sealing of shafts and adits, sealing of mine openings, demolition of surface structures, stabilization of waste rock piles, placement of a vegetated cover and site restoration.

All mine shafts and adits will be filled with waste rock, demolition debris and, if necessary, other suitable material to ensure long-term stability of the close-out mines and control surface subsidence. The subsidence resulting from the collapse of abandoned mine workings can result in physical hazards to humans living in the area and could also lead to the creation of new pathways for migration of pollutants from the mine. Entrances to primary shafts, adits exist and other openings will be filled with solid non-shrinking concrete keyed into solid rock to control intrusion by humans. The demolition of the surface structures will be performed to ensure the site will be safe, discourage people from living close to the mining area and return the site to an appearance similar to the surrounding environment. Demolition debris will be used for filling mine shafts or will be buried within the waste dumps. Waste rock piles will be graded to stabilize sideslopes and improve drainage. A soil cover will be placed over the piles to limit radon emanation, infiltration and gamma radiation and control intrusion, dust and erosion. The remediated piles will then be revegetated to improve aesthetics and achieve integration into the landscape. Contaminated soils will be removed and will be buried within the waste rock dumps. Finally, all disturbed areas will be graded, reshaped and vegetated to mitigate geomorphic impacts and restore the site.

The basic remediation plan for the open pit mines involved: disposal of waste rock/mining debris in the open-pit, dewatering of the open-pit and treatment of the contaminated waters, demolition of surface structures, clean-up of contaminated soils and site restoration. The open pit will be filled with waste rock demolition debris and contaminated soils. This minimizes the volume of waste remaining on the surface. Dewatering will be required to consolidate the disposed residues. Contaminated waters will be either evaporated or treated 'in situ' and resulting sludges will be disposed in the open-pit. A vegetated cover will be placed over the filled-in pit to control radon emanation, erosion and water infiltration and will then be contoured to simulate the original topography. Demolition, cleanup and site restoration activities will be undertaken in a similar fashion to the underground mines.

RADIONUCLIDE CONTENT

In the old mines ^{226}Ra concentration range from 3.7 Bq/g (100 ρCi/g) to 9.25 Bq/g (250 ρCi/g) and the contact rates of radiation range from 0.5 μSv/h to 2.5 μSv/h, with background contact values on nearby sites of 0.45 μSv/h. The alpha concentration in mines ground-water are less than 0.1 Bq/L (2.7 ρCi/L) with the exception two sites.

THE SITES/ENVIRONMENT

Population density around the mining regions is very low (generally below 30 inhabitants/km^2) and the closest residences to the mines are about 2 km distant. Land use in the area is mainly agricultural including farming and cattle raising. The climate is continental with dry and warm summers and cold winters. Annual precipitation ranges from 542 mm/a to 1059 mm/a and occurs mainly during the fall and winter seasons. Annual potential evapotranspiration varies from 675 to 925 mm/a and about 50% occurs from May through September. All sites lie on granitic or metamorphic rocks, where groundwater flow takes place through the fractures with a very low permeability. Landscape around the sites is smooth and undulating and the natural vegetation consists of holm oaks with brushwood and some grass.

LEGISLATION (OBJECTIVES AND DESIGN CRITERIA)

Primary objectives for mine remediation were the following:

- Minimize risks to the public health and the environment.
- Prevent inadvertent intrusion into mines and waste rock piles.
- Restore the mining sites to simulate initial conditions as closely as possible.

Standards or design criteria which must be achieved in the remediation were less prescriptive than for the mill site, reflecting the lower level of radiological risks associated with the mines. These criteria may be summarized as follows:

- Dispersion and intrusion control: prevent inadvertent human intrusion into mines and dispersion of mining debris.

- Radon control: reduce radon flux and radon concentration over the site to background levels.

- Radiation control: reduce gamma radiation to background levels.

- Stabilization control: ensure long term stability of waste rock piles, open-pits and mine workings.

- Water quality protection: minimize contact between water and waste rock piles and prevent access to mine waters.

- Restoration: restore disturbed areas, mitigate environmental impacts and integrate the remediated site into the landscape.

- Construction works: minimize hazards to the workers and the environment.

Name of facility	Several names
Operator	Junta de Energía Nuclear
Location	Provinces of Badajoz, Córdoba and Jaen
Country	SPAIN
Approximate size	From 20 000 t to 200 000 t of uranium ore
Age(a) of operation (from start up, through closedown or remediation complete, if applicable)	Period of operation: 1950-1976
Climate	Continental climate with dry and warm summers and cold winters. Annual precipitation ranges from 542 mm/a to 1059 mm/a
Nearby population (Size and distribution relative to the site, distance, land use in the near-by vicinity, etc.)	Population density around the mining regions is generally below 30 inhabitants/km^3 and the closest residences to the mines are about 2 km distant. Land use in the areas is mainly agricultural including farming and cattle raising.
Ore body type: Unconformity-related/sandstone/vein/etc Monometallic/poly metallic (list other metals mined)	Granitic and metamorphic rocks

OPERATIONAL DATA

	Waste rock types		Mill tailings		Heap leached waste	
Quantity (metric ton)	From a few to 70 000 t					
Acid generating	Yes	No	Yes	No	Yes	No
Remediation technique for acid wastes						
Size	All mines: 1 220 000 t of ore					
Use	Ore extracted for processing at Andujar Mill Plant					

Topography and altitude (m)	Landscape around the sites is smooth
Hydrogeology: **Aquifer:** **Type (e.g. localized, regional, etc)**	Groundwater flow takes place through the fractures with a very low permeability

Hydrology: **Distance to nearest significant drainage channel (m or km)** **Water flowrate volumes (m^3)/continuity** **Water quality, level/pH upstream** **Water quality, upstream/downstream impacts**	No rivers near the mines
Description of remedial measures	For the underground mines: sealing of shafts and adits, sealing of mine openings, demolition of surface structures, stabilization of waste rock piles, placement of a vegetated cover and site restoration. For the open-pit mines: disposal of waste rock/mining debris in the open pit, dewatering of the open pit and treatment of contaminated waters, clean-up of contaminated soils and site restoration.
Techniques used	
Regulations	Specific Spanish regulations
Objectives	- Minimize risks - Prevent inadverting intrusion - Restore the mining sites to simulate initial conditions as closely as possible
Criteria for success	See RADIOLOGICAL CONSIDERATIONS
Lessons learned	

UNITED STATES OF AMERICA

PART 1. GREEN RIVER URANIUM PLANT (MILL)

This summary provides information on the decommissioning and closeout of the uranium milling facility in Green River, Utah by the US Department of Energy UMTRA (Uranium Mill Tailings Remedial Action) Project. In addition to items (1) through (18) below, Figures 1-6 provide details on the location, characteristics and conditions of this facility.

NAME OF FACILITY
Green River Uranium Plant

OPERATOR
The owner and operator of the uranium mill was the Union Carbide Corporation which built the mill in 1957 and operated it from 1958 through 1961. In 1986, DOE took control of the site and performed environmental remedial action. The facility was closed out in 1991.

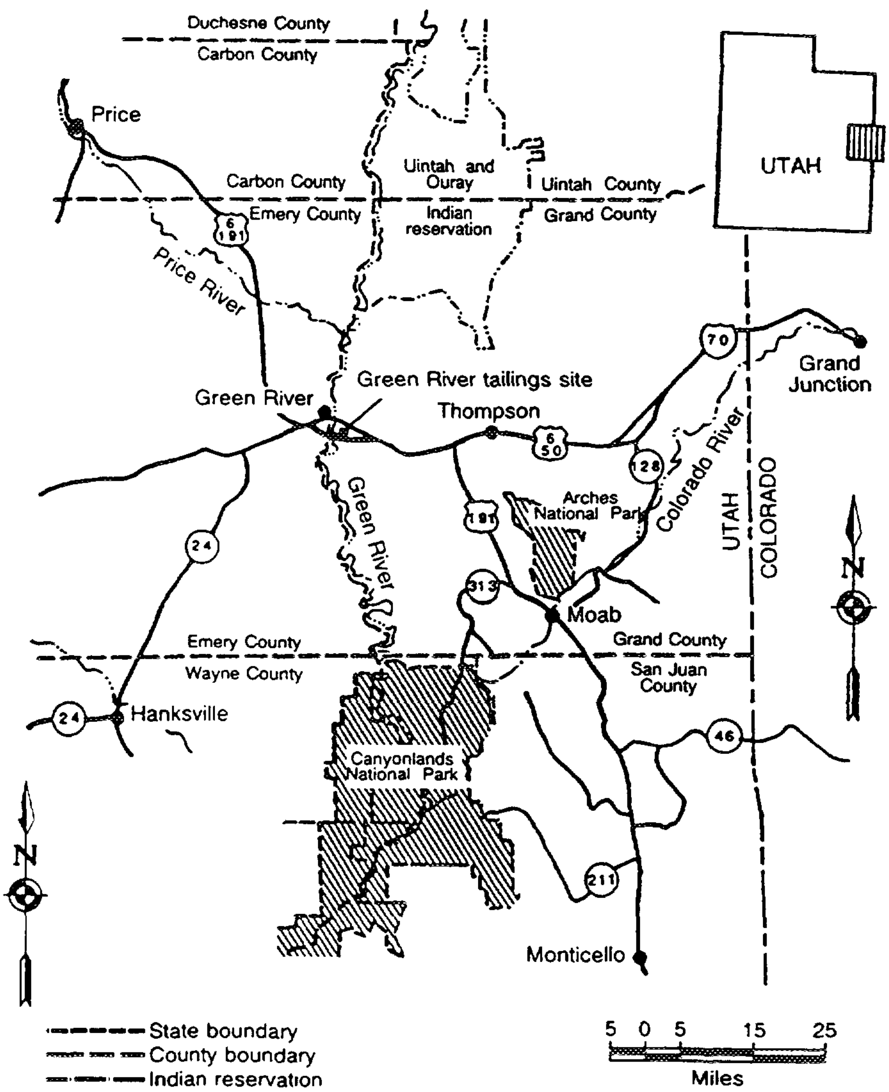

FIG. 1. Location of the Green River, Utah, tailings site.

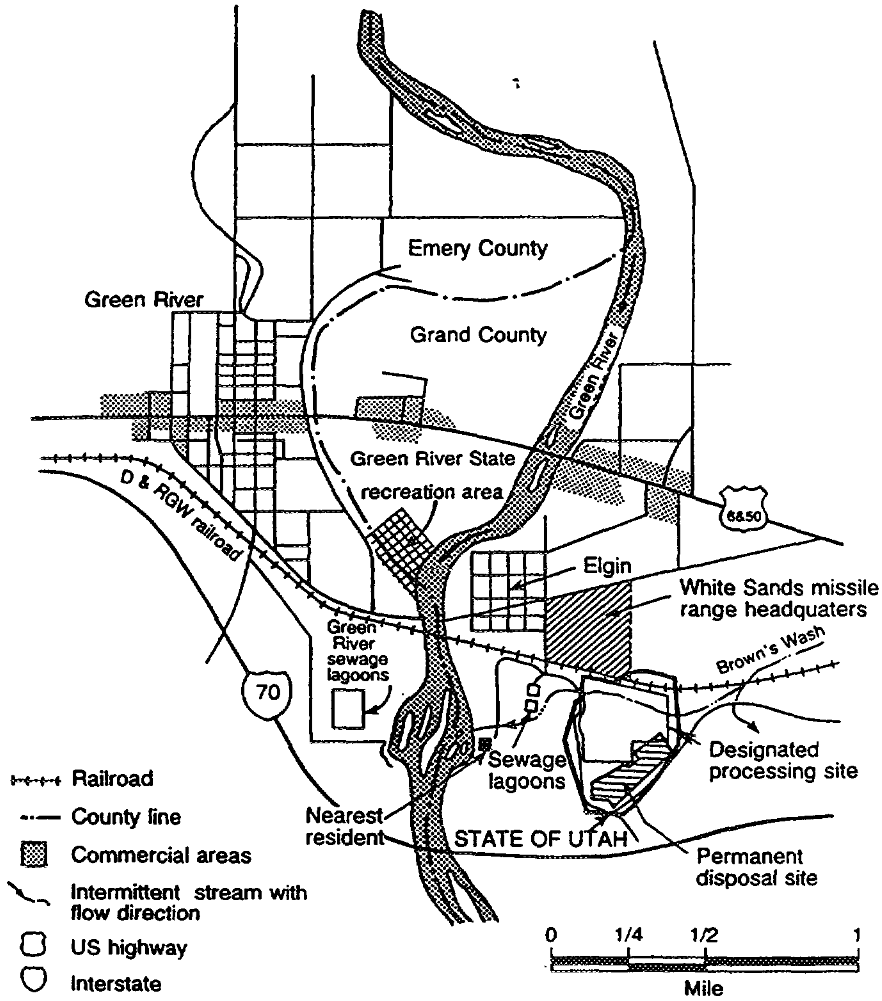

FIG. 2. Details of the Green River, Utah, disposal site area.

LOCATION

The Green River mill and disposal cell sites are located approximately 1.6 km to the southeast of the city of Green River, Utah in Grand County (see Figures 1 and 2), at a latitude of 38°59'59'' North and longitude of 110°08'20''.

APPROXIMATE SIZE

The fenced Mill Site area was 18.2 ha, with a related tailings pond size of 3.2 ha. The completed disposal cell and controlled areas are 1.1 and 3 ha respectively.

AGE (yr) OF OPERATION

The mill was constructed in 1957 and operated from 1958 through 1961. It was abandoned (but still owned by the original operator) through 1986, when the State of Utah took possession at the request of the federal Government. While the DOE performed environmental restoration (1987-1990), the site was under the control of the federal Government.

CLIMATE

The climate is arid with wide ranges in daily and annual temperatures.

(a) Precipitation: The average annual precipitation is 15 cm and the average snowfall is 25 cm. The average annual evaporation total is 150 cm. Rainfall is fairly evenly distributed throughout the year with slightly higher amounts in August and September. Summer rains typically result from thunderstorms which are limited in extent. The maximum snowfall occurs in January.

(b) Temperature: Annual temperatures average 11 °C, with a range from -5 °C in January to 25 °C in July. Temperature extremes have reached -32 °C and +42 °C.

DEMOGRAPHICS

Land use in and immediately adjacent to the city of Green River are primarily residential, agricultural and commercial. About 80% of the land in the area is owned by the federal government, 13% by the State of Utah, and 7% is privately owned. The primary land use is irrigated cropland: 876 ha; pastureland: 184 ha; and residential area: 160 ha. Historically, the population presence was related to uranium mining and milling activity. Population levels declined beginning in 1980 as a result of decreasing energy minerals exploration and development. In 1986, the population of Green River was 850.

ORE BODY TYPE

There were no nearby ore bodies close to the Green River Mill. It was situated close to a perennial river and transportation corridors. The mill processed ores from many small mines within 100 km of the central location at Green River. The ore was found mostly as loosely cemented sandstone (with clay and asphaltic material). The uranium was associated with the carbonaceous matrix. The overall milling grade averaged 0.29% uranium by weight.

OPERATIONAL DATA

About 166 000 tons of uranium ore were processed over the mill's 3-year life span. After crushing and grinding, the ore was screened and processed by flotation to form a carbonaceous concentrate. The flotation tailings were separated in sand and slime fractions. The sands were then leached with sulfuric acid, with the leached slurry washed and spent sands discarded to the tailings area. The recovered slimes and pregnant solution were then rejoined with the initial slime fraction. Any excess acid was neutralized with ammonia. The mixed product was then dewatered and dried for rail shipment to Union Carbide's uranium mill in Rifle, Colorado (about 200 km to the east) for further processing.

In 1959, a flash flood breached the tailings dam, and about half of the tailings present at the time were washed down a local creek bed (Brown's Wash). The total tailings remaining in the pile when the mill was abandoned in 1961 was 140 000 tons contained in about 87 000 cubic meters covering 3.2 ha. There was no attempt (until DOE's restoration in 1987) to recover the tailings which were washed out in 1959. There were no mine waste rocks brought to the mill site or heap leach piles used during operation.

TOPOGRAPHY AND ALTITUDE

The mill and disposal sites are located in the Gunnison Valley, approximately 0.8 km east of the Green River, at an elevation of 1244 m above mean sea level. The valley is bordered to the north by the Book Cliffs, which rise to 1950 m high and to the south by the cliffs and mesas of the Green River. Vegetation is sparse (virtually non-existent) except along the wet lands near the river. The sites are located in the northern part of the Canyon Lands section of the Colorado Plateau physiographic province. The Colorado Plateau is a major tectonic block comprised of Paleozoic and Mesozoic sedimentary rocks underlain by a core of Precambrian rocks that lie across the states of Utah, Arizona, New Mexico and Colorado. The sites are located on a slope between an upper abandoned river terrace and the present floodplain of the Green River and its local tributary, Brown's Wash. The sites lie on Quaternary upper terrace deposits and floodplain alluvium and on Cretaceous Mancos shale and Dakota sandstone bedrock (see Fig. 3).

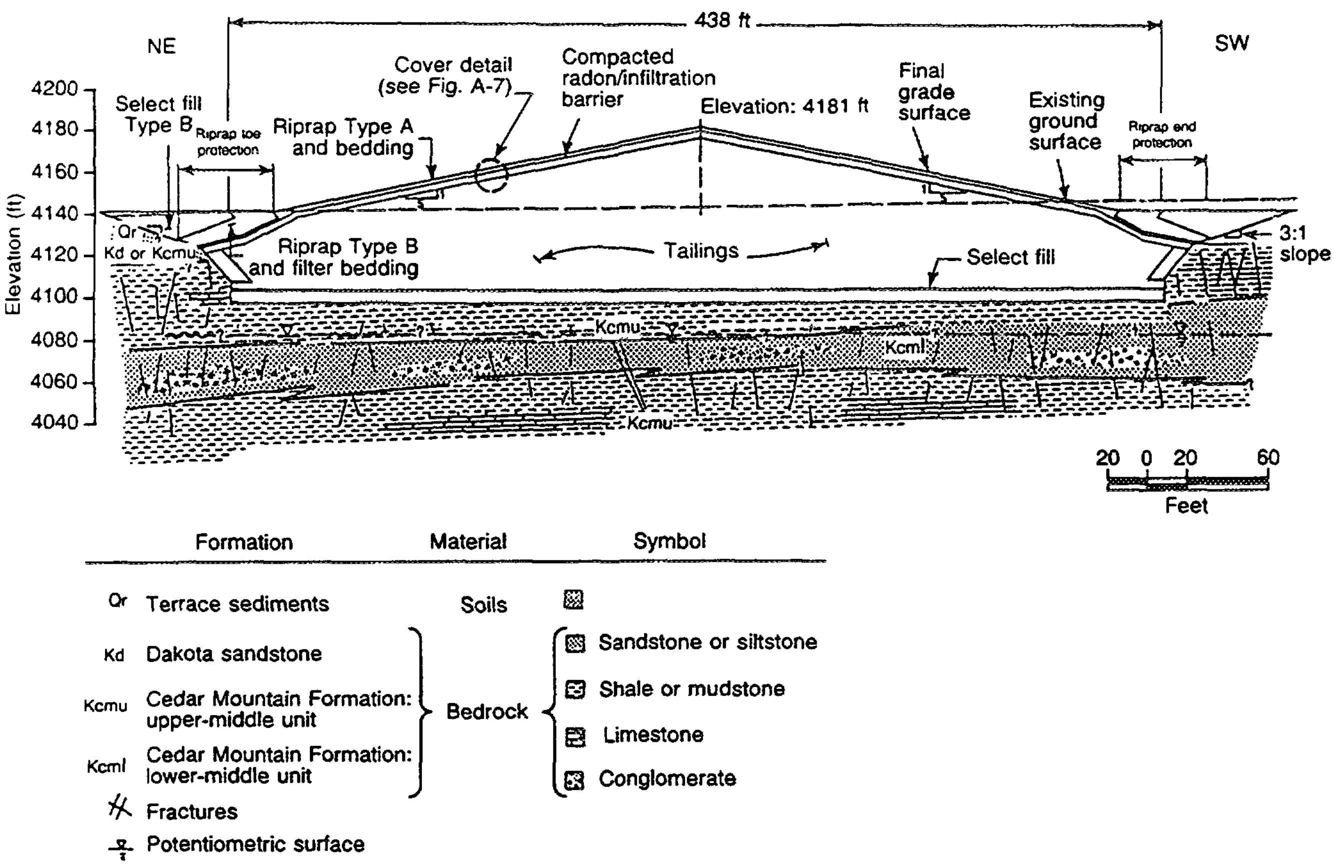

FIG. 3. Diagrammatic cross-section of disposal cell and foundation; Green River, Utah, disposal site.

HYDROGEOLOGY

Within the upper 60 m of the underlying Cretaceous and Quaternary sediments, there are four distinct water-bearing units. The upper shallow unconfined groundwater is present in Brown's Wash alluvium, and is limited by the lateral extent of the alluvium. Confined and semi-confined groundwater is present in the three underlying hydrostratigraphic units. Tailings seepage has contaminated groundwater in the upper two units. However, the background (naturally occurring) water quality is also poor. These aquifers are not used because of the poor quality. Most drinking water is supplied by upstream river sources by the city. There is no current use of Brown's Wash groundwater.

HYDROLOGY

Prior to the remedial action, storm water runoff carried contaminants from the site down Brown's Wash to the Green River. The amount of discharge (and resulting concentrations) were related to the storm event size. There was no perennial discharge from the facility during operation. However, large quantities of tailings were released during storm events both during facility operation and while it was abandoned (before remedial action began). Measurements made of upstream and downstream levels in the Green River are not available.

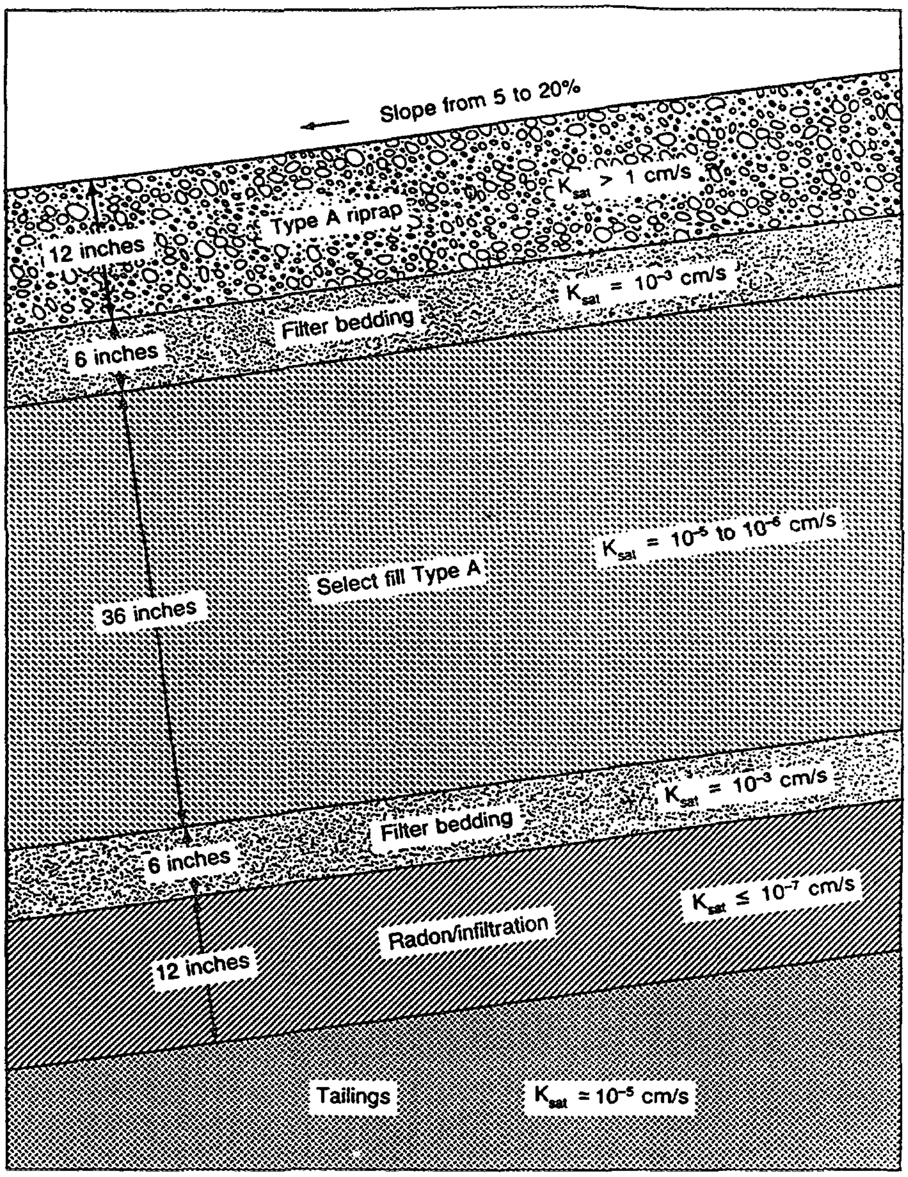

FIG. 4. Disposal cell cover system, Green River, Utah, tailings site (see Fig. 6 for location of this detail in relation to the disposal cell). (K_{sat} = saturated hydraulic conductivity).

DESCRIPTION OF REMEDIAL ACTIONS

Residual radioactive materials were isolated and stabilized on-site, which involved relocating the materials to an area 200 meters south of the original mill site. The office, mill and crusher buildings and facilities were decontaminated and left intact (all equipment within the buildings had been previously removed by the owner when the site was abandoned). The roaster and utility buildings were demolished without decontamination and the demolition debris was placed along with the tailings in the disposal cell.

All contaminated materials were covered by a multi-component cover designed to minimize water infiltration and radon exhalation (see Fig. 4). The cover contains the following layers (starting with the layer above the contamination):

(i) Infiltration/radon barrier: This is 30 cm thick and is composed of compacted silty clay. It was designed to protect the groundwater by minimizing infiltration and to reduce radon flux to well below the regulatory limit of 0.75 Bq/m^2/s. The lower 30 cm of silty clay soil was amended by 6% bentonite (by weight) through tilling during placement in 15 cm lifts. The 6% bentonite was included to lower the saturated hydraulic conductivity to less than 2×10^{-8} cm/s. A layer of filter bedding was then placed above this very low permeability layer.

(ii) Frost protection barrier: Then an additional 90 cm of the same silty clay (without bentonite) was placed protect the first layer. The maximum projected frost penetration depth is 100 cm at the cell's side slope toe.

(iii) Bedding layer: This is a 15 cm layer to prevent movement of the infiltration/radon barrier layer into the overlying riprap erosion protection layer.

(iv) Rock erosion protection layer: This is designed to protect the disposal cell from runoff, flooding, and geomorphic encroachment of gullies. The uppermost portion of the erosion protection barrier is a 30 cm thick layer of 2.5-10 cm riprap (Type A rock). Around the toe of the cell, a 90 cm thick apron of 25-75 cm riprap (Type B rock) was placed below the local ground surface.

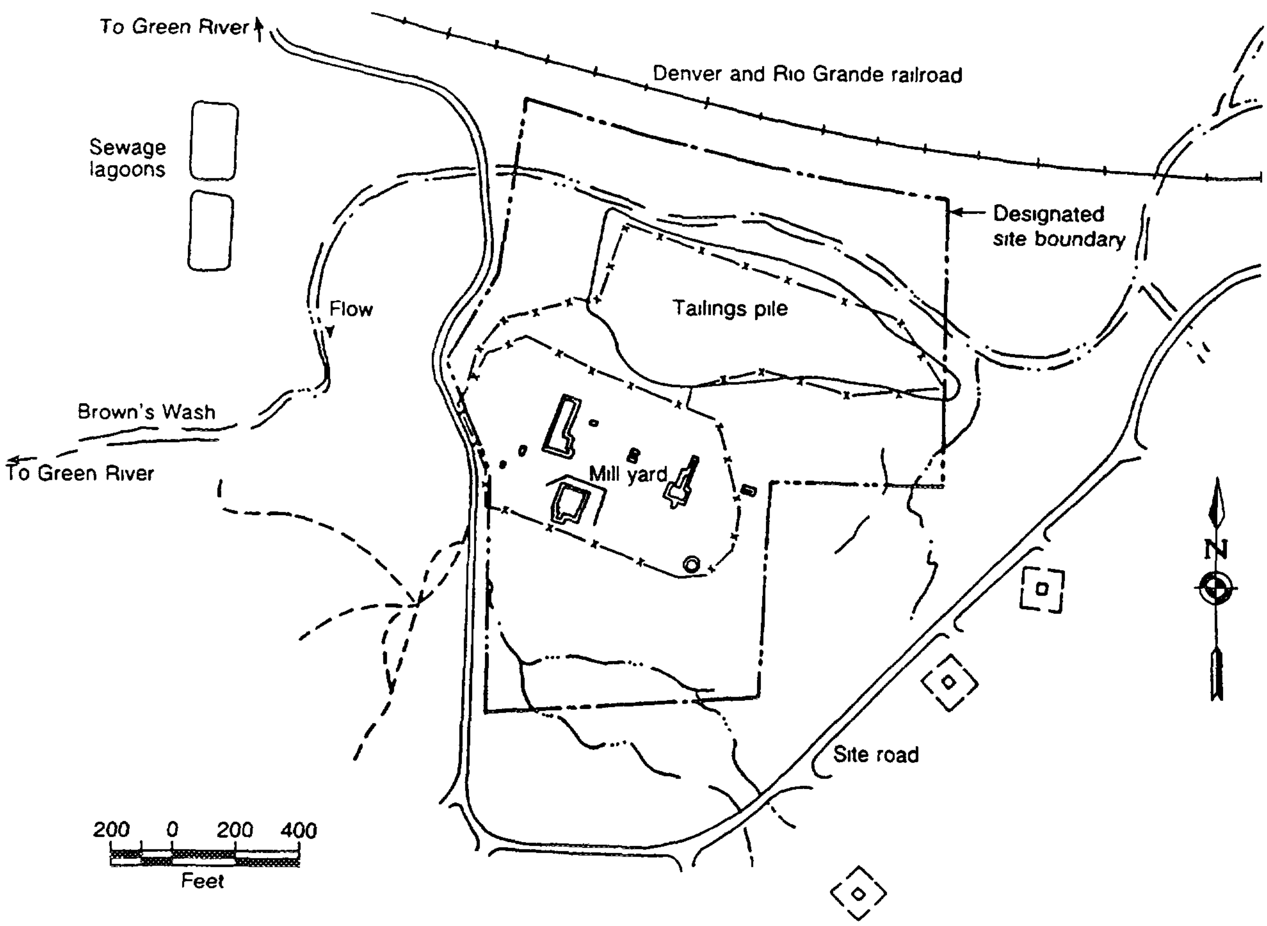

FIG. 5. Current conditions, Green River, Utah, tailings site.

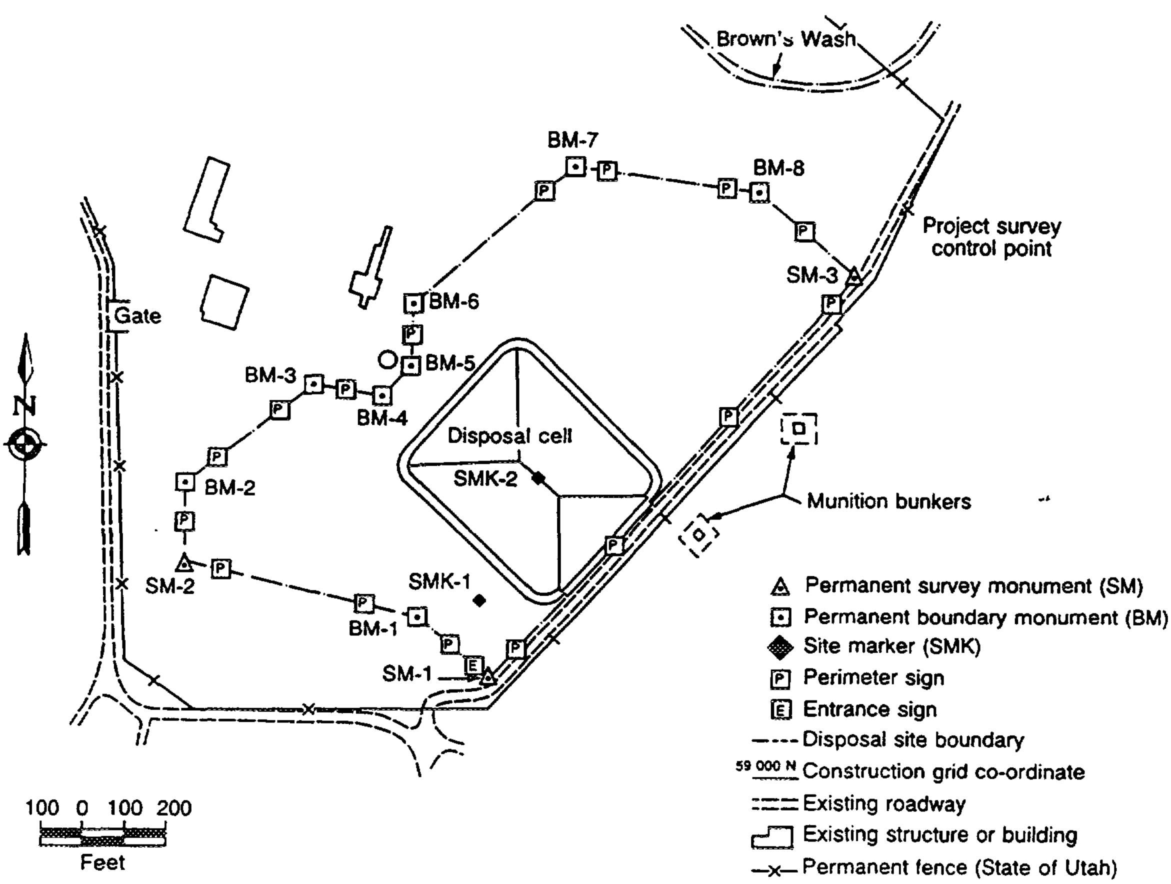

FIG. 6. Final site conditions, Green River, Utah, disposal site.

All radioactively contaminated materials from the former site and surrounding areas were consolidated into the single cell (see Figures 5 and 6). Residual levels in Brown's Wash were also excavated. Excavation criteria for radioactive materials were based on 0.18 Bq/g of Ra-226 activity. No determinations of uranium or other chemical substances were used for identification of material to be encapsulated. The former mill site was regraded to promote surface drainage and all disturbed areas were backfilled. All disturbed areas were revegetated with native grasses. The floodplain of Brown's Wash was also regraded. The final disposal cell was fenced and markers installed to warn future intruders of the contents of the cell.

TECHNIQUES USED

The disposal cell was sited on a terrace 22 m above the channel and floodplain of Brown's Wash to avoid the problem of channel migration over time. Geomorphologic modeling was performed to demonstrate that migration would not reach the cell location for more than 1000 years. The riprap toe protection apron extends 6 m on the surface from the edge of the cell side slopes to ensure ground erosion does not occur from sheet flow runoff of the cell itself. Existing gullies near the cell were filled to minimize erosion potential and the formation of new gullies, and the entire area was graded to promote sheet flow and reduce flow concentrations that could lead to gully formation.

The infiltration/radon barrier was constructed of compacted silty clay with bentonite amendation. The hydraulic conductivity target for this barrier was based on unsaturated flow travel times of water from surface infiltration to be greater than 1000 years before impacting any of the underlying groundwater aquifers. Disposal cell design features, such as cover construction, siting in an arid climate, drainage through the bedding layer, limiting the tailings placement moisture content to minimize draining of construction-related water, and including an underlying buffer layer to absorb exiting contaminants were all intended to keep contaminants from reaching groundwater in less than the design life of 1000 years.

REGULATIONS

The Uranium Mill Tailings Radiation Control Act (UMTRCA) (Pub. L. 95-604) established the regulatory framework for the cleanup and disposal of uranium mill tailings in the United States. Before this law was passed, uranium mill tailings were essentially unregulated. In the UMTRCA, the US Congress acknowledged that misuse of tailings for construction was one of the areas of biggest concern. Control of tailings was not included in the original licensing procedures for uranium mills by the Atomic Energy Commission, because the tailings were not known to be hazardous; thus, tailings were not controlled under the AEA. With the passage of UMTRCA, the US Congress included uranium mill tailings under the AEA. 'Residual radioactive materials (RRM),' as defined under Title I of the UMTRCA, means waste in the form of tailings resulting from the processing of ores for the extraction of uranium and other valuable constituents of the ores; and other wastes at a processing site that relate to such processing, including any residual stock of unprocessed ores or low-grade materials.

The US Environmental Protection Agency (EPA) was assigned the responsibility of establishing regulations for cleanup and disposal of uranium mill tailings at active and inactive sites. The US Nuclear Regulatory Commission (NRC) was designated as the agency responsible for enforcing the EPA standards. The distinction between inactive and active sites was based on those sites that did not have existing production licenses with the NRC at the time the legislation was passed (hence, inactive) and those that did (active). Inactive sites are sometimes referred to as Title I sites, and the active sites are sometimes referred to as Title II sites, based on the title numbers of the legislation.

The UMTRCA designated the DOE as the agency to clean up the 22 inactive mill sites, with 24 tailings piles. The owners of the active sites were required to comply with the standards individually. The legislation also required that the sites be managed in perpetuity by either the DOE or, in limited cases, the state or a federal agency designated by the President.

OBJECTIVES

In the UMTRCA, the EPA was directed to promulgate standards that were similar to the agency's Resource Conservation and Recovery Act (RCRA) standards, where appropriate. The EPA issued draft standards for cleanup and disposal in 1981, and final regulations in 1983. The key points of the standards include the establishment of radium soil cleanup standards, the establishment of a disposal cell longevity standard of 200 to 1000 years, and the creation of a disposal cell radon flux standard.

More specifically, the regulations state the following:

- The concentration of Ra-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than:

- 0.18 Bq/g of Ra-226 averaged over the first 15 cm of soil below the surface.

- 0.56 Bq/g of Ra-226 averaged over 15 cm-thick layers below the surface layer.

- The design radon flux standard shall be 0.75 Bq per square meter per second for disposal cells, or releases of radon-222 concentrations in air, outside of the disposal site, shall not exceed the average annual background level by more than 18 Bq per cubic meter.

- The indoor radon-222 standard shall be 0.02 working levels (in any case, not to exceed 0.03 working levels, including background levels).

- The disposal cell longevity shall be 200 to 1000 years.

- Groundwater considerations shall be determined site by site.

In 1985, a federal court directed the EPA to redraft specific portions of the inactive standards related to groundwater. (At the same time, the court upheld the active-site standards in their entirety.) The EPA issued draft groundwater standards for disposal and cleanup in 1987. The final standards become effective in 1995. The groundwater disposal and cleanup standards include requirements to identify hazardous constituents; establish concentration limits at either background levels, maximum concentration limits (MCL) or alternate concentration limits (ACL); and monitor compliance. This is in keeping with the federal court's direction to make the regulations similar to the RCRA and the active-site standards.

An important part of the groundwater regulations is the provision for supplemental standards. Groundwater can be considered of 'limited use' if the level of total dissolved solids (TDS) reaches or exceeds 10 000 mg/l; if there is widespread ambient contamination that is not the result of the milling and that cannot be restored using normal water supply treatment methods; or if the aquifer is incapable of producing more than 570 liters per day for a sustainable period. The philosophy behind limited-use groundwater is that these aquifers are not considered to be human drinking water resources. The standards require the DOE to consider impacts to existing or future potential beneficial uses and to protect the public health and the environment. The benefit of supplemental standards for groundwater compliance is often a lower cost for disposal, from the standpoint of both disposal siting issues and cover permeability issues.

To meet these standards, US mill tailings are either stabilized in place (SIP), stabilized on-site (SOS), or stabilized by relocating to an alternative site. The final location and configuration affects the final disposal cell design. Each type of stabilization can vary from above-ground disposal to different degrees of below-grade disposal. The ultimate goal of disposal alternatives is to assess technically acceptable alternatives in determining the most cost-effective option.

The disposal site selection process considers the geological stability of a site and its impact on disposal cell design, including evaluation of both the seismotectonic and geomorphic setting of the site. The type of stabilization used at UMTRA Project sites is greatly influenced by the expected magnitude of hydrologic impacts. Impacts from watershed runoff, flooding from nearby steams, surface water quality impacts, aquifer parameters, depth to groundwater, direction of groundwater flow, and potential impacts of tailings seepage on groundwater quality (including compliance with EPA groundwater standards) can necessitate relocation of the pile within the site boundaries or to an alternative site. For SIP or SOS options, there are greater restrictions with regard to improving surface water drainage conditions.

CRITERIA FOR SUCCESS

The EPA standards required that certain features be incorporated in the design of the disposal cells. This prompted the NRC to develop procedures and approaches for complying with the standards. The longevity standard led to a disposal cell design capable of withstanding probable maximum precipitation (PMP) and probable maximum flood (PMF) events. Designs for PMPs and PMFs ultimately led to NRC rock durability criteria. The longevity requirement also resulted in a disposal cell design incorporating natural materials, because man-made materials have not been proven to last 1000 years. The radon flux standard led to emphasis on the cover design to prevent radon emanation. As a result of the groundwater standards, cover permeabilities became a major factor in the DOE's efforts to achieve disposal cell compliance. Therefore, the criteria for success is based on meeting all of the EPA standards during the design of the disposal cell ('design' standard).

At the Green River disposal cell, no erosion control monitoring features are required beyond the periodic surveillance and maintenance inspections that include checking for any developing erosion features. Seven wells along the downgradient sides of the disposal cell were constructed to monitor (long term) water quality in the two middle hydrostratigraphic units. Sampled annually, DOE will take corrective action should future monitoring results indicate that the design of the disposal cell was faulty (contaminant levels from the cell reach the wells before 1000 years).

UNITED STATES OF AMERICA

PART 2. GUNNISON SITE (MILL)

A. *THE GUNNISON SITE FACILITY*

TYPE

The Gunnison site (Figures 1 and 2) is an inactive uranium mill site that operated from 1958 to 1962, producing uranium concentrate (yellow cake) for exclusive sale to the US Government from ore extracted from underground mines within a 40 km distance from the site. An acid leach/solvent extraction technique was used to process 540 000 US tons of ore with an average uranium oxide content of 0.15%.

STATUS

The mill site is inactive, and presently undergoing active remedial action by the US Department of Energy as part of the Uranium Mill Tailings Remedial Action (UMTRA) Project, with a projected completion date of 1994. The remedial action alternative was selected on the basis of safety analyses/assessments of disposing of the buildings and wastes at an off-site, remote location 15 km from the present site.

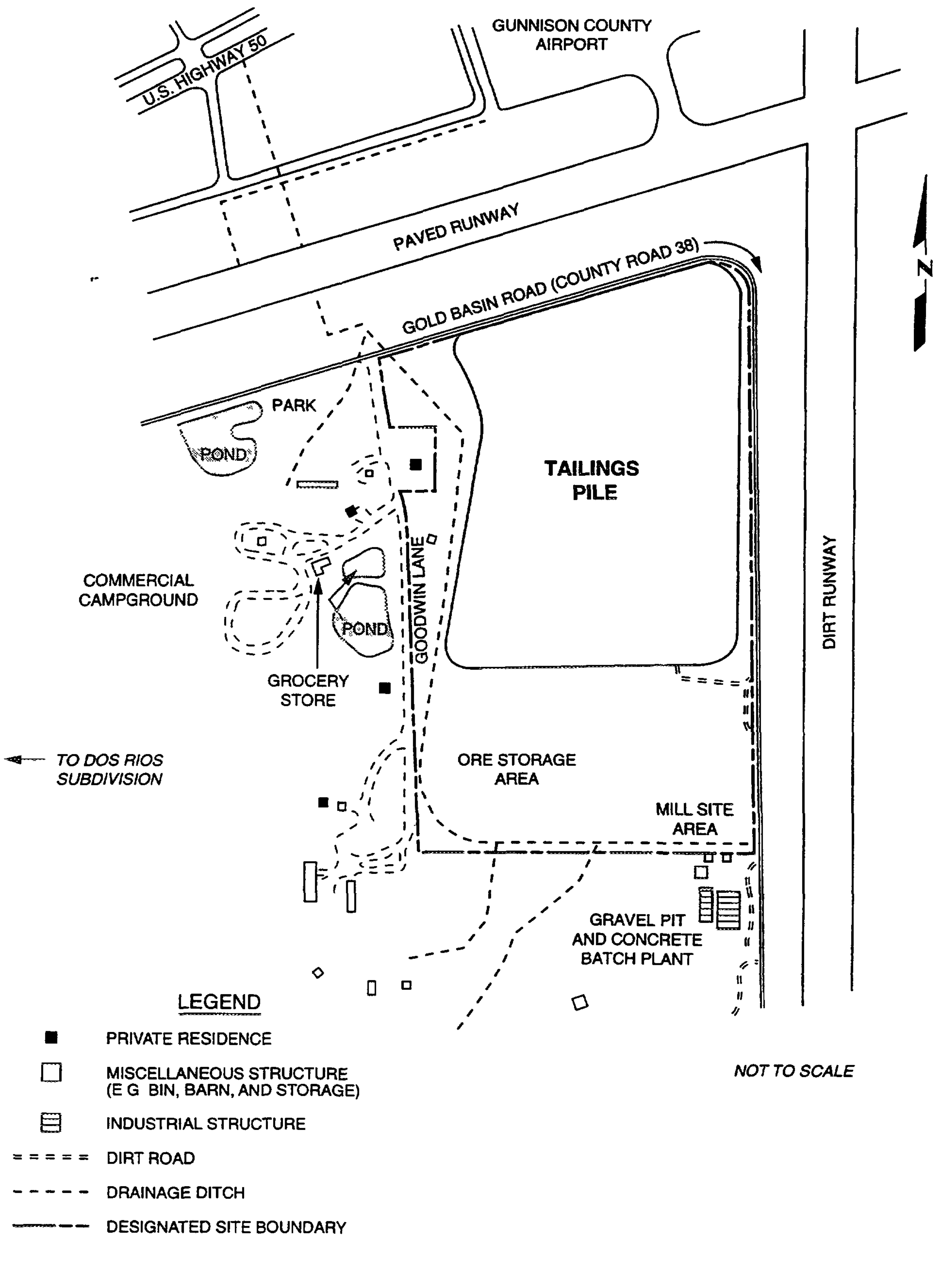

FIG. 1. Land use in the vicinity of the Gunnison processing site, Gunnison, Colorado, USA

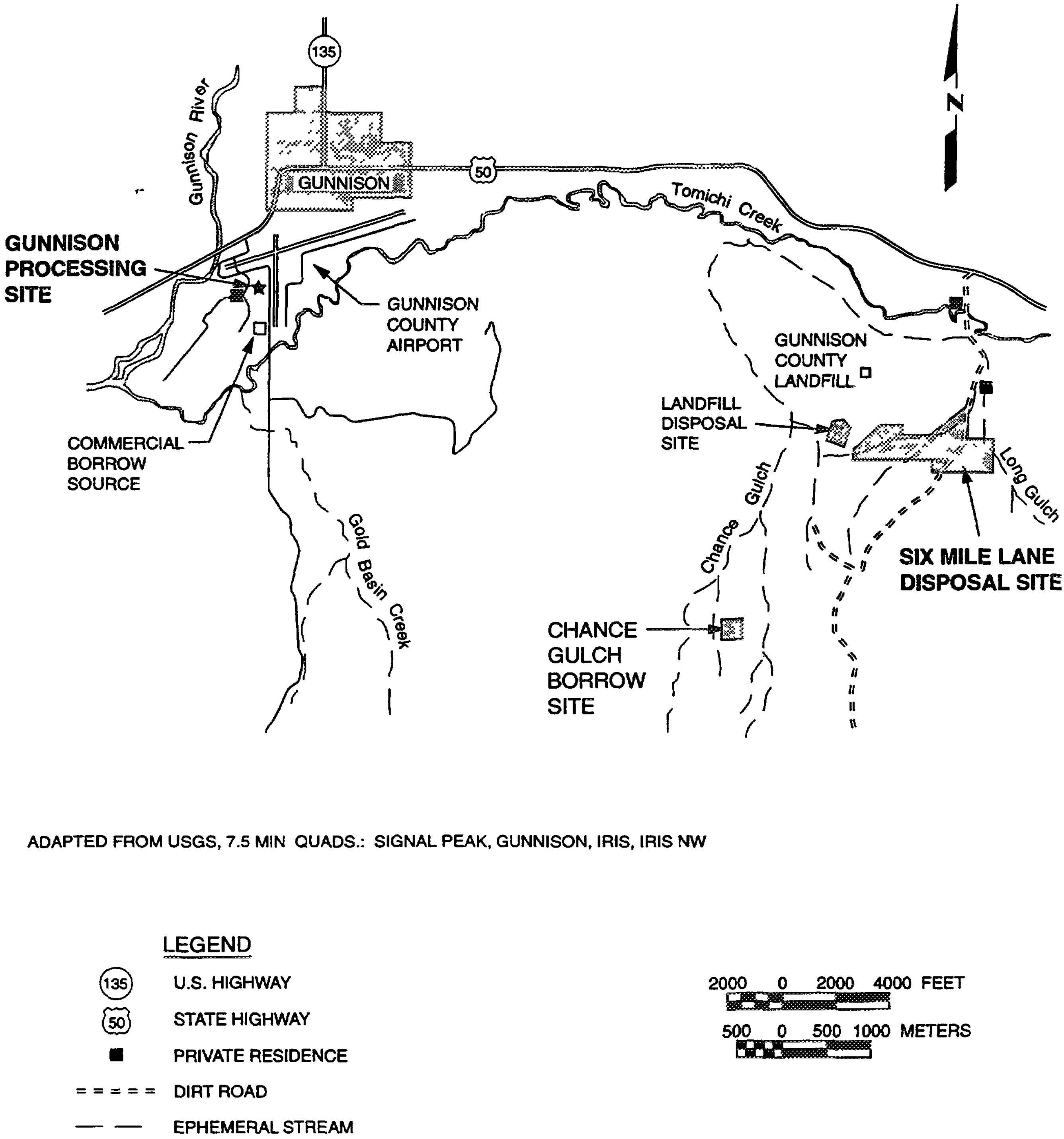

FIG. 2. Location of the landfill disposal and borrow sites, Gunnison, Colorado, USA.

DESCRIPTION

The site consists of a 12 ha mill/ore storage area that contained an office building, mill building, and water tower, as well as a 14 ha tailings pile that received tailings slurred from the adjacent milling area. Approximately 375 000 m^3 of tailings were produced and contained in a rectangular shaped pile with a approximate depth of 3 m. A 6.5 ha off-site area northeast and adjacent to the site contained windblown tailings to an average depth of 15 cm, which were produced during previous milling operations, and the ten year period after operations were terminated prior to placement of a temporary soil cover 0.15 m thick.

ENGINEERING FEATURES

For the period 1978 to 1992 (approximately), the tailings pile was contoured to promote positive drainage, and covered with a 15 cm, sparsely vegetated earthen cover to limit surface water and wind erosion of tailings. The tailings pile area was controlled by a barbed wire fence with appropriate radiation warning signs, and its occupancy or use was prohibited. The mill building was partially decontaminated and, although not fully decontaminated to present regulatory requirements, the mill yard/ore storage area was used for a variety of light industrial activities. No other engineering features were constructed to maintain the inactive site prior to the initiation of remedial action in 1992.

RADIONUCLIDE CONTENT

The Radium-226 (Ra-226) concentrations for the entire site, including the windblown and subpile foundation soil areas, ranges from 1 to 1409 picocuries per gram (ρCi/g) and averaged 226 ρCi/g. Migration of Ra-226, thorium-230, and uranium into the subpile foundation soil has occurred to an average depth of one meter. In addition, the acidic nature of the tailings pile leachate has produced differential migration of Th-230 relative to Ra-226 over approximately 40% of the subpile region. Radon concentration on the periphery of the tailings pile average 5.3 ρCi/l and the radon flux on the tailings pile averaged 72 $\rho Ci/m^2s$. Gamma exposures over the site range from 15 to 364 micro R/hr, and averaged 71.7 micro R/hr. In contrast, radiological characteristics at background locations near the site are: Ra-226, 1.7 ρCi/g; radon concentration, 1.0 ρCi/g, and a gamma exposure of 17.7 uR/hr. A discernable uranium and sulfate groundwater plume in the underlying alluvial aquifer in the southwesterly direction from the site has been detected at distances up to 1000 m in the off-site environment, with uranium concentrations exceeding 0.045 mg/l.

B. THE SITE/ENVIRONMENT

GEOLOGY/HYDROLOGY

The site is located on the alluvial deposits of a river, which is the major aquifer in the area. It is composed of poorly sorted clay to boulder-sized particles. It is approximately 40 m thick and is underlain by compacted rock. Water levels range from 0.3 to 3 m below the land surface. The highest levels occur in the summer, during which time the bottom of the tailings pile may become saturated. Soils beneath the tailings are cobbly sandy loam and loam with 70% by weight having a size fraction greater than a A 4 mesh sieve, and a relatively low clay content.

It is assumed that most of the water flowing beneath the site originates as recharge along the aquifer. During periods of high stream flow, portions of the aquifer will receive water directly from the stream. Other sources of recharge are canals and precipitation. Groundwater in the alluvial aquifer flows to the southwest; however, buried stream channels may divert some flow from this direction. Flow velocities in the aquifer average 350 m/a.

GEOCHEMISTRY

The native groundwater is fresh and neutral. The average total dissolved solids content is 240 mg/L and the average pH is 7.2. The water is potable, although the proposed standard for nitrate was exceeded by a factor of 1.1 in one sample.

Acidic and oxidizing conditions exist in the tailings pile and through the vadose zone down to the water table below the tailings. The geochemical conditions at the site facilitate the transport of metal constituents into groundwater. Contaminants may be transported from the pile by two mechanisms. First, precipitation percolating down through the top of the pile may transport contaminants into the underlying groundwater. Second, groundwater may move up into the base of the pile during high water periods and become contaminated while in contact with tailings or tailings pore solution.

The elevated levels of uranium, heavy metals, and other constituents found in tailings pore solution and in groundwater immediately under the tailings pile indicate that contaminants, particularly uranium and sulfates, are leaching out under the influence of environmental processes.

SURFACE HYDROLOGY

As regards the surface hydrology, several common mechanisms of contaminant transport may be in operation. First, precipitation and snow melt may carry both dissolved contaminants and contaminants sorbed onto soil particles along surface drainages to nearby ponds and also to the river. Metal contaminants transported as dissolved species would be diluted as they enter large water bodies. Alternatively, dissolved species could precipitate, or become sorbed onto sediments, or be sorbed into biota. Contaminants which are transported from the tailings area sorbed onto soil particles would be deposited as pond and river sediments. Variations in hydrochemical conditions or biological actions could also mobilize sorbed constituents into surface waters. Characterization data indicate, however, that surface water transport of contaminants has been limited to a drainage ditch directly adjacent to the tailing pile.

A second mode of contaminant transport from the tailings pile is via groundwater discharge to surface water bodies. It is believed that the aquifer under the site discharges to the river downgradient during certain seasons. Once the contaminated groundwater discharges into surface waters, the dissolved constituents would be significantly diluted.

CLIMATOLOGY

The area in which the site is located has a cold mountainous climate. The annual average rainfall is 280 mm/a with no one year exhibiting a major portion of the precipitation. Snowfall measured on-site averages 1500 mm/a, 88% of which occurs between November and March.

The site is located at an altitude of 2350 m. Wind measurements at an airport which boarders the site indicate that wind is predominantly from the north, occurring in this direction 15 to 18 per cent of the year. Average wind speeds are 10-12 km/h. The strongest winds in the area are from the southwest to west-northwest quadrants.

LAND AND WATER USE

As regards the land and water use in the vicinity of the site, immediately west are a number of residential properties. To the north and east, the site is bounded by an airport. An operating gravel pit and concrete plant are south of the site. There are more than 100 private domestic wells within 1.6 km and downgradient of the site. A campground is also within several hundred meters of the west boundary of the site. To the north of the site at distances ranging from 1 to 10 km is a town of approximately 6000 inhabitants.

C. *LEGISLATION*

The inactive uranium mill has been designated as part of the Uranium Mill Tailings Remedial Action (UMTRA) Project. As such, the remedial action of the site is mandated by federal law, and control and cleanup of the site must comply with regulations promulgated by the US Environmental Protection Agency (EPA) under 40 CFR 192. Under these regulations, the inactive site must cleanup and stabilized in accordance with the following provisions:

- Stabilization and control of radiological material for up to 1000 years, to the extent reasonably achievable, but at least 200 years.

- Disposal cell designed for long-term stabilization of radiologically contaminated waste shall be designed such that the average surface radon flux does not exceed 740 mBq/m^2s, or the annual average radon concentration at the boundary of the disposal cell site shall not exceed background concentrations by more than 18.5 mBq/L.

- The Ra-226 concentrations, above background concentrations, in remediated land, averaged over 100 m^2 and 0.15 m depth increments, shall not exceed 185 mBq/g averaged over first 0.15m of soil below the surface, and 555 mBq/g of soil more than 0.15 m below the surface.

- Remediation of habitable structures for unrestricted use shall be such that reason efforts shall be made to reduce radon exposures below a 0.02 working level (WL), but not to exceed 0.03 WL. Gamma exposures in remediated structures shall not exceed 20 uR/hr above background exposure rates in the area.

- Radionuclides other than Ra-226 (for example, Th-230, and U) that exist on the site in sufficient quantities and concentrations as to pose a health risk, shall be remediated to concentrations whose impacts are compatible with those posed by the residual Ra-226 standards.

- Groundwater restoration concentrations are presented in Table I.

Groundwater restoration to mitigate impacts of other hazardous constituents will be based on pathway analysis.

D. *SAFETY ASSESSMENTS*

Safety Assessments performed to evaluate long-term environmental impacts on the existing site conditions (No Action Alternative) and alternative off-site stabilization options included.

TABLE I. CONCENTRATION LIMITS (CONCENTRATIONS OF THESE CONSTITUENTS SHALL NOT EXCEED THE FOLLOWING LIMITS OR BACKGROUND, WHICHEVER IS HIGHER)

Element/Radionuclide	Limit
Arsenic (As)	0.05 mg/L
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr)	0.05
Lead (Pb)	0.05
Mercury (Hg)	0.002
Molybdenum (Mo)	0.1
Nitrate (as N)	10.0
Selenium (Se)	0.01
Silver (Ag)	0.05
Combined Radium ($^{226,228}Ra$)	5 pCi/L
Combined Uranium ($^{234,238}U$)	30
Gross alpha (excluding Rn,U)	15

EXTERNAL GAMMA EXPOSURE

Exposures to remedial action workers and the general public were assessed. Primary exposed group was determined to be occupational workers, but engineering controls and implementing appropriate radiological protection would limit the dose to well below occupational limits over 21 month remedial action period. Exposure of populations residing near either the existing site or remote disposal site would be negligible due to their proximity to the sites, and the presence of interim or permanent earthen covers (0.60 m) to control radon releases.

SEISMIC STABILITY, MAXIMUM PRECIPITATION AND FLOODING ASSESSMENTS

Analysis of seismic activity in the disposal site area was performed to provide engineering parameter to design the stabilized disposal cell: the area is not seismically active.

An assessment of the flooding potential at the processing site was performed to determine whether a the No Action or an onsite disposal cell alternative was a viable remedial action option. The high potential for flooding over the design life caused the rejection of both alternatives.

The maximum precipitation analysis served to design the disposal cell slopes, size the rock riprap, and develop surface water diversion ditches to ensure the long-term integrity of the disposal cell.

CYCLIC FREEZE/THAW ASSESSMENTS

Assessments were made to delineate the impacts of the cold, long winters in the mountainous disposal cell area on the stabilized tailings pile radon barrier cover as a function of freeze/thaw cycles. Long-term reduction in placement density, and induced cover cracking could compromise the cover's integrity, and produce surface radon fluxes in excess of the design criteria. A 2 m frost protection layer of uncontaminated soil was designed for placement over the main high clay content radon barrier to mitigate against freeze/thaw events.

RADON RELEASE IMPACTS

The surface radon flux for the temporary soil cover on the pre-remedial action site and tailings pile, and the clay radon barrier for alternative disposal cell designs were calculated using a multi-layer, two phase, steady-state radon diffusion model in one-dimension, RAECOM [1]. The site characterization data and laboratory measurements of contaminated waste's physical, and radon diffusion and emanation properties were used as input parameters for the computer calculations.

Various scenarios for the placement of waste in the disposal cell were evaluated to optimize the construction sequence and clay radon barrier thickness, and a 0.60 m cover thickness was determined to be required to comply with the 740 mBq/m^2s surface radon flux standard. A sensitivity analysis on this cover thickness, based on average parameter values, was also performed by considering the statistical variation in the data obtained from a limited number of samples per parameter.

Atmospheric dispersion were also made to determine the impact of radon released from the surface of the unremediated site, including the temporary soil covered tailings pile, and alternative disposal cell designs. A gaussian plume model was employed to calculate radon concentrations, and indoor and outdoor health effects (e.g. cancer) risks to populations living at selected receptor locations. Meteorological data from the airport near the site was used to provide the joint frequency distribution of wind speed and stability class, and windrose.

SUPPLEMENTAL STANDARD FOR Th-230 CLEANUP

A supplemental standard was developed for the cleanup of Th-230 in areas were Th-230 had differentially migrated below the depth required to remediate in-situ Ra-226 in accordance with promulgated standards. The Th-230 cleanup protocol required that the excavation of subpile soil first comply with the in-situ Ra-226 cleanup standard, independent of the groundwater table encountered at the time of excavation. If, upon satisfying the in-situ Ra-226 cleanup standard, elevated Th-230 still remained at elevated concentrations, then deeper excavation would be performed until the 1000 year projected Ra-226 concentration (in-situ Ra-226 plus the Ra-226 that grows-in in 1000 years due to the decay of in-situ Th-230) was less than 555 mBq/g, or the groundwater table was encountered. To demonstrate that any residual Th-230 remaining above the saturated zone during median to low water periods, after the site had been remediated with clean backfill soil, did not pose adverse health effects, a pathway analysis was performed to show that the surface radon flux, and the radon exposure working level in a hypothetical house constructed on the site were acceptable (WL less than 0.02).

GEOCHEMICAL

Geochemical assessments were made of the subpile foundation soil and the soil underlying the disposal site to determine respective adsorption/precipitation characteristics for uranium, thorium, and heavy metals, and support groundwater modelling. Laboratory mixing jar and column tests were performed using representative soil samples, and a synthetic tailings pore water. On the basis of this study, it was concluded that: (1) excavation to a depth that would satisfied the Th-230 cleanup protocol (Supplemental Standard) would also be sufficient to remove the acid generation potential of the subpile soil at the processing site; (2) uranium adsorption/precipitated on soil in the vadose and saturated zones below soil depth required to satisfy the Th-230 cleanup protocol would not be highly elevated, stable, and not adversely impact future groundwater restoration efforts. Therefore, a separate supplemental standard for uranium soil cleanup was not needed.

Combining these tests results with water infiltration and transient drainage studies performed on the disposal cell designs and subsoil region, it was further concluded that the buffering capacity and adsorption/precipitation properties of the disposal cell subsoil were sufficient to attenuate the radionuclides and heavy metal leached from the stabilized waste material, and, therefore, not adversely impact groundwater reserves.

GROUNDWATER MODELLING

Several groundwater assessments were performed at the processing site. The first investigation used a DOE developed pathway model (see DECHEM© in Reference [2]), which includes algorithms to calculate constituent concentrations at down gradient well locations, as a function of a user specified soil profile of contaminants and time after remediation, due to leaching and adsorption of metal or chemical ions in the vadose and aquifer soil zones, groundwater dispersion and flow. Major constituents considered were uranium, molybdenum, and arsenic. Results indicated that after the tailings pile had ben removed, subpile radionuclides remediated to comply with the Ra-226 standard and Th-230 soil cleanup protocol, natural flushing in less than 15 years would reduce the concentration of these constituents to safe levels.

Seven exposure scenarios have been evaluated to determine current and future potential human health risks from groundwater at the processing site in a second impact assessment. The current scenarios include characterization of risks to adult and children residents in the vicinity of the site. The future scenario evaluates potential residential development of the site after the tailings are removed and the surface contamination is remediated in 1994. This is a feasible scenario since the site is currently privately owned and the adjacent land is used for residence with private wells, and because it is likely that the aquifer underneath the site will remain contaminated for a number of years after the tailings pile is removed.

The current use residential scenarios evaluate pathways associated with the use of groundwater and surface water: ingestion of drinking water, dermal absorption of contaminants during bathing, ingestion of vegetables and fruits irrigated with contaminated water, and ingestion of fish from the ponds and creeks. The exposure pathway involving occasional dermal contact with water and sediments from surface water bodies was judged to be a relatively insignificant pathway compared to the pathway involving daily dermal contact during showers. An additional pathway of inhalation of mists is also being evaluated.

MODELS

For purposes of this study, the model for groundwater consumption, i.e. the intake equation and intake parameter values are given in [3]. The same reference contains the equations for calculation of intakes due to the dermal pathway. The model for fruit and vegetables consumption includes the soil-to-plant concentration ratios published in [4] which allow estimation of plant concentrations of substance given that the soil concentration of the substance is known. The values for ingestion rates of crops were obtained from data published in [5].

A simple model was used [1] to estimate potential contaminant concentrations in fish caught in downstream stretches of the creek and river near the site. The model assumed that surface water was the main source of contaminant concentrations in fish and that concentrations in surface water were in equilibrium with concentrations in fish tissue. Thus experimentally determined fish bioaccumulation factors could be used to calculate the expected proportion of contaminant.

UNCERTAINTIES

The following sources of uncertainties have been identified:

- Uncertainties which stem from the environmental sampling data; the seasonal variations in groundwater contaminant concentrations have not been fully characterized.

- A number of exposure parameters used to calculate intakes were intentionally overestimated in order to obtain an exposure estimate likely to be protective of health.

- Uncertainties also arise in the assumptions used in transport modelling; some soil-to-plant uptake factor can be highly variable and can affect the exposures by a factor of 100.

RESULTS

The results obtained can be characterized as follows:

A number of the contaminants of concern have been consistently measured at elevated levels in area residential wells which are used as a primary source of drinking water. The daily consumption of water represents a potentially significant pathway by which residents are exposed to site contaminants.

In this context, the radiological intakes of various radionuclides due to ingestion of drinking water ranged within 1 and 100 kBq/L, whereas other exposure pathways exhibited lower intakes, not exceeding some units of kBq/L, such as consumption of fish or ingestion of vegetables grown on the site.

In the residential scenario, the overall potential carcinogenic risk which would result from the drinking water, dermal contact while bathing, and the ingestion of foodstuffs was estimated to be 4×10^{-2}. The majority of this risk (98% of the total) was due to exposure from contaminated drinking water.

Based on these results, the following recommendations could be formulated:

(a) Alternate water supplies or water treatment should be provided to households where the cancer risk exceeds the value of 10^{-4}; however, it may be preferable to define an area of action rather than specific houses;

(b) To prevent additional exposure, institutional control on the groundwater below and adjacent the site should be established.

Complete details of environmental assessment of remedial action at the site is contained in Ref. [6], and modeling techniques are described in the Technical Approach Publication for the UMTRA Project [2].

REFERENCES

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