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Guidebook on environmental impact assessment for in situ leach mining projects

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FOREWORD

Environmental impact assessments and/or statements (EIS) are a prerequisite for opening or expanding uranium mining projects. Their overall objective is to ensure that all matters affecting the environment to a significant extent are fully examined and taken into account before irrevocable development decisions are made. Since an EIS contains extensive information related to the physical, biological, chemical and socio-economic condition of an area proposed for development, it provides invaluable guidelines for minimizing environmental impact during operations as well as for environmental restoration and decommissioning after a mine is closed.

In addition to providing guidelines and requirements for all environmental aspects of a proposed mining project, The EIS is intended to:

- Provide information to interested individuals or groups that may be impacted by a proposed development,

- Provide a forum for public consultation and informed comment on a proposed project,

- Provide a framework in which decision-makers may consider the environmental aspects of a proposed development in parallel with economic, technical and other factors.

This report provides guidance on conducting environmental impact assessments for proposed uranium *in situ* leach mining projects. It will be useful for companies in the process of planning uranium project development as well as for the regional or national authorities who must ultimately approve such developments. Environmental case histories from four countries, Australia, the Czech Republic, Kazakhstan and the United States of America provide information on conducting an environmental assessment and preparing the environmental impact statement (EIS) which is based on the assessment. These case histories are not meant to represent strict guidelines for preparing an EIS or even firm recommendations, but will serve as examples of the type and extent of work involved in environmental assessments. This TECDOC is one of a series of IAEA publications covering all aspects of *in situ* leach uranium production, from exploration to exploitation, socio-economic impacts and decommissioning. The IAEA has already published a number of reports including Manual of Acid I*n Situ* Leach Uranium Mining Technology, IAEA-TECDOC-1239. The IAEA officers responsible for this publication were J.-R. Blaise, C. Ganguly and K. Wenrich of the Division of Nuclear Fuel Cycle and Waste Technology.

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1. INTRODUCTION

1.1. Overview

Over the last three decades environmental planning has become increasingly important in many countries. Today it is a fundamental and essential part of planning of any new uranium production facility. While it is generally recognized that *in situ* leach (ISL) uranium mining technology has environmental and safety advantages as compared to conventional mining and milling, it is also accepted that ISL projects should not be started without giving appropriate consideration to potential environmental consequences. Environmental planning is frequently taken into consideration through some type of environmental assessment. This must be completed before a project is authorized to proceed with development. The evaluation is usually done by conducting an environmental impact assessment and producing an environmental impact statement.

An Environmental Impact Assessment (EIA) is a process in which environmental factors are integrated into project planning and decision-making. The EIA identifies, predicts, interprets and communicates information, and proposes preventive and mitigative measures, to minimize impacts of a proposed action on the environment. Its purpose is to evaluate the environmental implications (negative or positive) of carrying out a development project, before irrevocable decisions are made.

The environmental impact statement is produced by the proponent of the mining project, members of the public in the area of the proposed development and the regulatory authority, which will judge the acceptability of the project and, if deemed acceptable, will issue the appropriate approvals.

1.2. Background

Environmental assessment has been an important consideration for the nuclear industry since the creation of the International Atomic Energy Agency in 1957; however, the degree to which environmental assessment has been embraced varies from one country to another. The past 20 years have seen a rapid growth in environmental legislation with increasing requirements for environmental assessment. Thus, environmental assessment is still an evolving process. This document gives guidance for environmental assessment of uranium *in situ* leach projects.

Uranium is mined to provide fuel for nuclear powered electrical generating stations, and in so doing, it preserves other fuels, such as liquid hydrocarbons that have more valuable uses than electricity production (e.g. as transportation fuels). In addition, nuclear power generates electricity without releasing large quantities of "greenhouse gases" and, thus, may avert future severe environmental consequences. World coal resources exceed current uranium resources in terms of available energy, but better technology is required before these resources can be fully utilized without environmental risk. Nuclear power has demonstrated the ability to produce electricity with acceptably low environmental impacts and thus is expected to make an important contribution to the worldwide energy mix in the future.

1.3. Justification and definitions

Mining should be conducted in such a manner that the environment is not damaged to the extent that large areas of land are permanently removed from future beneficial use. Hence it is important that an assessment be done of the potential impacts of a mining operation and that development proceed in such a manner as to keep environmental degradation as low as reasonably achievable (the ALARA concept) with technical, economic, and social factors being taken into consideration.

The following definitions describe the terms as used in this document. It is, however, recognized that terminology differs from one country to another and that these terms may have special meanings in some jurisdictions, which go beyond what is intended here.

The *environment*, in the broadest sense, encompasses man and his world, comprising both animate and inanimate components. The physical environment includes surface geography, geology, air, soils, climate, surface water, and groundwater. The biological environment comprises all living organisms, including plants and animals (both vertebrates and invertebrates). In examining the environment through various topics, impacts on human health are ultimately considered. Increasingly in many countries, the social and economic (frequently called socio-economic) environment is included in environmental assessment. Social and cultural issues may be more important where mines are proposed in undeveloped areas that may be populated by indigenous people, who have a very different culture from that of the society interested in developing the mine.

Environmental impact assessment (EIA) is a process in which environmental factors are integrated into project planning and decision making. An environmental impact assessment is comprised of an examination of the local environment around a proposed project, an examination of the proposed project, and a prediction of the potential impacts of the project on the physical, biological and socio-economic environment, with the objective to judge the acceptability of the project and control those impacts to acceptable levels, while maintaining the viability of the project.

An environmental impact statement (EIS) is a document that describes the local environment, the proposed project, its potential impacts on the environment, and possible mitigating measures, and outlines proposals for the decommissioning and remediation of the project. An EIS is the document in which the proponent sets out its assessment of the impact on the environment of a proposed project to regulatory agencies and the community.

1.4. Participants (stakeholders and interested parties)

Generally, the environmental impact statement is produced by the proponent of the mining project, often with the assistance of specialists. Members of the public in the areas of the proposed development may have legitimate concerns about the nature and impacts of the project; their concerns need to be identified and addressed. The third participant in environmental assessment is the regulatory authority that will judge the acceptability of the project and, if deemed acceptable, will issue the appropriate approvals.

1.5. Purpose of the guidebook

Environmental impact assessment is an important part of project planning. The purpose of environmental assessment is to assess potential impacts of a project on the physical, biological and socio-economic environment with a view towards determining mitigating measures for significant impacts, and ultimately judging the acceptability of the project, balancing the potential impacts against the benefits.

The guidebook will provide guidance on the preparation of an environmental impact assessment of *in situ* leach mining, which will be useful for companies in the process of planning uranium development, as well as for authorities who will assess such developments. A glossary of technical terms is included in Appendix X.

2. CONSIDERATIONS FOR ENVIRONMENTAL IMPACT ASSESSMENT

2.1. General

If all the interested parties (i.e., project proponent, regulatory authorities, and interested public) have the opportunity for input into the environmental assessment, then there is a high probability that the environmental assessment process will be successful. In addition to identifying potential environmental impacts and specifying appropriate mitigative measures, the environmental impact statement (EIS) must also incorporate plans for the final decommissioning and rehabilitation of the site. The regulatory authorities and the public must be assured that significant unavoidable environmental damage that occurs during production will be mitigated as part of the decommissioning phase.

The key to an environmentally sound ISL project is planning, which allows the organization to identify critical environmental issues in advance, to anticipate and prepare mitigation plans for operating risks to prevent failures, and to control the development, operation and closure processes. Following the guidelines described will assist in creating an ISL project where the health and safety of its employees and the public are protected; the environmental impact of its activities is addressed; and the economic benefits are achieved.

Appendix IX describes a number of factors to consider in drafting an EIA for a uranium mining project. The list is more of a checklist than a firm recommendation to examine every topic in detail. A schematic representation of the overall feasibility and environmental assessment process is shown in Figure 1.

2.2. Feasibility study

After a potentially viable uranium deposit has been identified, it is normal to conduct a feasibility study to determine whether or not the deposit can be developed economically. The feasibility study usually entails definition of the ore reserves and design of a method for recovering the uranium. The capital, operating, and decommissioning costs are estimated and compared with the projected revenue generated by the sale of the product. To properly conduct this assessment, it is important to do a preliminary environmental baseline study and to estimate the potential impacts of the project on the local environment. Coupled with this is the need to examine the regulatory requirements that may be imposed upon the development. Mitigation of undesirable environmental impacts and stringent regulatory requirements could significantly affect the economics of a project. It is important to assess these factors before proceeding too far with the development. The environmental information needed for the feasibility study is similar to that required for an environmental impact statement, but at a lesser level of detail. From an environmental perspective, the feasibility study needs only to consider those issues that could have serious economic impacts on the project.

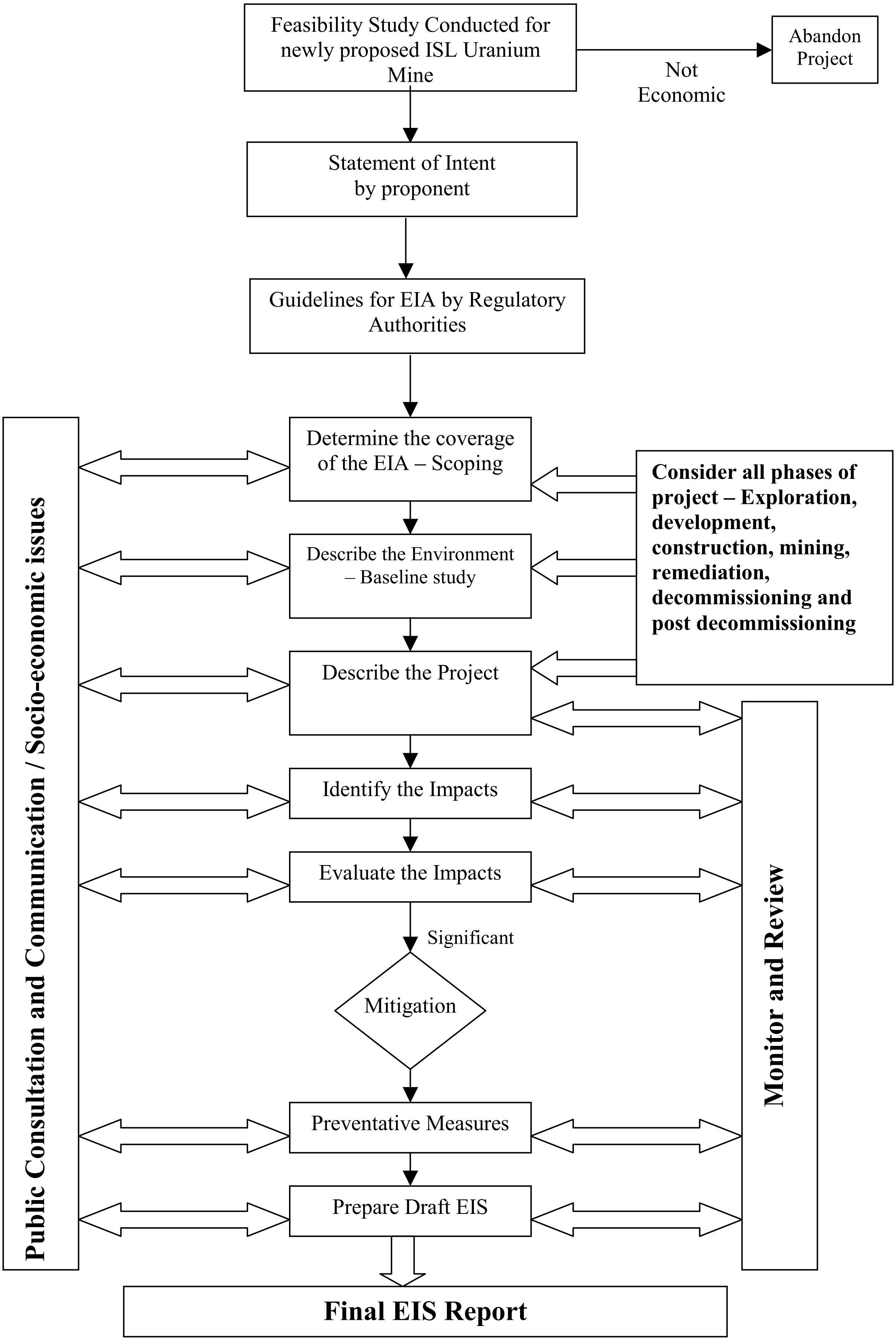


FIG. 1. Feasibility and environmental assessment process.

2.3. Participants in the EIA process

2.3.1. Proponent

The proponent is that legal entity, which is proposing the establishment of a new mining and milling project or a significant change to an existing project (e.g. the development of a new orebody at the existing site). The proponent will usually make the applications for whatever approvals are required, perform the environmental field work, produce the environmental impact statement, conduct a public information programme, defend the project in any hearings that may be required, respond to any requirements placed on the project by the process, and initiate the actual project after the necessary approvals are received.

2.3.2. Regulatory authorities

Most countries with uranium deposits have a regulatory authority that issues permits or licenses for the operation of uranium mines and mills, inspects them during the operation and approves decommissioning. The licensing process may involve several stages, and an environmental assessment is a frequent requirement of the approval process. Depending upon the location of a proposed mining project, more than one level of government may have an interest in the development. For greater efficiency, most countries combine these interests into a single process.

2.3.3. Public

Concern for health, safety, and the environment has grown rapidly during the past decade. There is an increasing public concern about nuclear energy and its regulation, reflected in demands for more information on the licensing process and the safety performance of nuclear operations.

Uranium mining projects have been subject to a level of scrutiny that frequently goes far beyond what can be justified by their potential for environmental damage. It may be, however, that these objections are a result of misinformation or a lack of knowledge. Both should be addressed by the proponent through a suitable public awareness programme.

For the purposes of environmental assessment, the term public may be limited to only the local inhabitants of the site of the proposed project, or it may have a broader connotation to include the regional population or the population of the country as a whole. Public input to an environmental assessment can occur at several points in the process, which would assist in the preparation of the EIA guidelines. In some countries public meetings are held at the beginning of the process to solicit public views on the issues to be dealt with in the environmental impact statement. Whether this is required or not, the proponent is well-advised to seek the views of the public. After the EIS has been issued, the public generally is allowed to offer comments on it. In assessing the importance of the public input, proximity to the project site is an obvious factor. However, it is frequently necessary for an environmental assessment to balance impacts on a small local population against the greater good for the country.

2.4. Scoping

To set a good foundation for the rest of the EIA process a thorough scoping process needs to be undertaken.

Scoping can be commenced soon after the project proposal has been clearly defined and include public and other key stakeholder consultation and participation early in the exercise.

The objective of effective scoping is to describe both the environment and the project in sufficient detail, identify and assign priority to all issues of potential impact and most importantly set limits on what will and will not be included in the EIA. When describing the project particular attention should be paid to those elements that are of greatest concern to key stakeholders. When describing the environment it is important to ensure that all potential environmental impacts are included.

Before proceeding with the detailed environmental studies, it is important to discuss the proposed project, as well as the planned studies, with the applicable regulatory agencies and with local residents. In some jurisdictions there are specific requirements to determine the concerns of local residents and to address these concerns in the environmental assessment.

2.5. Baseline environmental conditions

Baseline studies will characterize and document the existing environmental conditions prior to development. Those environmental elements that have a likelihood of being affected by the proposed project will be the focus of data collection. Knowledge of baseline environmental conditions is important for two reasons: first, to form a basis for the assessment and second, to provide a record of initial conditions, which will be essential both during operations, and when project decommissioning takes place.

The first section of the environmental assessment will include a description of the project location on a national, regional and local basis with increasingly more detailed maps. The regional and local geology and geography lead into a description of the local terrestrial habitat. Descriptions of climate, surface water hydrology, hydrogeology, soil, water and air quality, and natural radiological conditions are required in the baseline document. Any rare or endangered animal or plant species in the area of the project must be identified. A description of resource use including land use, agriculture, livestock, wildlife harvesting, fishing, tourism, etc. is also an integral part of the document. Finally, a description of the socio-economic environment indicating the inhabitants of the areas potentially impacted areas and the nature of their livelihood and culture will round out the description of baseline conditions. The level of investigation of each of these issues is dependent on the size and type of project, e.g., groundwater may be a major issue at an *in situ leach* (ISL) project.

Table I shows the elements that are typically considered in designing a baseline data collection programme.

Table I. Elements to design a baseline data collection

Physical	Biological	Socio-economic
Topography	Fauna, terrestrial & aquatic	Land use
Geology	Flora, terrestrial & aquatic	Water use
Hydrology/hydrogeology	Endangered species	Industrial activity
Climate	Radiological analyses	Cultural resources
Soils		Local population
Air quality		Employment
Radiological background		

2.6. Project description

The project needs to be described in detail, including the well field, plant, waste management system, and transportation of both raw materials and product. When describing the project, it is important to focus on those elements of the project that are of greatest concern to the public and key stakeholders.

A description of regional and local geology, leading into the mineralization and ore reserves, planned drilling activities, pumping system, uranium processing system with particular attention paid to the hydrogeology is helpful in orienting the reader to the technical parameters of the project.

Although not strictly environmental matters, safety and radiation protection of workers are frequently issues in environmental assessments. A description of mining methods, including types of equipment, types of work, safety analyses and radiation exposure estimates and equipment layouts are helpful in estimating exposures.

Waste management considerations are of particular importance, including liquid wastes, solid radioactive wastes, contaminated equipment and general refuse.

Cataloguing resource requirements including electricity, water, fuel, chemical reagents and construction materials helps quantify potential competition for resources.

An explanation of the transportation of uranium product, chemical reagents and general supplies with preferred and alternative routes documented helps transportation authorities.

A conceptual decommissioning and rehabilitation/remediation plan is part of the project description because the emissions after decommissioning are likely to be very different from those during operations, and may continue for a very long time.

In describing the project, it is often useful to mention the options considered for development and reasons for selecting the preferred option. It also can be beneficial to give some consideration to the impacts of not proceeding with the project.

2.7. Identification of potential environmental impacts

Investigation of impacts must consider both the short and the long-term and include all phases of the project (i.e. construction, mining, remediation, decommissioning and post decommissioning).

Once the baseline information on the ecological, cultural, air, land and water resources has been collected, and the mining plan established, it is possible to identify the probable environmental impacts. Concurrently, impacts to the local social structure and economy are estimated. The level of effort and detail spent in collecting baseline information and identifying potential impacts will logically be related to the planned activities.

The nature of the orebody and planned mining method can have a major influence on the severity of the impacts to the environment. In some situations it may be necessary to modify mining methods to reduce probable impacts to the environment to an acceptable level. Detailed planning during each phase of the mining project can help reduce impacts to the environment.

Cumulative impacts from past, current and potential future industrial and agricultural activities also need to be considered along with their potential linkages and interactions among all the predicted impacts.

2.8. Potential environmental impact evaluation

In the first step, the impact itself (the magnitude) is determined (predicted). Then the level of impact in terms of its relative value must be evaluated (value judgments). The key elements for evaluating environmental impact significance are level of public concern, professional and scientific judgment, disturbance/disruption of ecosystems and degree of negative impact on social values and quality of life.

The purpose of impact evaluation is to assign relative significance to the predicted impacts associated with the project and then to determine the priority in which impacts are to be avoided, mitigated or compensated. This ranking is obtained from the perceived importance of the impacts to the environment and to the human constituencies concerned with the assessment. Impact evaluation also provides a means of comparing various development options and of communicating evaluation results to the public and to decision makers.

A wide variety of analytical methods and models is available to aid in this evaluation. A central challenge is to select one or more methods that are best suited to particular project type and possible environmental disturbances. The criteria employed within the method of choice should emphasize the following four factors: ecology, social, environmental standards, and statistical significance.

2.9. Preventing, mitigating and monitoring

Having identified all the significant impacts during the assessment, it remains to mitigate these and implement preventative measures. In some cases unacceptable impacts may be avoided at the design or construction stage with relatively minor modifications to the original plan. However, some impacts may demand a major change, for example, the elimination of a particular milling reagent. It is important that the design and operating departments work closely with the environmental department at the planning stage to develop cost effective mitigating measures.

Monitoring programmes generally arise from the findings of the assessment. The proponent proposes monitoring programmes based on the identified potential impacts and sensitive areas in the local environment. Regulatory agencies generally must approve monitoring programmes and often will make certain monitoring requirements a condition of the operating license or permit. As these monitoring programmes become more complex, the cost rises dramatically. It is vital that the assessment identifies good marker biota, if this type of monitoring is to be undertaken; otherwise the cost of the monitoring programme could become an unsupportable burden on the project.

2.10. Remediation and decommissioning

A major aspect of the environmental assessment process is the development of the decommissioning and final rehabilitation plan, including the reclamation of all land, air and water resources that are likely to be adversely affected by the proposed mining and milling operation. The decommissioning plan will be based on a number of factors including the mine plan, and the baseline environmental information, and the need to consider those factors that will assure the long-term physical, geotechnical and geochemical stability of the site.

It is important to integrate the mine plan and decommissioning plan to the greatest extent possible, such that remediation of a mined area can be started as soon as mining is completed. Significant economic savings to mine owners may result from this practice through a decrease in reclamation costs. Further, wherever practical, completion of rehabilitation work during mining operations, limits the amount of rehabilitation work after completion of mining.

The objective of the decommissioning and closure plan is to restore the affected surface and groundwater such that they are suitable for uses for which they were suitable prior to mining. Methods to achieve this objective for both the affected groundwater and surface waters are described in the following sections. An acceptable closure plan prepared at the time of permit application, prior to the development of a mine, will be an interim plan, as the plan is based upon forecasts and projections. The life and operation of the mine may necessarily change. Hence, the closure plan is dynamic and will periodically need to be re-evaluated as the operation goes on.

An initial reclamation cost estimate should be prepared for all aspects of the project. A 25% overall contingency is applied to the total cost estimate. The estimate should be updated on an annual basis during the entire life of the project.

2.11. Socio-economic impact

In today's world, the standards and practices in environmental protection are as much determined by social attitudes as they are by scientific and technical assessment.

Socio-economic issues have become increasingly important in recent years. Impacts on local populations may disrupt current local lifestyles but there may also be positive impacts by providing employment in an otherwise depressed area. Current resource use, such as agriculture, wildlife harvesting, fishing, and tourism are important. Cultural issues must be considered, including both, current conditions, and archaeology and history. The costs and benefits of the project must be carefully weighed.

Early in the process a relationship must be established with the various stakeholders to create a consultative process and community involvement. This process provides a forum for discussing the community's needs, feelings and attitudes and the developer's needs, and is used to optimize social and economic benefits to the community and the developer.

There is an expectation from the community that the developer will begin community consultation at the planning stage of the project and continue throughout the project life.

3. DESCRIPTION OF ISL

3.1. Importance of ISL

Despite its limited applicability to specific types of uranium deposits (sandstone deposits), *in situ* leach extraction of uranium accounted for about 18.3% of worldwide production in 2002 (6 410 tonnes of Uranium of the total world production of 36 040 tonnes) [1]. In 2002, ISL production took place in Australia, China, Kazakhstan, the Russian Federation, the United States of America and Uzbekistan. As of 1 January 2003, Reasonably Assured Resources (RAR) and Estimated Additional Resources-Category I (EAR-I) recoverable at costs less than US$ 40/kg U and amenable to ISL extraction total 526 200 t U, or 21% of the total RAR and EAR-I recoverable at costs less than US$ 40/kg U [1]. ISL amenable resources account for nearly all of the RAR and EAR-I recoverable at a cost of less than US$ 40/kg U in Kazakhstan and Uzbekistan, which together account for about 25% of the worldwide RAR and EAR-I in this cost category. Similarly, Australia, the Russian Federation and the United States of America also have significant ISL amenable resources at a cost less than US$ 40/kg U.

In 2002, the combined annual capacities of existing ISL production centres was about 10 000 tonnes of uranium.

ISL has economic and environmental advantages for producing uranium from carefully selected deposits when projects are properly designed and operated by experienced personnel. The importance of ISL is expected to increase, with development of new projects underway in Australia, Kazakhstan and the Russian Federation.

3.2. The ISL method

3.2.1. General description

In situ leach (ISL) mining is defined as the leaching of uranium from a host sandstone by chemical solutions and the recovery of uranium at the surface. ISL extraction is conducted by injecting a suitable leach solution into the ore zone below the water table; oxidizing, complexing, and mobilizing the uranium; recovering the pregnant solutions through production wells; and, finally, pumping the uranium bearing solution to the surface for further processing.

ISL involves extracting the ore mineral from the deposit, with minimal disturbance of the existing natural conditions of the earth's subsurface and surface. In contrast to underground and open pit mining, there are no rock dumps and tailings storage facilities, no dewatering of aquifers, and much smaller volumes of mining and hydrometallurgical effluents that could contaminate the surface, air and water supply sources. Therefore the impact of ISL on the environment is much less than for other mining methods as long as projects are properly planned, operated and closed using best practices.

Evaluating the suitability of an orebody for uranium extraction by ISL requires information regarding the accessibility of the uranium mineral to the leaching solution and its solubility in the leaching solution. Based on current technology the orebody should be situated below the natural water table in a permeable zone, most likely a sandstone. Impermeable beds above and below the host sandstone (aquitards) ensure better hydrologic control of leaching solution during mining and facilitate restoration of the groundwater quality following completion of mining.

Selection of the lixiviant, or leaching solution, is a key factor in designing an ISL operation. This selection is driven by uranium recovery efficiencies, operating costs, and the ability to achieve satisfactory groundwater quality restoration. The primary choice is between a sulphuric acid lixiviant and bicarbonate-carbonate lixiviant. In general acid systems would not be considered for calcareous deposits because of high acid consumption. Sulphuric acid systems have long been used in Eastern Europe and Asia, while carbonate systems are preferred in the USA. Acid systems are now employed in Australia on orebodies that reside in saline aquifers.

In ISL extraction the primary source of potential contamination is the acidic leaching solution. The low pH of the fluid results in the dissolution of various metals contained within the host rock. The combination of low pH and elevated concentrations of metals as well as radionuclides creates a risk to surface waters and soil (from spills) and a separate risk to adjacent groundwaters.

ISL has evolved to the point where it has been demonstrated to be a controllable, safe, and environmentally benign method of uranium mining that should operate under strict environmental controls.

3.2.2. Advantages and disadvantages

In situ uranium mining technology can be both an economic and environmentally acceptable method for extracting uranium. Because of the lower capital and operating costs associated with *in situ* mining, and because of the minimal environmental impact of this mining technique, ISL is the only uranium mining method used in Kazakhstan, the United States and Uzbekistan. The advantages of ISL extraction of uranium relative to conventional mining include:

- Lower capital and operating costs,
- Shorter lead times for mine development,
- Much smaller workforce required,
- More flexible mine planning and quicker ramp-up in response to market improvements,
- Inherently safer working environment,
- Limited environmental impacts,
  - No waste rock,
  - No tailings,
  - No ore dust or direct ore exposure,
  - Lower consumption of water,
  - Economic recovery of lower grade ores (increases resource utilization).

To be mined by ISL, uranium deposits must be located below the water table in permeable sandstone aquifers. These sandstone aquifers provide the “plumbing system” for both the original deposition and the recovery of the uranium.

ISL is not, however, without potential environmental consequences, particularly its potential impact on groundwater.

- Lower recovery factor of in-place reserves.
- Risk of groundwater contamination.
- Applicability limited to specific types of uranium deposits (sandstone deposits).

3.2.3. ISL well field

To effectively extract uranium deposited by circulating groundwater, geologists first thoroughly define the aquifer system through surface drilling, geophysical logging, and detailed mapping of the ore trends. Well fields are then laid out to best fit the orebodies and the natural hydrogeological conditions.

Once the shape and position of the orebodies are mapped, the locations of injection and recovery wells are planned to effectively contact the uranium ore. A typical well is shown in Figure 2. The individual wells are connected together by pipelines to allow the production well fluids to be gathered together into trunk lines and piped to an ion exchange facility for uranium removal. Similarly, the water is returned to the injection wells by a network of piping.

Wells are cased and grouted to ensure that leaching fluids only flow to and from the ore zone and do not affect any overlying or underlying aquifers. Submersible electric pumps or air lifts are used in the production wells to move fluid to the surface and into the uranium recovery plant.

As shown in Figure 3, a well field design is typically a grid with alternating production and injection wells. The spacing between the wells usually ranges from 20 to 30 meters. A series of monitoring wells are situated around the well field to ensure that leaching solutions do not move outside the mining area. Monitoring wells are normally also completed in the overlying and underlying aquifers within the well field. All monitoring wells are periodically sampled to verify the containment of the leach solutions.

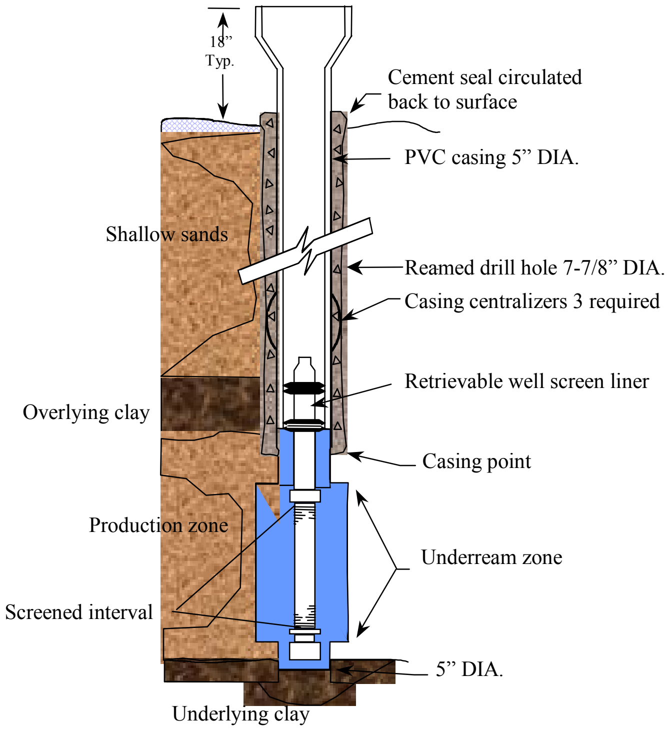


FIG. 2. Typical ISL well layout.

The pregnant or uranium bearing solution from the production wells is pumped to the treatment plant, where the uranium is typically removed in an ion exchange (IX) resin system. The uranium is stripped from the ion exchange resin, and then precipitated by a chemical process.

Most of the leaching solution is refortified with chemicals and returned to the injection wells, but a small amount may be bled off and treated as waste water. This bleeding off process solution is designed to create a hydraulic cone of depression within the well field to ensure there is a flow of fresh groundwater into the well field from the surrounding aquifer, which minimizes the potential for leaching fluid moving away from the well field.

3.2.4. *Well field remediation*

After ISL mining is completed, the quality of the groundwater in the production zone must be restored to a baseline standard determined before the start of the operation, so that the groundwater is suitable for any use that it was suitable for prior to mining. Contaminated water drawn from the aquifer is routed through reverse osmosis (RO) or similar equipment and the clean water is re-injected. Fluids containing high dissolved solids may be disposed of by deep well injection into existing salt water horizons.

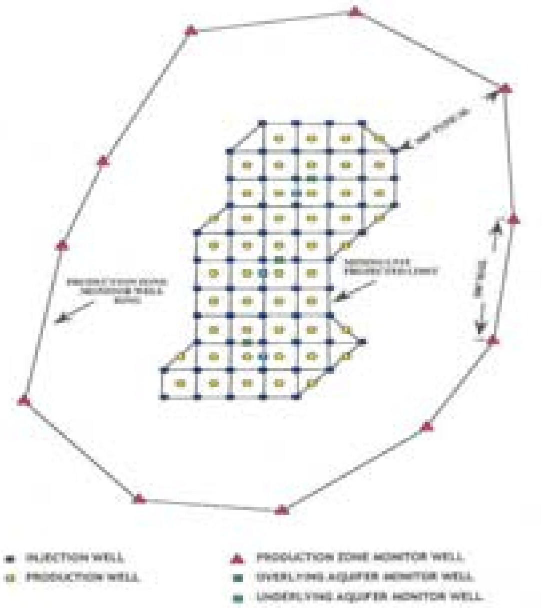


FIG. 3. Typical well field development pattern.

Upon decommissioning, all wells are sealed and capped, process facilities are removed, all evaporation ponds are reclaimed and re-vegetated and the land is returned to its previous uses, or as otherwise agreed with the regulatory body and the land owners.

Because the potential impacts on local groundwater quality may be greater for ISL mining than most conventional mining, an expanded discussion of groundwater issues follows.

3.2.5. *Water quality criteria*

The final standard of water quality to be achieved during restoration is based on pre-mining baseline data from each mining unit, the applicable use suitability category and available technology and economic conditions at the time of restoration. Baseline is derived by using the mean of the pre-mining baseline data, taking into account the variability between sample results (baseline mean plus or minus tolerance limits, after outlier removal).

3.2.6. *Remediation criteria*

Remediation criteria for the groundwater in a mining unit are generally based on the mining unit (production-injection well field) as a whole, on a parameter by parameter basis.

Restoration target values need to be established for all parameters affected by the mining process. The mean of the pre-mining values will typically be the restoration target values for the initial mining units. These parameters may, however, vary depending on the laws of the regulatory body that has jurisdiction over a given operation. If during restoration, the average concentration of a parameter in the designated production area wells of a mining unit is not reduced to the target value within a reasonable time, a report needs to be prepared describing the restoration method used, predicted results of additional restoration activities, and an evaluation of the impact, if any, that the higher concentration has on the groundwater quality and future use of the water. This report becomes the technical basis for determining if the higher concentration of a particular species can be accepted as an Alternate Restoration.

3.2.7. Rehabilitation method

The primary restoration technique may be a combination of several methods such as natural attenuation, groundwater sweep, and clean water injection.

The concept of groundwater rehabilitation by natural attenuation has gained increasing worldwide acceptance during the past decade. Natural attenuation has an inherent economic advantage as it is by far the lowest cost option for groundwater remediation. The total dissolved solids (TDS) content of a plume of contaminated or perturbed groundwater is gradually altered by hydrodynamic dispersion and physical-chemical reactions between the fluids and host rock. The overall rate and effectiveness of natural attenuation depends on acid neutralization capability of the host rock, the ion exchange characteristics of clay minerals, and the hydraulic gradient of the aquifer. It must be appreciated that neutralization of residual acidic groundwaters by natural attenuation may require tens, perhaps hundreds, of years [2].

In recent years efforts have been devoted to accelerating the natural attenuation process by employing groundwater sweep, described below, and similar techniques. Higher flow rates within the aquifer coupled with a blending of fresh waters and perturbed groundwater (dilution) combine to expedite the initial phase of neutralization and TDS reduction. However, the final portion of the attenuation process is still driven by natural hydro-geochemical processes and thermodynamics.

Groundwater sweep involves withdrawing water from selected production and injection wells that draw uncontaminated natural groundwater through the leached area, displacing the leach solutions. Clean water injection involves the injection of a better quality of clean water in selected wells within the production area while pumping other production and/or injection wells, which again displaces the leaching solutions with the better quality water. The source of the clean water may be from an Electrodialysis Unit (EDR) or Reverse Osmosis (RO) type unit, water produced from a mining unit that is in a more advanced state of restoration, water being exchanged with a new mining unit being placed in operation, or a combination of these sources. Water withdrawn from the production zone during restoration will first be processed through an ion exchange unit to recover the uranium, then will be treated and reused in the project, treated and discharged with regulatory approval, or routed to a holding pond for future treatment and/or disposal.

Chemical reductants are beneficial because several of the metals that are solubilized during the leaching process, are known to form stable insoluble reduced compounds, primarily as sulphides. Prominent among such metals is uranium, which is concentrated as a result of the reduced state of the orebody. The introduction of a chemical reductant into the mine zone at the end of a mining phase is designed to expedite the return of the zone to natural conditions and to return as many of the solubilized metals as possible to their original insoluble state. By effecting this partial restoration directly within the formation (*in situ*), the external impact of groundwater restoration is minimized.

The chemical reductant may be added above ground to the clean water stream being injected into selected wells. The reductant could be a sulphur compound such as gaseous hydrogen sulphide (H_2S) or dilute solutions of sodium hydrosulphide (NaHS) or sodium sulphide (Na_2S). Dissolved metal compounds that are precipitated by such reductants include those of arsenic, molybdenum, selenium, uranium, and vanadium. All of these may be present in concentrations above baseline levels at the conclusion of mining.

The reductant normally is introduced during the middle of the restoration process because the introduction of sulfur and sodium increases the total dissolved solids (TDS) level of the injected fluid. Once the reducing conditions are re-established, oxidant free clean water can be injected to effect the final reduction in TDS. If gaseous hydrogen sulphide is chosen for use, a programme for its safe handling needs to be prepared and submitted to the appropriate agency prior to its use.

3.2.8. Restoration sampling

When sampling results indicate that restoration has been achieved, the designated production area wells will be sampled and analysed for a full suite of parameters such as those listed in Table II. If the data confirm restoration is complete, this will initiate the stability demonstration period. In the stability demonstration period the full suite assays will be repeated periodically for those same wells.

Table II. Baseline water quality parameters

MAJOR IONS	TRACE METALS	RADIOMETRIC
Calcium	Arsenic	Gross Alpha
Magnesium	Barium	Gross Beta
Sodium	Boron	Radium–226
Potassium	Cadmium	Radon–222
Total Carbonate	Chromium	
Bicarbonate	Copper	
Sulphate	Iron	
Chloride	Manganese	
Ammonium	Molybdenum	
Nitrite + Nitrate	Selenium	
Fluoride	Uranium	
Silica	Vanadium	
TDS	Zinc	
Alkalinity		
pH		

When the sampling data indicate that the mined out aquifer has been restored and stabilized, a report documenting this will be filed with the appropriate regulatory agencies along with a request for certification of restoration. Plugging of wells and surface reclamation of the mining unit can commence only after receipt of a restoration certification.

During restoration, sampling of monitor wells for each mining unit may continue at the same frequency and for the same parameters as during mining. However, during stability monitoring the monitor well sampling frequency can be reduced and the sampling terminated at the end of the stability demonstration period. Unless requested otherwise and approved by the applicable regulatory agencies, the production area wells in a mining unit to be sampled for determining restoration and stability normally are the same wells used for collecting pre-mining baseline data.

3.2.9. Well plugging (decommissioning) procedures

Wells no longer needed for operations or restoration and stability demonstration will be plugged. The pumps and tubing will be removed from the wells and each well will be filled from its base to within 1.5 m of the surface with an approved abandonment mud or a cement slurry. The casing will then be cut off a minimum of 0.5 m below the surface and a cement plug will be placed at the top of the casing. The area will then be backfilled, smoothed to blend with the natural terrain, and reclaimed as specified in an approved surface reclamation plan.

3.2.10. Surface reclamation

All lands disturbed by the mining project need to be returned to their pre-mining land use, unless an alterative use is justified and is approved by the regulatory agencies and the landowner, i.e. the farmer desires to retain roads or buildings. The objectives of the surface reclamation effort are to return the disturbed lands to production capacity equal to or better than that existing prior to mining. Soils, vegetation and radiological baseline data are used as a guide in evaluating final reclamation.

3.2.11. Surface disturbance

The primary surface disturbances associated with ISL are the sites for the uranium recovery plant and evaporation ponds. Surface disturbances also occur during drilling programmes, pipeline installations, road construction, and pumping station construction. These disturbances, however, involve relatively small areas or have only short-term impacts.

Disturbances associated with evaporation ponds, ion exchange satellite plants and field flow control buildings, will be for the life of those activities only. Disturbance associated with drilling and pipeline installation will normally be limited, and can be reclaimed and reseeded in the same season. Vegetation normally is re-established over these areas within two years. Disturbance for access roads should also be minimized.

3.2.12. Topsoil handling and replacement

Limiting soil disturbance is an important goal for a mining operation. Topsoil from the well sites, evaporation ponds and facilities is stockpiled and the piles seeded with a cover crop to control erosion. Shaping, seeding with a cover crop and mulching of stockpiles helps to minimize loss to erosion. Placing identifying signs on each topsoil stockpile helps prevent misuse of the stockpile. Soil stockpiles need to be actively managed to retain their structure and flora so that they will remain a useful resource for rehabilitation activities.

Within the well fields, topsoil removed from new access roads and flow control station building sites will be stockpiled as discussed above. If unanticipated high traffic roadways are developed, the top soil on such roadways would be subject to the same programme of removal, stockpiling, seeding and mulching to control erosion. For areas where only limited temporary disturbance occurs, such as for well sites and pipeline construction, the topsoil may be bladed to one side and then re-spread over the area and mulched as soon as construction is completed. A mixture of native grass seed suitable for a long-term cover can be used to protect topsoil stockpiles and/or re-top-soiled areas which are expected to remain in place for longer than one year prior to final seeding. These will provide protection for the topsoil and will minimize losses to wind and water erosion.

Additional measures taken to protect the topsoil in the well field areas include restricting normal vehicular traffic to designated roads and keeping required traffic in other areas of the well field to a minimum. Seeding of disturbed areas with a cover crop in a well field not needed for normal access helps to minimize erosion.

After contouring for final reclamation has been completed, mechanically loosening the remaining access roads or hard packed areas is recommended prior to top-soiling. Topsoil will then be spread evenly over the disturbed areas and seeded. The goal of final contouring is to blend the disturbed areas into the natural terrain and to establish drainage and to eliminate depressions that could accumulate water.

3.2.13. Revegetation practices

Establishing an extended reference area that includes the primary vegetation types that may be disturbed serves as a reference for measuring the relative quality and quantity of vegetation established during reclamation.

During mining operations seeding the topsoil stockpiles, and as much as practical of the disturbed well field and pond areas with a cover crop helps to minimize wind and water erosion. After top-soiling for the final reclamation, an area can normally be seeded with oats to establish a stubble crop then reseeded with grasses the next growing season using an approved mix of live seed of native species.

Fencing of vegetation in larger reclaimed areas prevents damage from livestock grazing until the newly established plant community is capable of maintaining itself under normal management practices.

Criteria for determining the success of the reclamation efforts needs to include 1) post-mining vegetation cover and production equal to that on an appropriate comparison area, 2) species composition and diversity capable of supporting the planned post-mining use, and 3) a reclaimed vegetation community able to sustain environmental pressure at a rate equal to that of the surrounding native areas.

3.2.14. Site decontamination and decommissioning

Once groundwater restoration in the final mining unit is completed, decommissioning of the recovery plant site and the remaining evaporation ponds can be initiated. In decommissioning the recovery plant, the process equipment may be dismantled and sold to another licensed facility or decontaminated. After decontamination, materials that will not be reused or that have no resale value, such as building foundations, may be buried on-site or managed in accordance with regulatory requirements.

The plant site then needs to be contoured to blend with the natural terrain, surveyed to ensure gamma radiation levels are within acceptable limits, top-soiled, and reseeded as per the approved reclamation plan. After all liquids in an evaporation pond have evaporated or been disposed in a licensed facility, the precipitated solids and the pond liner can be removed and disposed of in a licensed facility. The area will then be contoured to blend with the natural terrain, surveyed to ensure gamma levels are not exceeded, then top-soiled and reseeded as per the approved plan.

Gamma surveys are conducted during the decommissioning of each mining unit. Site decontamination and decommissioning are regulated by the regulatory authority, that provides guidelines to the mining operators.

3.2.15. Final contouring

Recontouring of land where surface disturbance has taken place will restore it to a surface configuration, which will blend in with the natural terrain and will be consistent with the agreed post-mining land use. Proper environmental management will ensure that no major changes in the topography result from an ISL mining operation.

3.2.16. Radiation protection

All radiation safeguards that are applied to conventional mining and milling are applied at an ISL mining operation, despite the fact that most of the orebody's radioactivity remains well underground and there is, therefore, minimal increase in radon release and no ore dust. Employees are monitored for alpha radiation contamination and personal dosimeters are worn to measure exposure to gamma radiation. Routine monitoring of air, dust and surface contamination are undertaken along with extensive water quality testing to ensure and document that all environmental, health and safety objectives of the operation are met.

4. MODEL ENVIRONMENTAL ASSESSMENT PROCESS

Completing an environmental impact assessment is an important part of planning. The impact of each project is evaluated in the context of the pre-existing environment and regulatory and licensing requirements. An impact on the environment is any change in the biophysical and/or social environment caused by or directly related to a former, on-going or proposed activity. Social and biophysical impacts are inextricably linked together: humans and their environment are interdependent and interactive, as humans need a healthy environment in order to survive.

As with all industrial activities proper environmental planning is an essential part of development of uranium ISL mining projects. However, through its demonstrated performance, ISL mining has been shown to have clear environmental and safety advantages when compared to conventional mining. Furthermore with proper environmental assessment and good operational practice ISL uranium projects may be developed, operated and closed with little or no safety and environmental impacts.

The environmental impact statement is produced by the proponent of the mining project with input from members of the public in the area of the proposed development and the regulatory authority, which will judge the acceptability of the project and, if deemed acceptable, will issue the appropriate approvals.

4.1. Baseline environmental information

The pre-ISL mining status of the environment needs to be characterized and documented to assist in the assessment process, and to provide a record of the initial conditions. Baseline data collection requirements are normally specific to a particular project site, and may be specified by the governing regulatory agency with input from affected third parties. The following gives the elements that are typically considered to be of interest in a baseline data collection process.

It is necessary to consider baseline data from both regional and local areas. The extent of the regional assessment will be dependant on both the project area and the specific conditions being considered. The importance of careful and accurate collection of baseline data cannot be overemphasized. These data will be employed to assess not only the antecedent conditions of the site, but also to assess the environmental performance and regulatory compliance of the ISL project during its operating life. Further, these data form the basis for certification of final restoration and reclamation of the air, soils, and waters within and around the site.

Added importance is placed on this information when other non-related activities in the immediate area have the potential to create similar, adverse environmental impacts.

- Site location

  The site location and layout for the proposed *in situ* leach operations need to be described using maps that show the relationship of the site to local water bodies (rivers and lakes), geographical features (highlands, forests), transportation links (roads, rails, waterways), political subdivisions, population centres (cities) historical and archaeological features and non-applicant property (farms, settlements).

- Meteorology

  A description of the general climate of the region and local meteorological conditions, based on data collected onsite or at nearby meteorological stations is needed to establish baseline and operating conditions. Data to be collected include precipitation, temperature, wind direction and speed, humidity, evaporation, etc.

  The occurrence of potentially severe weather in the area and its effects needs to be described.

  Data periods need to be defined by month and year, and cover a time period that is sufficient to identify long-term trends and support meteorological modeling. The length of the time will vary on a case-by-case basis.

- Geology

  A description of the regional geology based on referenced information helps establish a geologic context for an operation.

  The geology in the mining area can be described using geologic cross-sections based on geophysical logs and field investigation. The production zone and confining zones need to be identified on the cross-sections. When applicable, the depositional environment of the host aquifer can be discussed, including the physical characteristics (grain size, sorting, etc.) and mineralogical composition of the ore-bearing units, especially the finer fractions of the ore.

- Surface hydrology

  Surface water quality and quantity will need to be characterized where use, quality and quantity could be affected by the mining operations. Mapping the contributing drainage area to the mining area will establish the acreage involved and help identify groundwater/surface water interactions that need to be discussed.

- Subsurface hydrology (Hydrogeology)

  Regional groundwater quality needs to be defined for the mining area based on groundwater quality data collected for a sufficient length of time to identify any important spatial and time variant properties of the potentially affected and surrounding aquifers, to show the pre-mining hydro-geochemistry of the area, and to identify existing or anticipated impacts of adjacent mines on the groundwater quality within the area. In addition, consideration should also be given to the requirements of any existing beneficial users of the aquifer concerned. Table III lists water quality parameters that should be measured.

  A representative number of samples will be needed for each affected area. The number of samples necessary to define groundwater quality varies with the area to be studied. More samples will be necessary for partially confined aquifers and for shallow water table aquifers which may react more quickly to seasonal changes and to surface affects. Evaluation of the reliability of the data is an integral part of the data gathering programme.

  The importance of properly defining the baseline groundwater quality for individual mining units cannot be overemphasized. The method for detecting, each fluid excursions and the extent to which aquifers must be reclaimed are dependent on well characterized mining unit aquifers.

  Baseline water quantity

  Potentiometric surfaces with sufficient data points to spatially define affected aquifers need to be superimposed on topographic maps for analysis. Locations of all wells used in developing the potentiometric surface map along with their individual water elevations helps to validate the maps.

Table III. Typical baseline water quality indicators to be determined during pre-operational data collection

Trace and Minor Elements		
Arsenic	Copper	Nickel
Barium	Fluoride	Selenium
Boron	Iron	Uranium
Cadmium	Manganese	Vanadium
Chromium	Molybdenum	Zinc
Common Constituents		
Ammonia	Carbonate	Potassium
Alkalinity	Chloride	Silica
Bicarbonate	Magnesium	Sodium
Calcium	Nitrate	Sulphate
Physical Indicators		
Specific Conductivity	Total Dissolved Solids	pH
Radiological Parameters		
Gross Alpha	Gross Beta	Radium–226 and –228

Aquifer properties

Pump tests are necessary to define aquifer properties. The purpose of the testing is to define aquifer properties within the affected area, especially hydrologic boundary conditions, layering effects, directional permeability, and the vertical confinement of the production zone. Transmissivity data of sufficient detail is necessary to confidently identify axes of directional transmissivities in the production zone.

Documentation of groundwater use within the area that may be affected by mining, is essential in order to identify competing interests for groundwater allocation.

Parameters to be considered are:

Hydraulic conductivity
Transmissivity
Storage coefficient
Total porosity
Effective porosity
Aquifer thickness
Piezometric surface
Hydraulic gradient
Permeability
Ambient temperature (seasonal variations)

- Abandoned drill holes

Documentation of all known pre-mining wells and drill holes in the proposed mining and adjacent areas will help to ensure that proper abandonment procedures were used; plugging of each abandoned well or hole needs to be verified.

- Flora and Fauna

A description of the flora and fauna in the vicinity of the site, their habitats and their description is necessary to help identify potential impacts on each species. Species that are critical to the structure and function of the ecological system or a biological indicator of radionuclides or chemical pollutants in the environment need to be identified. An inventory needs to be made of the terrestrial and aquatic organisms, on or near the site, their relative abundance, and species that migrate through the area or use it for breeding grounds. Documentation of populations and distributions of domestic fauna, in particular cattle, sheep and other meat animals, and game animals, that may be exposed to radionuclides is essential to establish potential impact on the food chain. The occurrence of rare, threatened, or endangered species, on and within a minimum of 1 km of the licensed area need to be noted, along with information on surveys/literature searches conducted for presence/absence determination.

- Soil/subsoil

Descriptions of the physical and chemical characteristics of top-soils and their delineation into mapping units help plan site reclamation. To achieve this, the following are usually provided.

- A soil inventory map with soil units and affected surfaces outlined.
- Soil mapping unit and profile descriptions.
- Quantitative estimates of all suitable topsoil for areas where significant disturbances may occur.

Soil sampling sites need to be clearly marked on the soils map, and the sampling density approved by regulatory authorities. The major soil horizons, (A, B, and C) should be separately described, sampled, and analysed. Typical analysis schemes may include the following parameters:

pH	(hydrogen ion activity)
Conductivity	(µS/cm @ 25ºC)
Water saturation	(% moisture)
Particle Size Analysis	(% clay, silt, sand, etc.)
Texture	
Soluble Ca, Mg, and Na	(mg/l)
Carbonates	(% weight)
Chloride	(mg/l)
Sulphate	(mg/l)
Selenium	(ppm)
Arsenic	(ppm)
Nitrate-Nitrogen	(ppm)
Ammonia	(ppm)
Organic carbon	(% weight)
Total carbon	(% weight)
Uranium	(ppm)
Molybdenum	(ppm)
Vanadium	(ppm)
Gross alpha	(Bq/kg)
Gross beta	(Bq/kg)
Radium–226	(Bq/kg)

- Background radiological characteristics

Evaluation of radiological background of the site should be made before operations start, including measurements of radioactive elements (daughter products of uranium, thorium, radium) occurring in soil, air and surface and groundwater that could be affected by the proposed operations.

- Background non-radiological characteristics

Information on site specific non-radiological characteristics, particularly those that are related to expected site related effluents needs to be collected including such indicators as heavy metals and other toxic substances in surface water and groundwater, atmospheric pollutants and dust, which could affect water and air quality.

Other regional sources for these same indicators also need to also be documented.

- Noise

Noise level measurements made at different periods of time (day and night), at the projected site of the mine and nearby habitations will help identify those that may be affected by the project. Identifying sources of significant noise levels will help in preparation of noise mitigation plans.

- Previous and present industrial activities

Previous and present industrial activities, with their possible negative impacts on the environment (air and water contamination, noise, visual impact, etc.) need to be documented, with emphasis placed on information regarding potential contaminants from these industries that could also be expected from ISL site effluents.

An inventory of existing and abandoned wells and boreholes should be made, including those used for agricultural purposes.

- Previous and present agricultural activities

Documentation of previous and present agricultural activities in the vicinity of the proposed project will help identify domestic animals and other meat animals, and crops that may be part of the food chain delivering radiation exposure to man.

- Local population

Population data, based on the most recent census, including maps that identify places of population grouping, within a minimum of 5 km radius from the projected mining area needs to be gathered to help in assessing the socio-economic impact of the proposed project.

- Employment

Characteristics of employment, within a minimum of an 80 km radius from the projected mine, need to be documented, including type of activities, levels of employment, unemployment and availability for employment related to the project (permanent or contracted).

- Other environmental features

These include environmental site characterization information that does not clearly fall into any of the above subsections. These typically will be site specific, and may be used by the applicant to mitigate unfavourable conditions, or to provide additional information in support of the description of the proposed facility. Table IV could help to specify characteristics of each environmental component of the project area.

Table IV. Characterization of the environmental components of the project area

Environmental components	Conditions or details	Physical characteristics	Chemical characteristics		Other characteristics
			Radioactive	Non-radioactive	
Air	Climate Meteorology Location, morphology of earth surface	+	+	+	+
Water	Surface Sub-surface Groundwater	+	+	+	+
Rocks	Available mineral resources or its absence in available horizons		+	+	
Soil	Variety Value	+	+	+	+
Flora	Variety Endangered species		+	+	
Fauna	Variety and abundance Endangers species		+	+	

Human	Population Employment Previous Activity: Present Activity Infrastructure Plants Farms Roads, etc.	+	+	+

4.2. Project description

The proposed ISL project needs to be described in detail, including all steps from the beginning to the end of the project. Descriptions of the major phases of exploration, pilot testing, commercial operation, groundwater restoration, waste remediation, site remediation and decommissioning, post decommissioning, and associated social-economic activities with supporting written procedures, maps, data, and time lines are essential for full characterization of the project. In preparing this information, it is important to recognize that a key element of an environmentally sound ISL project is an understanding that each phase of the project is equally important and must be conducted in an environmentally responsible manner. As such, waste management and pollution prevention are important aspects of each phase. To aid in the design of management of environmental safeguards, it is recommended that waste management be emphasized for each working phase, and that these individual programmes be integrated into an overall waste management programme (or phase) for the Life of the Project (LOP).

- Exploration

  Drilling-type, drilling mud, water used, borehole abandonment, noise, spill prevention, etc.

- Pilot testing (see commercial operation list below)

- Commercial operation

  Construction,
  Drilling-type, drilling mud, core, water used, etc.,
  Well completion (casing, cementing, screening, mechanical integrity testing, etc.),
  Pipelines (setting surface or subsurface, leak monitoring, etc.),
  Tanks,
  Ponds (settling, evaporation, etc.),
  Airborne emissions,
  Liquid disposal (wells, land application, surface discharge, etc.),
  Solids disposal (radioactive, non-radioactive),
  Central processing plant (tankage, pipelines, materials, control and management system),
  Training and safety,
  Transportation,
  Topsoil protection / preservation,
  Services,
  Noise.

- Groundwater remediation

Leaching solution treatment, volumes, type of treatment, pore volumes, water consumption, discharge volumes, quantity and quality, expected limits for the end, well decommissioning, materials used, etc.

Liquids waste disposal, etc.

- Remediation and decommissioning

  Typical decommissioning activities include:

  Plugging and abandoning wells,
  Conducting radiological surveys of facilities, process equipment, and materials to evaluate the potential for exposure during decommissioning,
  Removing contaminated equipment and materials to an approved disposal facility or reusing them,
  Buildings decommissioning,
  Ponds decommissioning,
  Decontaminated items to be released for unrestricted use,
  Surveying excavated areas for contamination and removing any contamination,
  Road reclamation,
  Backfilling and recontouring disturbed areas,
  Performing final site soil radiation background surveys,
  Revegetating disturbed areas.

- Waste management (Life of Project)

  Liquid waste disposal,
  Solid effluent waste disposal,
  Gaseous effluent and airborne particulate waste disposal.

- Post decommissioning

  Groundwater monitoring,
  Vegetation monitoring,
  Air monitoring,
  Soil stability monitoring.

- Associated socio-economic activities

  Employment,
  Infrastructure improvement (roads, railroads, electrical supply, etc.),
  Education improvement (schools, instructions),
  Cultural influence,
  Community consultation and information dissemination.

Table V may help to organize the structure and types of activities and impacts, and establish links between them.

Table V. Links between activities and impacts

Types of activities	Types of facilities or mechanisms and engines	Types of effluents or impacts	Characteristics of effluents or impact
Exploration			
- Preparing for drilling	Excavation	Gaseous, dusty, mechanical	Toxic gases, Changing of soil density
- Drilling and abandonment	Drilling machine, Compressor, Electrical generator Compressor	Gaseous, dusty, mechanical	Radioactive water
- Hydrological tests	Trailer	Liquid	Toxic gases
- Decommissioning		Gaseous, dusty, mechanical	
Construction of testing or operating plant			
- Preparing for construction - Clearing - Cut/fill - Dredging	Excavator Different engines	Gaseous, dusty, mechanical	Toxic gaseous Changing of soil density Noise, etc.

4.3. Potential environmental impacts identification

Once the baseline environmental information and the ISL project description are complete, it is possible to identify potential environmental impacts. At the same time impacts to the local social culture and economy are estimated.

Materials and activities, with potential for environmental impacts include:

Chemical components from ISL process (acids, bases, oxidants, radioactive components, heavy metals, other metals, etc.),
Lixiviants,
Other chemical stocks (oil, fuel, etc.),
Top soil disturbances,
Yellowcake, liquid wastes, solid wastes, scrap materials, etc.,
Excavations,
Others (noise, etc.)

Sources for such materials and activities to impact the environment include:

Operating well casing (subsurface),
Pipelines (surface),
Well heads,
Process vessels,
Storage tanks,
Pump seals,
Ponds (air, soil),
Yellowcake packaging,
Disposal well casing leaks,
Yellowcake drying system,
Transport vehicles,
Fire,
Ancillary equipment (electrical transformers, air compressors, machinery, tools, etc.).

Pathways for such materials to travel include:

Airborne dispersion,
Surface waters,
Groundwaters,
Food chain.

Resulting targets where such materials could interact to create environmental impacts include:

Local environment,
Regional environment,
Surface water,
Groundwater,
Soils,
Flora,
Fauna,
Livestock,
Humans.

In this case the main parts of the environment are mentioned as targets. It is understood that the final targets are flora, fauna and humans, as all live in the impacted environment.

4.4. Potential environmental impact evaluation

Impact prediction or evaluation is a complex process, which defines:

- The relationship of each impact to the project,
- The probability of impact occurrence,
- The magnitude, spatial and temporal extent of each impact.

In addition the nature of all significant impacts needs to be specified as direct, indirect, cumulative or residual.

The relative significance of the predicted potential impacts associated with the project is estimated during this step. Based on this, the priority in which impacts are to be avoided, mitigated or compensated is determined. This ranking is obtained from the perceived importance of the impacts to the human constituencies concerned with the assessment.

Key factors for establishing impact significance are:

- Level of public concern,
- Scientific and professional judgment,
- Disturbance/disruption of the environment, and
- Degree of negative impact on social values and quality of life.

As a wide variety of analytical methods and models for evaluating impacts is are available, the challenge is in selecting those that provide the needed information in the most cost-effective way. Assessment criteria generally will include:

- Ecological importance,
- Social importance,
- Environmental standards, and
- Statistical significance.

One method that may be used for the evaluation of impacts is to conduct a risk assessment. The risk assessment process involves the establishment of context, identification of risks, evaluation of risks then the treatment of risks. Throughout this process there is a requirement to monitor and review and to communicate and consult. This publication previously covers the establishment of context and identification of potential environmental impacts to facilitate utilization of the risk assessment process in the evaluation of these impacts.

The risk assessment process may utilize a risk matrix for the qualitative evaluation of impacts (risks). There are many matrix models currently available one example taken from the Australian Standard for Risk Management, AS/NZS 4360: 1999 is provided in Figure 4.[3]

Each potential impact is assessed in the matrix and a rating of High, Moderate or Low risk assigned. Impacts identified as having a high risk require mitigation, those found to have a moderate risk can be mitigated utilizing the As Low As Reasonably Practicable Principle (ALARA), with additional efforts to reduce risks to be pursued on a cost vs. benefit basis. Impacts identified as having a low risk are considered tolerable and no mitigation measures are normally undertaken.

Another conventional method is to determine importance weighting (Table VI). This involves a structured approach for assessing importance of each identified impact area. In completing this process, it is important to include all key stakeholders to ensure an accurate assessment is obtained.

Clearly defined criteria allow the assignment of significance in a rational way through the process, and provides a measure of consistency necessary for the comparison of alternatives and serve as a documentation of the values and beliefs on which judgments are based.

In order to compare different project alternatives the relative value of each type of impact must be assigned. An example of this process follows, in which the various phases of an ISL project (section 4.2) are rated according to their potential impact upon the environment.

The procedure description, according to Ron and Wooten in Sadar 1995 [4], modified for ISL is as follows:

- Selection of the evaluation group, and explanation of process of weighting concept,
- Each evaluator will choose a column for each impact area and mark as appropriate,
- Each evaluator to review on completion to ensure ratings are relative to each other,
- Total weighting is determined for each impact area and total scores obtained,
- The completed tables are then collected and an overall weighting for each impact obtained,
- Completed results (overall averages) are then presented to each evaluator for individual comparison to their results,
- Comments received back from evaluators, and process repeated from step 2 if individual scores are modified. If no changes are required, the final results are issued.

	CRITICAL	MAJOR	MODERATE	MINOR	NEGLIGIBLE
	ENVIRONMENTAL EFFECTS				
OCCURRENCE OVER FACILITY LIFE	Very serious effects with impairment of ecosystem function. Long term, widespread effects on significant environment	Serious effects with some impairment of ecosystem function. Relatively widespread medium-long term impacts.	Moderate effects but not affecting ecosystem function. Moderate short-medium term widespread impacts	Minor effects. Minor short-medium term damage to small area of limited significance.	No lasting effect. Low-level impacts. Limited damage to minimal area of low significance.
SEVERAL 1 mth – 1 yr	**HIGH**	**HIGH**	**HIGH**	**HIGH**	**MARGINAL**
LIKELY 1 – 10 yrs	**HIGH**	**HIGH**	**HIGH**	**MARGINAL**	**MARGINAL**
POSSIBLE 10 - 100 yrs	**HIGH**	**HIGH**	**MARGINAL**	**MARGINAL**	**LOW**
UNLIKELY 100 - 1000 yrs	**HIGH**	**MARGINAL**	**MARGINAL**	**LOW**	**LOW**
VERY UNLIKELY 1000 – 10 000 yrs	**MARGINAL**	**MARGINAL**	**LOW**	**LOW**	**LOW**
REMOTE 10 000 – 100 000 yrs	**MARGINAL**	**LOW**	**LOW**	**LOW**	**LOW**
IMPROBABLE > 100 000 yrs	**LOW**	**LOW**	**LOW**	**LOW**	**LOW**

HIGH	UNACCEPTABLE RISK. RISK REDUCTION MEASURES REQUIRED
MARGINAL	MARGINAL RISK. RISK REDUCTION MEASURES CONSIDERED. ALARA PRINCIPLE APPLIES
LOW	TOLERABLE RISK. RISK REDUCTION NOT NORMALLY UNDERTAKEN

FIG. 4. Qualitative risk assessment matrix. [3]

Table VI. Environmental impact evaluation

Importance:	**Low**				**Medium**				**High**	**Total**	**Weight**
Impact area	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
Exploration			3							3	0.037
Pilot testing		2								2	0.025
Drilling and well completion					5					5	0.062
Pipelines - surface				4						4	0.049
Process vessels							7			7	0.086
Storage tanks						6				6	0.074
Ponds								8		8	0.099
Yellowcake drying and packaging			3							3	0.037
Liquid wastes generated					5					5	0.062
Solid wastes generated			3							3	0.037
Transportation and services		2								2	0.025
Disposal well							7			7	0.086
Groundwater restoration						6				6	0.074
Remediation and decommissioning					5					5	0.062
Fire hazard		2								2	0.025
Employment opportunities					5					5	0.062
Infrastructure improvement				4						4	0.049
Education (schooling)			3							3	0.037
Cultural impact	1									1	0.012
										81	1.000

4.5. Criteria for assigning impact significance

This section is adapted from and closely follows the criteria set forth by M.H. Sadar, 1995 [4].

The criteria developed for evaluation of impact significance need to:

- Permit the assignment of significance in a rational way through discussion and consensus,
- Provide a measure of consistency necessary for the comparison of options,
- Serve as documentation of the values and beliefs on which judgments are based.

Relevant criteria include the following:

Ecological importance

Criteria relating to ecological importance include aspects of the environment critical for ecosystem functioning as well as those valued for aesthetic or sentimental reasons:

- Effects on plant and animal habitat,
- Rare and endangered species,
- Ecosystem resilience, sensitivity, biodiversity and carrying capacity,
- Viability of local species populations.

Social importance

Biophysical impacts are translated into effects on factors valued by humans. The following concerns influence the perception of environmental value:

- Effects on human health and safety,
- Potential loss of species with current or potential value, or commercially available production (farmland),
- Recreational or aesthetic value,
- Demands on public resources such as social services,
- Demands on transportation and other infrastructures,
- Demographic effects.

Environmental standards

Environmental standards are among the most common means for assessing significance. These are criteria designed to contain certain environmental conditions within specified limits believed to be requisite to achieve social objectives (usually health related). Examples are limits on effluent discharge concentrations, clean air standards, water quality standards, etc.

Statistical significance

Some environmental characteristics may display shifts due to their normal (no-project) variability. A statistical significance threshold may be established to define an acceptable range of variation. This approach is often limited by the lack of knowledge concerning the nature of background variability (baseline conditions, trends) inherent in natural systems.

4.6. Measures for prevention, mitigation and compensation

Impacts may be thought of as costs and benefits that can occur within or beyond the immediate boundaries of the project. The purpose of avoidance, mitigation and compensation is to reduce the impacts to acceptable levels.

Avoidance is generally the most desirable. Since, if an impact can be avoided or prevented, then mitigation expenses are also avoided. This could be achieved through modifications of plants, designs, or schedules.

Both mitigation and compensation deal with the transfer of costs and benefits between the project and the public. This ensures that some of the costs that would otherwise fall on the public are transferred to the project, and that some of the benefits that would otherwise accrue within the project are transferred to the public.

Consideration must be given to means of mitigating and avoiding undesirable impacts. In addition a monitoring system must be specified to ensure that the measures work. Mitigation may involve environmental rehabilitation and/or replacement, and monetary or other forms of compensation. It may require changes in planning, design and engineering, and project management. Monitoring and follow-up are also important to verify the accuracy of impact predictions, establish what impacts actually occur, and to modify the mitigation measures to improve their effectiveness. It is essential that proposals for and commitment to mitigation and monitoring be made as early as possible in overall project development.

Whereas mitigation is associated with “mitigable” impacts, compensation is concerned with residual impacts — that is, impacts that remain after mitigative options have been exhausted. Compensation measures generally comprise monetary payments for damage caused by the project.

In the case of a productive unit such as a farm, compensation could be equivalent to the capitalized value of lost income from the farm.

Mitigation and compensation measures need to be assessed for their feasibility from technical, social and political viewpoints.

Monitoring goes hand-in-hand with making impact predictions and proposing prevention, mitigation or compensation measures.

Monitoring is essential to ensure whether impact predictions are accurate, as well as whether avoidance, mitigation and compensation measures are achieving the desired objectives.

An illustration of the application of these measures is described below for the potential impacts results from lixiviant excursions in an ISL well field.

Impacts: If wells are not properly completed, lixiviant can flow through casing breaks into overlying or underlying aquifers. Casing breaks can occur if the well is damaged during well construction activities or if water injection pressures exceed the strength of the well materials.

Prevention: Injection and recovery wells need to be constructed from materials that are inert to lixiviant and are strong enough to withstand injection pressures. Mechanical integrity tests of injection and recovery wells are used to inspect for casing leaks after a well has been completed.

Mitigation: During operations, volume of extracted solutions is 1-3% higher than injected, to minimize the likelihood of well field excursions by ensuring a net inflow of clean groundwater from the aquifer to the well field.

Monitoring: Monitor wells are used to identify potential lixiviant excursions. Monitor wells are installed around the perimeter of the well field to detect horizontal excursions within the orebody aquifer. Close proximity of monitor wells to the well field ensures early detection of excursions but they must be far enough away to avoid erroneous detections. Monitor wells are also developed in overlying and underlying aquifers to detect vertical excursions.

5. CONCLUSIONS

The results of the EIA are described in detail in the Environmental Impact Statement (EIS), conclusions of which outline the overall impact of the project, 1) Describing its broad-ranging and long-term benefits to the general public in the forms of employment; and infrastructure improvement and broadening of the economic base (taxes); and 2) Describing measures that will be taken to ensure that the project's environmental impact will be minimized thus ensuring that the site will be returned to baseline conditions as part of reclamation and decommissioning. Following are guidelines that need to be kept in mind in preparing the EIS [5].

1) Justification of practices. No practice should be authorized unless the practice produces sufficient benefit to the affected individuals or to society to offset the radiation or other harm that it might cause; that is: unless the practice is justified, taking into account social, economic and other relevant factors.

2) Limitation of effluents. Effluents shall be restricted so that the total impact caused by the possible combination of effluents and exposures from authorized practices, does not exceed any effluent limit specified in accepted environmental and medical standards.

3) Optimization of protection and safety. Protection and safety shall be optimized in order that the magnitude of permitted effluents, the number of people affected and the likelihood of incurring effluent events are kept as low as reasonably achievable, (ALARA), economic and social factors being taken into account, within the restriction that effluents to environment delivered by the source are subject to effluent constraints. For a comprehensive review of safety aspects of operations involving radioactive material, the reader is referred to Reference [6].

APPENDIX I. ENVIRONMENTAL IMPACT STATEMENT — BEVERLEY URANIUM MINE

I.1.1. Introduction

Heathgate Resources Pty Ltd, an Australian affiliate of General Atomics of the USA, proposes to establish and operate a uranium mine at Beverley in northern South Australia. Mining by *in situ* leach (ISL) methods is proposed to produce up to 1000 tonnes yellowcake per annum, for sale and export over a minimum 15 year mine life.

Beverley is located on the arid plains between the North Flinders Ranges and Lake Frome, approximately 600 km north of Adelaide and 300 km north-east of Port Augusta (Fig. 5). The uranium mineralization is present within Retention Leases covering an area of 8 km^2, located entirely within the Wooltana pastoral lease. The deposit contains an estimated in-place resource of 16 300 tonnes (35 850 000 pounds) uranium, of which a minimum of 65% is estimated to be recoverable by ISL mining methods.

FIG. 5. Location of Beverley Mine.

An Environmental Impact Statement (EIS) is required by State and Commonwealth legislation under the Commonwealth Environment Protection (Impact of Proposals) Act, 1974 and the South Australian Development Act, 1993.

The object of both Acts is to ensure that matters affecting the environment to a significant extent are fully examined and taken into account in decisions by the Commonwealth and South Australian Governments. The Beverley Uranium Mine proposal will be subject to a joint assessment by both governments.

The South Australian Department of Transport, Urban Planning and the Arts will take the lead role in the joint assessment, in close consultation with Environment Australia (Commonwealth Department of Environment).

This EIS addresses the mining proposal, the existing environment, impacts of the mine on the environment, environmental safeguards, monitoring and proposed rehabilitation measures. The EIS is intended to provide:

- A source of information for understanding the proposal and its impacts,
- A basis for public consultation and informed comment on the proposal, and
- A framework for considering environmental aspects of the proposal together with economic, technical, cultural and other factors.

I.1.2. Outline of In Situ Leach mining

ISL mining removes economic mineralization from the host ore without the physical removal of ore and over-burden. It requires multiple close-spaced wells in the ore, pipelines to and from the wells and a surface treatment plant, but does not require either underground mine workings or open cut pits.

In the ISL process, oxidizing and complexing reagents are added to natural groundwater from the mineralized zone. Oxidizing reagents are commonly oxygen or hydrogen peroxide, though other alternatives may be used. Complexing reagents may be acidic or alkaline: the present proposal is for an acidic leach using dilute sulphuric acid.

The mining solution (lixiviant) is pumped via multiple injection wells (Fig. 6) into the permeable orebody where it mobilises the uranium contained in the ore. In this process, some of the reagent is consumed. The resulting uranium-rich solution is pumped back to the surface via multiple extraction wells to a uranium recovery plant. At the plant, uranium is stripped from the solution and held for later precipitation, drying and packaging. The barren solution is refortified to replace used reagents, and recycled back to the injection wells. Within any given area, this cycle continues until the uranium remaining in the ore is depleted to uneconomic levels.

ISL mining is feasible where the geological and hydrological characteristics of the orebody are favourable. This is the case with the Beverley uranium deposit, where the uranium is easily mobilised, the mineralized zone occurs in highly permeable sandstones that are confined by largely impermeable strata above and below the orebody, and the mineralized zone is saturated with groundwater.

The design and operation of the well field control the flow of mining solution through the mineralization. Mining is generally limited to only part of a well field at any one time, although the whole well field will eventually be mined during the life of a mine. Injection and extraction wells are closely spaced, in the present proposal between 20 m to 40 m apart. Within the active mining area, the volume of solutions extracted is always slightly more than the volume injected. This ensures a slight continuous inflow from the surrounding formation into the active mining area, and minimises leakage of mining solutions away from the active mining area (excursions).

ISL mining is a relatively low impact mining method, since ore is not mined in the conventional sense. There is minimal surface disturbance, no over-burden removal, no ore treatment facility, no tailings generation or disposal requirements, a simple recovery plant which can be removed on completion of mining and surface rehabilitation once a well field has completed its operational phase. Comparatively little waste is produced.

I.1.3. Background to the proposal

Uranium mineralization was first discovered at Beverley in 1969. In 1982, the South Australian Uranium Corporation proposed development using the then relatively new ISL uranium extraction technology. An EIS was prepared and submitted, but the process was never finalised, and the project was shelved after 1983.

Heathgate Pty Ltd (now Heathgate Resources Pty Ltd) acquired the Beverley leases in 1990 and undertook further evaluation. In 1996, the company extended investigations with a view to establishing a mine at Beverley. Programmes have included baseline environmental studies, geological and uranium resource investigations, hydro-geological investigations and a field leach trial (FLT) (Fig. 7). The FLT at Beverley is operating under approvals given following a Declaration of Environmental Factors in 1997. The trial commenced in January 1998 and was scheduled to run for a maximum of 12 months.

The trial provides for a limited simulation of possible commercial operations. It is designed to operate in the same manner as a full-scale plant, utilizing well field injection and extraction conditions and well field patterns equivalent to that, which apply commercially.

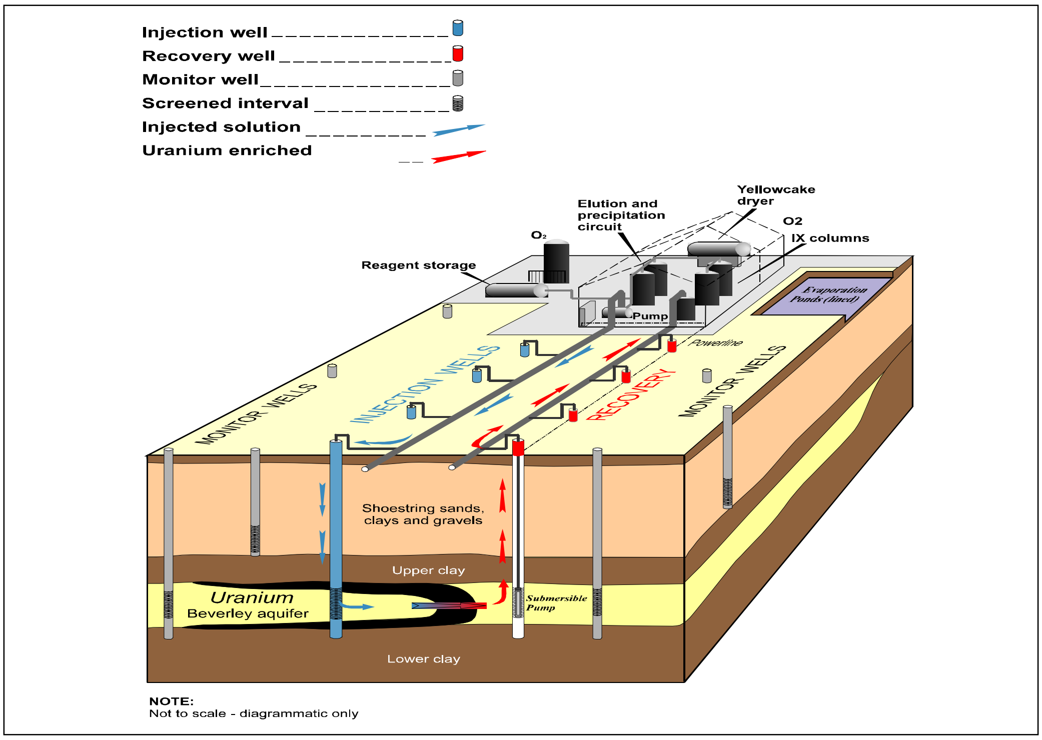


FIG. 6. Schematic processing model, In Situ Leach mining.

FIG. 7. The Beverley field leach trial plant.

Differences compared with a commercial operation include the use of individual rather than multiple well field patterns, the small size of the process plant and the limited flow rate of mining solution through the plant. The trial is progressing successfully, providing environmental information on water chemistry, aquifer responses, ore zone isolation and confinement, and radiological aspects, as well as refining operational parameters.

I.1.4. Need for the project

Heathgate uranium demand and supply forecasts up to 2010 predict a substantial shortfall in supply, with mine production being the only method of meeting the shortfall. Low-cost producers, primarily Australia and Canada, appear best placed to compete as suppliers.

Development of the mine is expected to bring local, regional and state employment, income and investment benefits, with minimum economic costs to the community. If the Beverley Mine does not proceed, it will benefit Australia's competitors in the shorter term (up to 20 years), although not significantly affecting world markets.

I.1.5. Proposed Beverley development

Development is proposed as either one of two alternatives, depending upon approvals as well as economic considerations. The development will either be a small commercial operation (Stage 1) followed by a larger commercial operation (Stage 2), or will proceed directly to the larger operation (Stage 2) (Fig. 8). Stage 1 envisages production of 200 tonnes per year of yellowcake at an average mining solution flow rate of 50 l/s, whereas Stage 2 production would be 1000 tonnes per year of yellowcake at an average mining solution flow rate of 250 l/s.

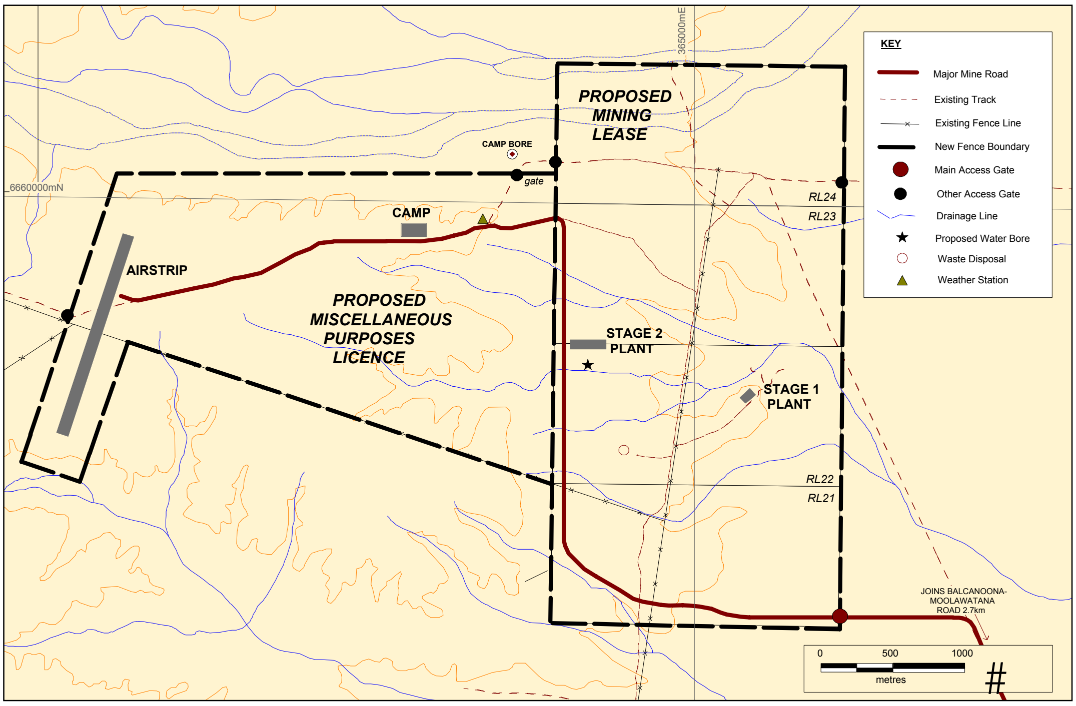


FIG. 8. Proposed major production infrastructure.

The Stage 1 Plant would be constructed at the site of the existing Field Leach Trial. Stage 1 is proposed as a modular plant, with components constructed off-site and transported to the location. Total field construction time is estimated at 45 days.

A full-scale plant (Stage 2) would require 12 months for planning, construction, development and testing before operation can begin. To the extent possible, Stage 2 Plant sub-assemblies would be fabricated off-site and delivered for installation. Some tanks, pipes, electrical equipment, concrete and other related items would need to be fabricated or assembled on-site.

Over the life of the mine, well fields would be developed into three ore concentrations. In total, the well fields would require the installation of some 1,100 injector/extractor wells, with additional monitoring bores. All injection and extraction wells will be cased with corrosion-resistant PVC or equivalent well casing and cemented over their entire length. Wells will completely seal off overlying sediments from the mining activities. To check integrity, wells will be pressure tested to 1000 kPa, a level substantially in excess of proposed operating pressures. As well as integrity tests prior to commencement of service, wells will be re-tested each 2 years of operational life.

Only portions of well fields would be in use at any given time. Injection and extraction wells have a limited economic life, dependent on the rate at which uranium is leached. Accordingly, the development, use, closure and rehabilitation of wells would be progressive and continuous throughout the mine life.

Active mining areas within a well field will generally consist of wells arranged in lines of injection and extraction wells spaced up to 40 metres apart. As the current active mining area is depleted, the mining solutions will be moved to the next mining area for reuse, reducing the overall volume of groundwater affected.

Infrastructure associated with the project would include offices, workshops, warehouse, laboratory, ablution facilities, parking, electrical power supply, new bore into the Great

Artesian Basin, fencing, airstrip, ponds, pipelines, production equipment, disposal wells, uranium recovery plant, well field distribution system, well fields, backup power supply, roads, Aboriginal Heritage Centre, Visitor Centre, accommodation for up to 75 persons, laundry, sewage treatment plant or septic system, kitchen and dining hall.

Power supplies and local roads would be the main off-site infrastructure. Electricity would be generated using natural gas, either generated at Compressor Station 3 on the Moomba-Adelaide gas pipeline with electricity supplied to site by power line; or generated on site with gas piped from the Moomba-Adelaide pipeline.

Alternative road routes have been evaluated. Borrow materials will be needed for roads as well as for on-site development such as the airstrip, and application will be made to establish at least four new borrow pits.

I.1.6. Product handling

Mining, processing, packaging and shipping of uranium is expected to be spread more or less evenly throughout the year. Yellowcake, packed in sealed 205 l steel drums, will be stored on site in a secure and monitored compound, with security requirements as defined by the Australian Safeguards Office. Adequate fencing, surveillance, and telecommunications will be in place at all times.

Yellowcake drums will be transported in sealed sea-freight containers, on semi-trailers, to Port Adelaide. The procedures for road transport to the port, including emergency response procedures, will be drawn up and presented to the regulators for approval. The transport rules will conform to current Australian Codes of Practice, IAEA transport recommendations; and International Maritime Organisation regulations for sea transport.

I.1.7. Waste

Radioactive solid waste

Unlike conventional uranium milling and treatment plants, *in situ* leach mining produces no tailings and hence has no requirement for a surface tailings disposal system.

There will be only limited amounts of radioactive waste requiring management. These include dried solids from filtration of suspended material in circulated groundwaters, salts from evaporation of waste streams, damaged ion exchange resin and plant filters, laboratory equipment and process equipment such as pumps, valves, and piping.

A low-level radioactive waste repository will be required for disposal of radioactive solids. The present proposal is for this repository to be established at the development site. If a national low-level radioactive waste repository is established in the Billa Kalina area of north-west SA, disposal there rather than on-site may be an option.

Non-radioactive solid wastes

The plant and the camp will both generate solid wastes, primarily packaging and containers. Recycling of materials, particularly paper, cardboard, glass, metals and plastics, will be maximised. Materials that cannot be recycled will be compacted into bound cartons and buried in a sanitary landfill onsite. The camp will also generate putrescible wastes, for which two alternative approaches to disposal are under consideration - composting and maceration.

Liquid waste handling

The primary waste streams from the mining operation will be a mining solution bleed at the plant, spent solutions from the uranium precipitation process, washdown water and filter cleaning water. These fluids would initially be collected in the plant holding ponds. Two options exist for disposal of these fluids; either to re-inject the fluid into the mineralized zone aquifer remote from potential future mining areas, and/or in areas already mined out, or to evaporate the water on the surface and then dispose of the resulting solids in an engineered disposal facility.

It is proposed that liquid plant wastes be returned to the orebody formation. This minimises the amount of material requiring near-surface disposal, the area needed for pond, and the release to atmosphere of radon.

I.1.8. Spills and accidental releases

Design and construction will concentrate on spillage control, by diking or by flow cut-off and flow isolation procedures and equipment. A quality assurance/quality control system will be applied, involving pre-operational testing of equipment, periodical testing and regular inspection of equipment, especially pipelines, and interlock monitoring on line flows and pressures with automatic shutdowns in response to flow or pressure changes. Consequently, spills, if any, will be small.

A containment system would be constructed for process areas in both the Stage 1 and Stage 2 plants. All spillages inside the diked areas would be washed to the adjacent plant holding pond. All holding ponds would be lined and fitted with a leak detection system.

Bulk chemical, fuel and lubricant holding areas would be designed and constructed in accordance with current regulations, including requirements for dike and lining.

In any spill, free liquids would be recovered. Any contaminated soils would be removed and placed in the disposal areas. Any yellowcake spills would be immediately recovered.

I.1.9. Geology

The Beverley Uranium Deposit lies in the western part of the Frome Embayment (Fig. 9). The deposit occurs in partly consolidated Tertiary sediments at a depth of some 100+ m. These sediments overlie the Great Artesian Basin (GAB) sediments. The Beverley Uranium Deposit consists of mineralization in three principal areas within the upper portion of the Namba Formation, which is overlain by the Willawortina Formation.

The permeable sediments of the Namba Formation, which contain the mineralization, are separated from the underlying GAB by the Alpha Mudstone. This is a hard clay layer, for which drilling has established a thickness of more than 85 m.

The mineralization is separated from the overlying Willawortina Formation by another, shallower clay layer.

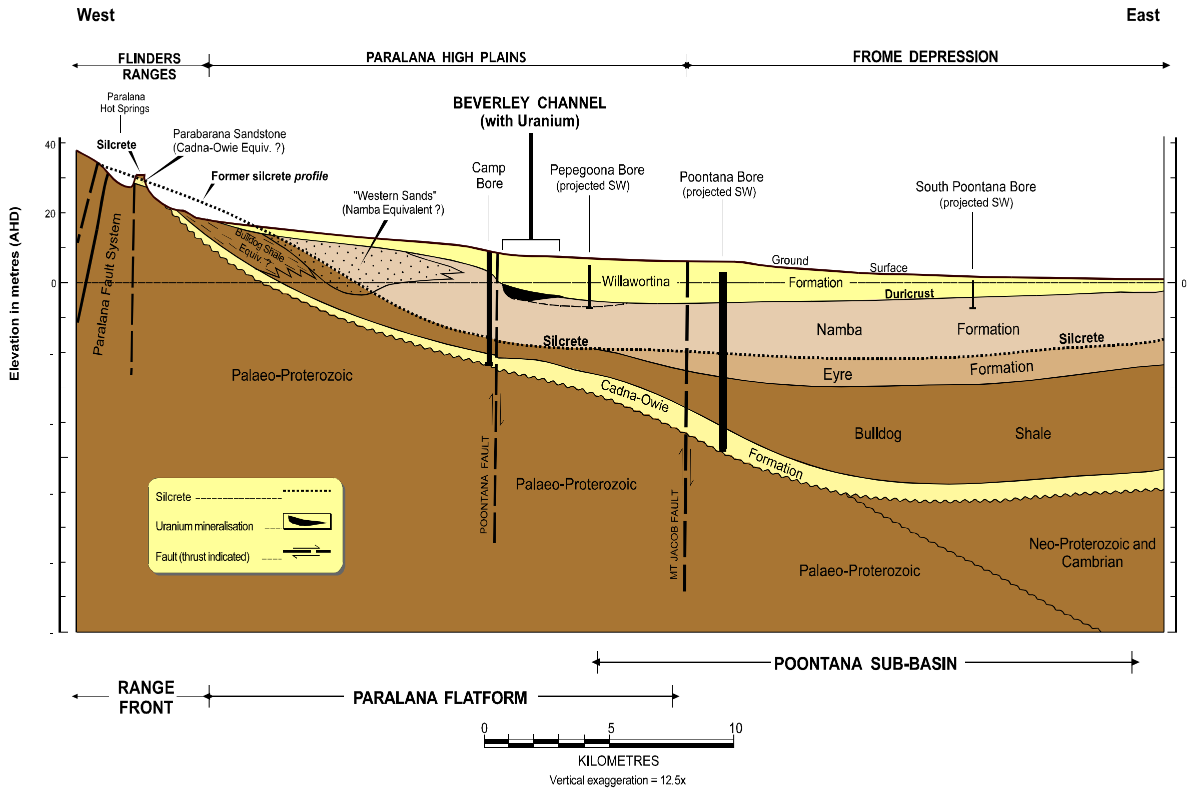


FIG. 9. Regional geological section.

I.1.10. Hydrogeology

Water use for the Beverley mine would be groundwater from the Namba Formation aquifer, recycled throughout the *in situ* mining process, and groundwater from the GAB for potable, plant and camp use. The groundwater in the Namba Formation aquifer will be modified by the mining process and by liquid waste disposal.

Groundwater in the Beverley mineralized zone is saline, with Total Dissolved Solids ranging from 3000-12 000 mg/L, and contains naturally occurring radioactive uranium and radium at (respectively) up to 50 times and 70 times drinking water limits. It is therefore entirely unsuitable as potable water, and the radioactivity renders it unsuitable, now and in the future, for agriculture or stock watering purposes. Mining will impact this aquifer, changing pH and levels of trace metals, and the aquifer at the end of mining will still remain unsuitable for use. The much higher quality groundwater in both the underlying GAB and in part of the overlying Willawortina Formation is and will remain both suitable and available for stock and other uses.

The Willawortina Formation comprises a number of thin aquifers of low water yield, separated by clay layers. Where water is present, the quality is suitable for general stock use. At the Beverley site, pumping tests associated with trials indicate there is no connection with the Namba Formation aquifer, even though the area was extensively drilled in the past. Well installation for mining purposes will include checks on the unlikely but possible presence of old open drillholes connecting the Namba and Willawortina Formation aquifers, and any such holes would be plugged before mining commenced in that area.

The demand of the development for water from the Great Artesian Basin is small. The total estimated water demand is 57 ML per year, as feed water to the camp Reverse Osmosis unit, plant wash-down and reagent make-up, water for dust suppression on dirt roads and miscellaneous uses, and water for drilling. This water is proposed to come from a single new well. Drawdown in the order of a few metres is expected close to the well. Drawdown interference with Camp Bore, some 2 km distant, will be minimal. Springs at Paralana Hot Springs and in northern Lake Frome will not be affected in any discernible way.

I.1.11. Surface water

The climate is arid and there are no natural permanent waters closer to the site than springs along the foothills of the Flinders Ranges. Watercourses flow occasionally, after major rainfall events.

The main surface water feature of the Beverley site is the large but intermittent watercourse of Four Mile Creek on the northern boundary. The creek rises in the Flinders Ranges and has a relatively narrow floodplain where it extends onto the site. There are minor creeks crossing the site, which have much smaller local catchments and much smaller potential flows.

Impacts on the surface hydrological features will be minor, since the placement of facilities has been designed to avoid them wherever possible and minimise interference where not. All major facilities will be placed well above the 100-year flood levels, and do not intrude on Four Mile Creek. Crossings of minor watercourses by access roads and pipelines have been minimised. Where crossings are necessary, access will be constructed to minimise alteration to surface flows.

Distributor surface piping will be necessary below the 100-year flood level in some parts of the proposed well fields. Here, pipes will be aligned along the direction of flow, where possible. Operations involving wells on floodplains will be suspended when there is a chance of flooding occurring. Some new access road construction will be necessary on the outwash of Paralana Creek, southeast of the site. Routes have been selected and construction planned to minimise downstream impacts.

I.1.12. Soils and erosion

ISL mining, involving no pit or major ore stockpiles, leaves the soil profile effectively intact. Impacts largely relate to surface disturbance for construction and in operation of well fields.

Most of the site has brown cracking clay soils, often silty clays prone to dusting. Lower plains portions have very silty and sandy clay soils. Alluvial soils are present in watercourse areas. Design, construction and operational methods are intended to minimize impacts on these soils, particularly as regards wind and water erosion and sediment movement.

To minimize scouring and water erosion, surface runoff from any new paved areas will wherever possible be dispersed onto the ground surface rather than directed into natural drainage. Structures that could create long-term local inundation, such as embankments and bunds on almost level ground, have been minimized in the proposed design. Movement of sediment down slope from the bare areas of the well field will be restricted by the use of devices such as geofabric silt fences.

Particularly within well fields, the ground will necessarily be bared for well construction and for much of any given well's operating life. Both the extent of bared areas and the period for which they are bared will be minimized, to limit dusting or sediment transport, by a combination of soil stabilisation, maintenance of some surface roughness and subsequent rehabilitation.

Strict control will be applied in well field development, delineation drilling, and other operational activities, which require access off paved surfaces. In all other cases, vehicle traffic will be strictly limited to roads.

I.1.13. Occupational radiation

The main pathways for radiation doses to workers in uranium mines are gamma irradiation sources, inhalation of radon daughters and air-borne long-lived alpha-emitting radionuclides, and ingestion of radioactive contamination. For Beverley, these pathways will be significantly reduced compared to conventional uranium mining, since there will be no physical exposure to ore or tailings, and airborne alpha-emitting dust sources will be few and minor.

Some gamma-emitting radioactive materials will be brought to the surface in solution and may accumulate in filtration solids, in solids in ponds, and as deposits in pipes and equipment. As well, drummed yellowcake will be a gamma source. Accepted radiation control methods will be applied to protect against direct exposure to gamma radiation, including monitoring.

Radon in groundwater pumped to the surfaced will, if exposed to air, diffuse into the atmosphere. The main radon sources will be:

- During well development,
- Where compressed air is used to bring groundwater to the surface,
- In the plant, although covered vessels will make this release minimal, and
- Releases from ponds.

Open-air ventilation will generally keep radon daughter concentration very low, but radon-generating operations may be halted in absolutely still-air conditions to avoid exposure.

Sources of radioactive dust are limited to spillages in the plant, drying out of ponds, and yellowcake packaging. Dust will be controlled by wet cleanup of spills, water cover in ponds to prevent dusting, the use of a zero emissions dryer for yellowcake to prevent fugitive dust emissions, and respiratory protection equipment in yellowcake packaging.

For protection against potential radiation doses from ingestion, Heathgate Resources will provide ablution and related facilities and implement policy, programmes, and procedures to ensure cleanliness and personal hygiene standards.

Gamma doses of plant operators are expected to be similar to those received by hydrometallurgical plant operators at other uranium operations. These are approximately 1 mSv/year for hydrometallurgical operators and 5 mSv/year for yellowcake operators, compared to the maximum of 20 mSv/year annual limit.

Annual average worker radon exposure is indicated to be in the order of 2 Bq/m^3, with a dose rate in the order of 30 µSv per year, a small fraction of the occupational limit of 20 000 µSv. Worker doses from inhalation of long-lived alpha-emitting radionuclides is estimated to not exceed 1 or 2 mSv per year.

I.1.14. Environmental radiation & public exposure

The gamma background radiation in the Beverley area exhibits considerable variability, with localised areas of higher values, particularly in creeks draining the uraniferous Mt Painter area.

The main exposure pathway by which members of the public might receive an increment of radiation dose from the mine site is through inhalation of radon daughters dispersed in air. Domestic stock will be excluded from the proposed mining lease, and hunting will be prohibited, so that the ingestion pathway via animals will be blocked. Also, there will be no significant fugitive dust sources.

The site is well ventilated, with few periods of totally still air. Even on otherwise still nights, cold air drainage from the Flinders Ranges provides some dispersion of radon emissions. Modelling has been applied to predict radon concentrations in air about the site, applying weather data collected continuously at the site over the past year.

The highest mine radon source would be the holding ponds, where radon concentration would be directly proportional to pond evaporation and the radium content of the water. Against a background level of 11 Bq/m^3, an upper estimate of 100 GBq/d was applied in atmospheric radon dispersion modelling using site-collected meteorological data. Results of this analysis predicted an increment in radon due to mine emissions of up to 4 Bq/m^3 within the leases in the vicinity of the holding ponds. The incremental increase is expected to fall to 1 Bq/m^3 within 1 to 2 km of the radon sources at the site. The increment along the public road nearest the site is predicted to be between 0.1 Bq/m^3 and 0.05 Bq/m^3. At North Mulga, the nearest residence some 10km from the site, average radon concentration increase is calculated to be 0.05 Bq/m^3. This converts to an estimated member-of-public dose due to radon emissions from the mine in the order of 4µSv/yr; an estimate which is orders of magnitude lower than the annual allowable public dose limit of 1mSV per year above natural background.

I.1.15. Radiation management

A Radiation Management Plan is required to be developed in accordance with the Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores, 1987, subject to approval by the Appropriate Authorities, and implemented for the project. The plan will address the Code's requirements, state Heathgate Resources' undertakings regarding the control of radiation and will ensure that doses are as low as reasonably achievable (ALARA). The plan will incorporate design parameters, procedural and operational controls particularly aimed at minimizing the spread of contamination, facilities for personal hygiene, workforce instruction and safety training, occupational and environmental monitoring programmes and external and internal reporting and review.

Ongoing monitoring during operations and Heathgate Resources' incorporation of the ALARA principle during design, construction, and operation, will be undertaken to provide assurance that the accumulating dose remains well below an annual limit of 20mSv. External gamma radiation will be monitored by personal thermoluminescent dosimeter (TLD) badges, with readings made by the independent Australian Radiation Laboratory. Radon daughter concentration will be monitored regularly in the plant area. Surface contamination will be monitored regularly, and hand contamination particularly. Air samplers will be used to monitor alpha-emitting dusts.

I.1.16. Socio-economic aspects

A total of some 50 permanent residents live within a 70 km radius of the Beverley Uranium Mine site. This figure includes staff at the Arkaroola tourist facilities, some 30 km distant. Actual population at Arkaroola varies with tourist demand.

Leigh Creek South, some 150 km to the west, is the nearest township and service centre. The Aboriginal community of Nepabunna, approximately 80 km from the Beverley site, is located on the western side of the Gammon Ranges. The community is established within Aboriginal Lands and operates as a self-contained settlement. The population fluctuates given the movement of residents to and from the township and is currently estimated to be about 120 persons.

Reflecting the pastoral nature of the region, the greatest proportion of the population is employed in agricultural uses (25%). A further 13% is employed in recreation/personal goods and other services, 10% in mining, and 9% in transport and storage industries.

For workforce, Stage 2 will operate with approximately 119 staff. Additional staff will be contracted for specific purposes, as required. Stage 2 production is estimated to create up to 275 jobs within South Australia.

Staff will generally be flown to the site on a regular charter aircraft service for rostered workdays and be flown back for rest-days. All staff will be housed at the camp on the Beverley site. Emphasis will be placed on hiring local personnel, with most operational staff coming from Nepabunna, Leigh Creek, the Iron Triangle region and Adelaide.

In Stage 2, state and national economic benefits are estimated to include royalties, payroll tax and indirect taxes to the State Government of up to AUS $1.1 million per year, purchases in South Australia of up to AUS $4.4 million per year and in the rest of Australia up to AUS $1.7 million per year. Adverse economic benefits to the State will be minimal, since infrastructure will either be developed by Heathgate Resources or, in the case of public road use, covered by a levy based on vehicle movements.

For the life of the mine, compensation and other benefits related to production will be paid to Native Title Claimants.

I.1.17. Aboriginal heritage

The Flinders Ranges is important for the culture and heritage of the Aboriginal people of the region. The Beverley Mine site is covered by four Native Title claims lodged under the provisions of the Native Title Act 1993. No determination has yet been made as to Native Title. Heathgate Resources has commenced negotiations with these claimants concerning agreements, which meet the requirements of the South Australian Mining Act for the purposes of granting a Mining Lease. Agreements have been reached with three of these groups.

The terms of the agreements include consultation on heritage, mining and environmental matters, Aboriginal employment, cross-cultural training of Heathgate workers, support for Aboriginal businesses and compensation payments related to the value of mineral production. An Aboriginal Heritage Centre, in conjunction with a Visitor Information Centre, will also be established at the mine.

As part of the EIS process, anthropological and archaeological investigations in conjunction with the two then registered Native Title claimants were undertaken in 1997 on the Retention Leases. Traditional beliefs concerning how the physical environment and landscape resulted from the actions of mythical figures in the Dreamtime, such as the myth of the kangaroo and euro and the myth of a "supernatural being" were recorded. Other myths cannot be told in the public domain. No myth left behind a site within the Retention Leases area requiring specific avoidance or behavioural restrictions, however a small depression with comparatively larger vegetation than the surrounding area near Four Mile Creek is considered to be of significance.

The nature and distribution of Aboriginal archaeological sites is strongly influenced by factors such as the access people had to water, food, suitable campsites and suitable rock types for rock art and stone artifacts production. Four archaeological sites have been documented in the area of the Retention Leases and the immediate environs, mainly on major stream frontages. One artifact has been found near Jenny Creek. On the plainlands covering most of the proposed development area, artifacts are very scarce.

The sites are considered to be artifact concentrations and background scatters, such as found throughout the plains adjoining the Flinders Ranges. No sites were identified as requiring entry on the South Australia Register of Aboriginal Sites. It is proposed to extend heritage investigations to cover additional infrastructure in the EIS.

I.1.18. European heritage

From the start of European use of the Flinders Ranges and immediate surrounds in the 1850s, the historical land use of the region has been primarily pastoral. Mining has been historically a secondary land use. Apart from coal post-World War II at Leigh Creek, other minerals have been successfully mined, particularly copper, gold, talc, and barite.

The Beverley site itself contains no artifacts of European occupation of historical value. Development of the uranium mine and its associated facilities would therefore have no impact upon the European heritage of the area.

I.1.19. National estate listings

The site is not directly subject to National Estate or similar listings. Sites on the Register of the National Estate in the district generally are Gammon Ranges National Park and its Balcanoona extensions, Arkaroola Gorge, the Mount Painter Area, and Paralana Hot Springs, 15 km south west of the site.

District public access to the site passes through the Balcanoona extensions to Gammon Ranges National Park. The preferred access for development purposes, via Yunta, also passes through the plains section of the Balcanoona extensions, but minimises the length traversed, compared with alternative access through the Flinders Ranges.

I.1.20. Vegetation

The main site land cover is perennial Mitchell grassland (Astrebla pectinata) with a very high component of bassias, Sclerolaena species. Slopes and shallow drainage lines have a tall shrubland cover of Eremophila and/or Acacia species. Four Mile Creek has a fringing woodland of red gum Eucalyptus camaldulensis and teatree Melaleuca along major channels. A very open tall shrubland of Acacia victoriae is present on the lower levels of floodplains. Higher levels of floodplains, as well as outwash areas, have a low very open shrubland of cottonbush (Maireana aphylla) or other similar shrubs, interspersed with Mitchell grasses. Distant from the site but potentially affected by some infrastructure development are low dunes with a tall shrub cover of hopbush (Dodonaea viscosa) and punty bush (Senna artemisioides subspecies) over a grassy understorey.

All vegetation likely to be affected by the proposed development is represented in the plains segment of the Gammon Ranges National Park. The maximum area of impact, estimated to be 6km if transient impacts are included, is less than 1% of the known distribution of Mitchell grasslands in the district.

Frankenia subteres, listed as rare in Schedule 9 of the National Parks and Wildlife Act 1972, has been recorded both within and beyond the Retention Leases. It is likely that the species is present throughout Mitchell Grass areas as a sparsely distributed plant. There are no other species recorded for the area which are listed under the South Australian National Parks and Wildlife Act or the Commonwealth Endangered Species Protection Act 1992.

Alien species are present, mainly associated with the intermittent watercourses. In line with experience on mine development elsewhere in the SA arid zone, invasions as a result of mine development are unlikely.

The Beverley site is in many respects a European-modified landscape, although still retaining a “natural” appearance. The nature of the vegetation has been significantly affected by over a century of apparently heavy past grazing, and use of Four Mile Creek as a timber source. For instance, some species normally expected with Mitchell grass in the region, particularly saltbush, are absent. Nevertheless, the Mitchell grass community has demonstrated a high degree of resilience in recovering both from past heavy grazing and past intensive mining exploration activities. The level of resilience demonstrated indicates the feasibility of returning the area to Mitchell grassland after mining.

I.1.21. Fauna

Recent surveys at and about the site have recorded 94 native vertebrate fauna species, including 19 mammal, 21 reptile, 1 amphibian and 53 bird species. Six introduced species have also been recorded. Additional fauna species have been recorded during previous investigations.

The Forrest’s Mouse Leggadina forresti has been recorded at the Beverley site in both recent and past surveys. This species, although regarded as rare in South Australia (National Parks & Wildlife Act, 1972), appears widespread and common in areas of suitable habitat, and has been recorded in several recent biological surveys in the wider region. The Narrow-nosed Planigale Planigale tenuirostris is not listed under the Act, but is regarded as uncommon. This species is also common in areas of suitable habitat in the vicinity of the lease area and throughout the wider region.

The habitats and environmental features on the Beverley site and those in the general vicinity are neither unique nor restricted in extent. Those habitats present are represented in regional conservation reserves. The total area to be affected by proposed mining activities is small in regional terms, and has been subjected to long-term heavy grazing pressure and intensive past exploration.

It is considered unlikely that any of the habitats present within the area to be disturbed are critical for these species’ continued survival in the region. However, the proposed operations may result in the loss of some individuals and/or the displacement of some native fauna on a local scale. The impacts are unlikely to be significant, however, given the extent of identical habitat in the immediate vicinity and the species' widespread distributions in the region.

The general area has demonstrated its ability to recover from previous more intensive and widespread operations. Thus the areas to be disturbed can be successively rehabilitated following the completion of mining activities and habitats for native fauna can be restored in the long term.

Some features of the development, do, however, pose specific impacts. Ponds have the potential to impose adverse impacts on native fauna, which are attracted to water features. Thus, careful management will be required to prevent such species gaining access to these features. Another effect of the mine would be the increase in vehicular traffic, which could adversely impact on certain fauna species, especially reptiles and terrestrial mammals. Whilst there will inevitably be some fauna road-kills, no significant increase above that associated with existing local roads is anticipated.

I.1.22. Land use

The primary existing land use is pastoral, with beef cattle run about the proposed development site. Heathgate Resources is negotiating an agreement with the lessees of Wooltana Station and issues related to water supply, fencing, stock control and roads are discussed with them on a co-operative and ongoing basis.

The Flinders and Outback Region is a key tourist area within South Australia with potential to expand its tourism industry. A significant element in tourist attraction to the Flinders Region is the sense of wilderness conveyed by open and largely uninhabited spaces. The incremental development of the region will to some degree detract from this experience. Over the 15 plus years of a Beverley Mine, the movements of vehicles and planes and the activities on the site will contribute slightly to the erosion of the sense of wilderness. However, the nature of the Beverley operation involves minimal surface impacts compared with other development activities in the region. The modest size of the overall project (compared with the Leigh Creek coalfields, for instance) plus the modest scale of plant and buildings, and the small numbers of traffic movements associated with it, will produce a very minor overall surface impact.

I.1.23. Visual

The main opportunity for viewing the mine site by tourists and visitors to the region would arise when travelling the Balcanoona-Moolawatana Road, which is some 5 km distant at the closest point. Despite the small probability of adverse visual impact, all buildings and infrastructure will be designed to blend in with the surrounding landscape (Fig. 10).

From the Flinders Ranges (Sillers Lookout) it is expected that even when fully operational, the mine will remain undetectable to the naked eye. It is anticipated that, at night, lights will be seen from both the Balcanoona-Moolawatana Road and Sillers Lookout. However, given that the beauty of the Flinders Ranges is appreciated during daylight hours, the use of lights at night is not expected to have a negative impact. In any event, the overall visual impact will be no more significant than structures normally associated with a pastoral station.

FIG. 10. Existing plant viewed from mine access track.

I.1.24. Sensitive areas

There are some areas within the Retention Leases that are considered as environmentally sensitive for reasons such as unusual vegetation, good faunal habitat, gibber/gilgai landforms posing erosion hazards or because they are flood-prone areas. Thus, care and environmental sensitivity would be required in surface activities throughout the development process. However, the resilience of the site is demonstrated by the almost complete regeneration following past intensive drilling.

Paralana Hot Springs is simultaneously of major significance to Aboriginal people, a tourist attraction, a site of particular geological interest, and the closest permanent natural surface water, albeit radioactive, to the site. The project will not impinge on the Hot Springs.

I.1.25. Decommissioning & rehabilitation

The primary objectives for decommissioning and rehabilitation are the removal of process facilities and the closure of ponds and wells; the removal or other disposition of supporting infrastructure such as fences, tracks and the camp; and the return of the landscape to an equivalent of its pre-mining condition and use.

Heathgate Resources intends to undertake the decommissioning and rehabilitation. As surety, a bond will be provided to the State of South Australia, adequate to cover the cost of decommissioning and rehabilitation.

Active mining areas would be progressively developed, used, closed and rehabilitated throughout the life of the mine, with rehabilitation commencing as soon as practicable after the completion of mining in an area. Hence at the final closure of mining operations, rehabilitation needed would be limited to the most recently active mining area and dismantled surface facilities.

Decommissioning of wells involves sealing with cement from bottom to near surface, installing locatable markers, and removing the wellheads to at least one-half metre below the surface.

At the conclusion of mining operations, most facilities would be removed as soon as practicable. Any remaining ponded process solutions would be treated and disposed of. Once this is accomplished, all remaining wells would be plugged and abandoned.

Concurrently, the plant and related facilities, depending on regulatory requirements, would be either demolished and disposed of in approved repositories, or sold and removed to another approved location. Sections of the plant may remain long enough to be used for treatment of remaining pond liquids.

Heathgate Resources' current planning assumes that it will be obligated, and directed, to remove all facilities on decommissioning. However, some of the associated infrastructure may be of further use on site or in the district, for example the proposed water bore and water treatment units, access roads, camp buildings and the Aboriginal Heritage Centre. It is proposed that disposal of these facilities be determined in consultation with appropriate regulatory authorities and direct stakeholders.

Facilities would be fully decommissioned no more than seven years from conclusion of the commercial operation. This period includes a post-completion monitoring period for vegetation maintenance, groundwater sampling, drainage repairs, and other activities to ensure the long-term permanent rehabilitation of the site.

I.1.26. Environmental safeguards, monitoring & management

An Environmental Management and Monitoring Plan (EMMP) will be produced, covering both general environmental issues and the specific requirements of legislation and Codes of Practice in relation to radiation. The EMMP is subject to approval by the regulatory authorities, who will determine the detailed requirements for environmental protection; who will have the responsibility for independent oversight of the monitoring, safeguards and environmental management; and to whom Heathgate Resources will be required to report regularly.

Development of the EMMP will take into account issues and responses raised in the EIS process, including public submissions on this EIS, as well as formal regulatory requirements. It will establish management processes and procedures, which ensure that environmental impacts are minimised. Processes and procedures will include monitoring of the impact, both general environmental and radiological, environmental auditing, reporting strategies and consultation processes.

As part of this plan, radiological monitoring, groundwater monitoring, biological monitoring, weather and microclimate recording and monitoring the effectiveness of rehabilitation will all be carried out. These will contribute to the maintenance of "essential ecological processes and life-support systems" required as part of Ecologically Sustainable Development principles.

Necessary components are already in place as part of the field leach trial, in particular radiological monitoring, including developed Radiation Safety and Occupational Health and Safety Manuals, microclimate recording, groundwater monitoring and landscape (vegetation/soils) monitoring (Fig. 11). These will be expanded for larger operations. Approaches to environmental management and monitoring intended for inclusion in the EMMP are discussed in the EIS.

Modifications to the EMMP will be initiated as required when operations and plant process refinements are made during the life of the mine. A committee will be established with the regulatory authorities to review environmental management/monitoring on a regular basis.

Community consultation generally is expected to be by means of published annual environmental reports. Consultation with Aboriginal communities will be undertaken periodically through the Native Title Advisory Committees established with the Native Title claimants.

Environmental safeguards and commitments proposed in this EIS will be incorporated into the EMMP. Major proposed actions have been mentioned in this document.

FIG. 11. A monitoring point as part of field leach trial management.

APPENDIX II. LICENSING OF IN SITU LEACH MINING FOR THE CROWNPOINT AND CHURCH ROCK URANIUM DEPOSITS, NEW MEXICO

The following case study is excerpted from a paper by Pelizza and McCarn. The licensing activities for the Church Rock and Crownpoint uranium properties was a particularly complex process as the areas to be encompassed by the license were changed during the licensing process, the areas reside within or near conflicting governmental jurisdictions, the efforts attracted the attention of numerous non-governmental organizations, (NGO), and the affected parties include Native Americans.

II.1.1. Introduction

Licensing of in situ leach recovery operations in New Mexico, adjacent to the Navajo Indian Reservation, required significant effort on the part of Uranium Resources, Inc. and the subsidiary, Hydro Resources Inc., since the submittal of the original application in 1988. On January 5, 1998, the U.S. Nuclear Regulatory Commission issued the license to operate following a lengthy Environmental Impact Statement process jointly managed by the U.S. Nuclear Regulatory Commission, the U.S. Bureau of Indian Affairs, and the U.S. Bureau of Land Management. The principal stakeholders include the State of New Mexico, the Navajo Nation and a number of citizen groups. The U.S. Environmental Protection Agency reviewed the Environmental Impact Statement.

Since licensing, Hydro Resources Inc. overcame legal challenges to the source material license from groups opposed to uranium development and obtained the necessary water rights from the State of New Mexico on October 19, 1999. On January 19, 2000, the Navajo Nation lifted its 1983 moratorium on uranium mining for uranium in situ leach (ISL) recovery.

The Grants Uranium Region is located in northwestern New Mexico and is part of the Colorado Plateau physiographic province. The Jurassic Westwater Canyon Member of the Morrison Formation in the San Juan Basin hosts the uranium. The Crownpoint and Church Rock ore trends are monometallic, regional redox-controlled, roll-front type uranium deposits and occur as stacked roll-fronts. Other uranium deposits in the Grants Uranium Region include humate-type sandstone deposits including the Ambrosia Lake District.

Total low-cost Reasonably Assured Resources (RAR) for properties controlled by Hydro Resources Inc. includes 32 730 tonnes U (85 million lbs U_3O_8). This paper reviews the process of developing and licensing this resource.

Hydro Resources, Inc. ("HRI") is a wholly owned subsidiary of Uranium Resources, Inc. ("URI") whose role is the operating company for acquisition, permitting (licensing) and developing of the New Mexico properties. The corporation has invested over $20 million in New Mexico since 1986 because the San Juan Basin is the most prolific uranium province in the United States with historical production of over 133 000 tonnes U (347 million lbs U_3O_8) nearly matching the resources of several of the world class Australian and Canadian deposits.

II.1.2. Property description

Church Rock

The Property - The Church Rock properties (Fig. 12) encompass 900.4 Ha (2 225 ac) and include mineral leases, patented mineral claims and unpatented mining claims. The properties are located in McKinley County, New Mexico, and consist of three parcels, known as Section

8, Section 17, and Mancos. None of these parcels lies within the area generally recognized as constituting the Navajo Reservation.

Resource - Section 8, Section 17, and the Mancos property contain approximately 2 500 tonnes U (6.5 million lbs U_3O_8), 3 230 tonnes U (8.4 million lbs U_3O_8), and 1 615 tonnes U (4.2 million lbs U_3O_8) of in-place RAR resources, respectively.

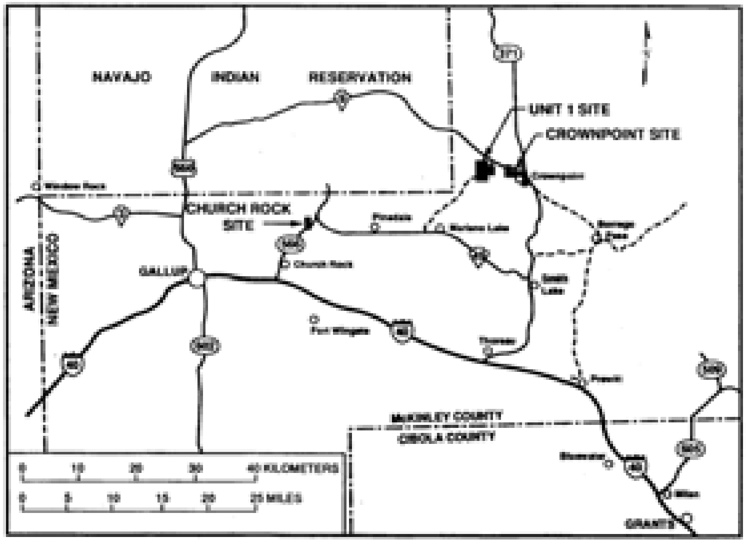


FIG. 12. Property locations in McKinley County, New Mexico.

Development Plan – HRI’s properties will be developed in accordance with the licenses issued by the NRC. It is anticipated that the first property to be developed will be Church Rock Section 8.

Crownpoint and Unit 1

The Property - The Crownpoint properties are located in the San Juan Basin, 35.4 km (22 mi) northeast of HRI’s Church Rock deposits and 56.4 km (35 mi) northeast of Gallup, adjacent to the town of Crownpoint. The properties consist of 638.6 Ha (1 578 ac).

In addition, HRI has 582.7 Ha (1 440 ac) of mineral leases hereinafter referred to as “Unit 1” from Navajo Allottees who are the beneficial owners of the surface and mineral rights. The leases are subject to approval by the Bureau of Indian Affairs (the “BIA”). None of these properties lies within the area generally recognized as constituting the Navajo Reservation.

Resources - The Crownpoint property contains approximately 15 000 Tonnes (39 million lbs U_3O_8) of in-place RAR resources. HRI estimates that Unit 1 contains approximately 10 385 tonnes (27 million lbs U_3O_8) of in-place RAR resources.

Development Plan – HRI’s properties will be developed according to the license conditions issued by the NRC. Under the license, the first operating property will be Church Rock followed by Unit 1 and Crownpoint.

II.1.3. Geological overview

Grants uranium region

The Crownpoint and Church Rock uranium deposits are located in the Grants Uranium Region. The Grants Uranium Region is located in northwestern New Mexico and is part of the Colorado Plateau physiographic province. The Grants Uranium Region has been the most prolific producer of uranium in the United States. With production as early as 1948, over 133 000 tonnes U (347 million lbs U_3O_8) has been produced from the region, mainly during the years 1953 through 1990. The district achieved a maximum production of 7 208 tonnes U (18.7 million lbs U_3O_8) in 1978.

Regional subsidence has preserved about 1000 m (3000 ft) of Triassic, Jurassic, and Cretaceous Sediments in the San Juan Basin. Stratigraphically, this series of sediments accumulated as a major transgressive sequence. The Triassic dominantly contains aeolean massive cross-bedded dune sands that continued into early Jurassic time. In late Jurassic time, major uplifts occurred to the west in the vicinity of the present Mogollon rim of Arizona causing deposition of massive arkosic alluvial fan deposits across northeastern Arizona and into northwestern New Mexico.

The Westwater Canyon member of the Morrison formation contains the majority of uranium deposits and was emplaced during this type of depositional regime. During deposition of this regional alluvial fan, abundant volcanic activity was also occurring which was deposited as interbedded tufts over the entire area of the San Juan Basin. At the beginning of the Cretaceous, a major subsidence occurred throughout the Rocky Mountain Geosyncline and Cretaceous seas transgressed the Jurassic continental deposits.

During the Jurassic period, abundant vegetation was present. With the decay of the vegetation, humic and fulvic acids migrated and were concentrated in channel sands upon burial. In addition to the vegetal material, volcanic tufts that were deposited with the sands yielded uranium to the groundwater. Where the humate was concentrated, uranium was absorbed from the groundwater and formed ore pods.

Through subsequent uplift and remobilization of groundwater, oxidized solutions reconcentrated uranium in rolls or stacked ore during both the Cretaceous and Tertiary. Many of these redistributed deposits, such as HRI’s properties, are large deposits amenable to ISL, and are relatively shallow. The Westwater Canyon Member shows a regional pattern of alteration from hematite at a distance from the redox front, to limonite in proximity to the front, and finally pyrite at and beyond the front.

The Church Rock/Crownpoint sites

HRI’s ore deposits are associated with well-developed channel sandstones in the upper three-fourths of the Westwater Canyon Member. Ore zones are irregular in configuration and elongated parallel to depositional features. Varying rates of ground-water flow controlled by sedimentary facies in each stratigraphic zone in the Westwater Canyon produced stacked ore deposits near one another, but not necessarily vertically above and below one another (Peterson, 1980). The deposits are found as irregular pods, or as the classic c-shape roll-fronts.

Uranium ore deposits that are amenable to ISL as planned by HRI must have been redistributed. All of HRI’s in place resources originally related to organic material in the

Westwater sandstone, and were largely deposited contemporaneously with the sandstone and since have been remobilized by oxidizing conditions in migrating groundwater and redeposited elsewhere when reducing conditions were again encountered. These natural geologic conditions in the production zone exhibit the required characteristics that favor uranium ISL. The effect of ore redistribution has been a natural refining process through which various trace metals have been selectively removed from some ore deposits. These conditions may play a role in the ease with which restoration proceeds in aquifers being produced using ISL recovery methods.

Most uranium mineralization in the region occurs as pore fillings or coatings in sandstone of the Morrison Formation, and less importantly in the Dakota Sandstone and Todilto Limestone (Hilpert, 1963). The major mineral is coffinite with minor amount, of uraninite, andersonite, bayleyite, uranophane, tyuyamunite, and carnotite present.

Mineral resources found at the Church Rock site vary in thickness, but average 3 m (9 ft) thick in each zone. Because the orebodies are stacked, the ore has a combined thickness of about 24 m (80 ft). Overall dimension of the orebody is 1600 m (5300 ft) long and up to 300 m (1000 ft) wide. Near Crownpoint, mineral resources are similar to the Church Rock deposits, varying in thickness, but averaging nearly 4 m (11 ft) thick in each zone. The stacked ore zones have a combined thickness of about 37 m (120 ft). The combined dimensions of the Unit 1 and Crownpoint orebodies exceed 8km (5 mi) long, and their width varies from 290 to 760 m (950 to 2500 ft) wide.

II.1.4. Licensing and permitting

Strategic implications

The production of uranium is subject to extensive regulations, including federal and state (and potentially tribal) environmental regulations, which have a material effect on the economics of the ISL operations and the timing of project development. Successful ISL recovery licensing strategy requires an overall understanding of all components of licensing, a sense for timing, and a coordinated legal and engineering team.

In the United States, basic production in all industrial sectors is significantly affected by the regulatory climate. Environmental issues must be fully accounted for in project in evaluating project economics.

Environmental considerations include the prevention of groundwater contamination (through proper design and operation of the well field and the use of monitoring wells to detect any potential excursions from the well field) and the treatment and disposal of liquid and/or solid surface waste or by-product materials (so-called “11e. (2) by-product material” under federal law). The majority of by-product material that is generated is liquid and generally is disposed of by a combination of reverse osmosis, brine concentration and evaporation or, after treatment, by surface deposition or discharge or through underground injection wells. Proposed plans for waste disposal must be approved by regulatory authorities.

The current regulatory track record for the ISL industry is well established. Many ISL projects have gone completely through the permit-operating-restoration cycle without any significant environmental impact. In fact, with nearly three decades of operations, the domestic ISL mining industry has never caused a serious environmental, health or safety risk or failed to restore an aquifer at one of its projects. However, the public anti-nuclear lobby can make environmental permitting difficult and permit timing less than predictable.

In New Mexico, there are two primary regulatory authorizations required prior to operations: a radioactive material license and underground injection control ("UIC") permits. In addition to its radioactive materials licenses and UIC permit, a prospective ISL operator may also be required to obtain a number of other permits or exemptions from appropriate governmental authorities, such as for waste water discharge, land application of treated waste water, or for air emissions.

Table VII illustrates the time-paths of all important activities associated with the Crownpoint and Church Rock deposits.

Radioactive materials license

Uranium production is subject to regulation by the U.S. Nuclear Regulatory Commission ("NRC") under the federal Atomic Energy Act and requires a radioactive materials license. HRI has applied for one NRC license covering all properties located in both the Church Rock and Crownpoint districts (except the Mancos property) and has included the properties in both districts (except the Mancos leases) under one Final Environmental Impact Statement ("FEIS") which is a prerequisite for the NRC license.

Submittal of Application (s) - HRI initiated the License Application process on April 13, 1988 by submitting an Environmental Report to the NRC. The Environmental Report was also provided to the Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), and others. On April 25, 1988 HRI submitted an Application to the NRC for a Source Material License ("License") to produce uranium commercially using ISL recovery at its Church Rock property. HRI amended its Application on May 8, 1989, to include uranium recovery processing at an existing facility in Crownpoint and again on April 23, 1992 to include ISL recovery on Unit 1, west of the existing facility at Crownpoint. Finally, on July 31, 1992, HRI amended its Application to include ISL recovery on lands associated with the existing facility in Crownpoint. HRI's Application to conduct ISL recovery and processing at the Church Rock, Unit 1, and Crownpoint sites is referred to collectively as the Crownpoint Uranium Project.

Environmental Impact Statement Process - Pursuant to NRC's regulations for implementing the National Environmental Policy Act, in 1992 the NRC, BLM, and BIA initiated a scoping process to identify significant issues to be addressed in a Draft Environmental Impact Statement ("DEIS"). A Notice of Intent to prepare the DEIS was published in the *Federal Register* on August 29, 1992. Two public scoping meetings were held on September 24, 1992, in Window Rock, Arizona, and Crownpoint. At these meetings, NRC, BLM and the BIA described their review procedures and responsibilities, and HRI representatives described the proposed project. State, local, and tribal government agency representatives and concerned local citizens also made statements and asked questions at the meetings.

The NRC published the *Draft Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico* in October 1994 and conducted public comment meetings on it. The DEIS was prepared by an interagency review group consisting of the NRC, BLM and BIA. The BLM and BIA served as cooperating agencies to fulfill their statutory responsibilities to regulate mineral recovery activities on Federal and Indian Lands (Mining Law of 1872, Allotted Lands Mineral Leasing Act of 1909, Mineral Leasing Act of 1920, National Historic Preservation Act of 1966, Endangered Species Act of 1973, Federal Land Policy and Management Act of 1976).

The NRC conducted three public comment meetings to solicit oral and written comments on the DEIS. Two public comment meetings were held in Crownpoint, on February 22, 1995, and one was held in Church Rock, on February 23, 1995. A total of 76 participants provided oral comments at the meetings, and the NRC received 52 sets of written comments.

After compiling public comments, and other questions, NRC posed these to HRI as requests for additional information in letters dated January 11, 1996, February 9, 1996, and July 15, 1996. HRI's responses to these documents were forwarded on to NRC on February 20, April 1, and August 15, respectively.

Following the public input to the DEIS, and HRI's responses, on the basis of its independent review, in February 1997, the NRC published the *Final Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint New Mexico (FEIS).* The FEIS concluded that the potential significant impacts of the project can be mitigated, and that HRI will likely be issued a conditioned combined source and 11e(2) by-product materials license from NRC and minerals operating leases from BLM and BIA.

Consolidated Operations Plan - Because the licensing of the Crownpoint Uranium Project has taken a number of years, and included several property additions, with corresponding informational submittals, NRC has expressed concern that the Application information has become disjointed for the purpose of "tie-down provisions" in the operating license. To satisfy this concern and provide all the specifications and representations, which had been articulated to NRC in the past under one cover, in August 1997 HRI submitted a Consolidated Operations Plan. The Consolidated Operations Plan is an integral part of HRI's operating license.

Safety Evaluation Report and License Issued – The NRC Safety Evaluation Report was issued on December 4, 1997. The Safety Evaluation Report was compiled pursuant to HRI's safety plan that was described in the Consolidated Operations Plan. The Safety Evaluation Report and the FEIS provided the basis for NRC's decision to issue the Radioactive Materials License. In January 1998 the NRC issued a license that would allow operations to begin in the Church Rock district.

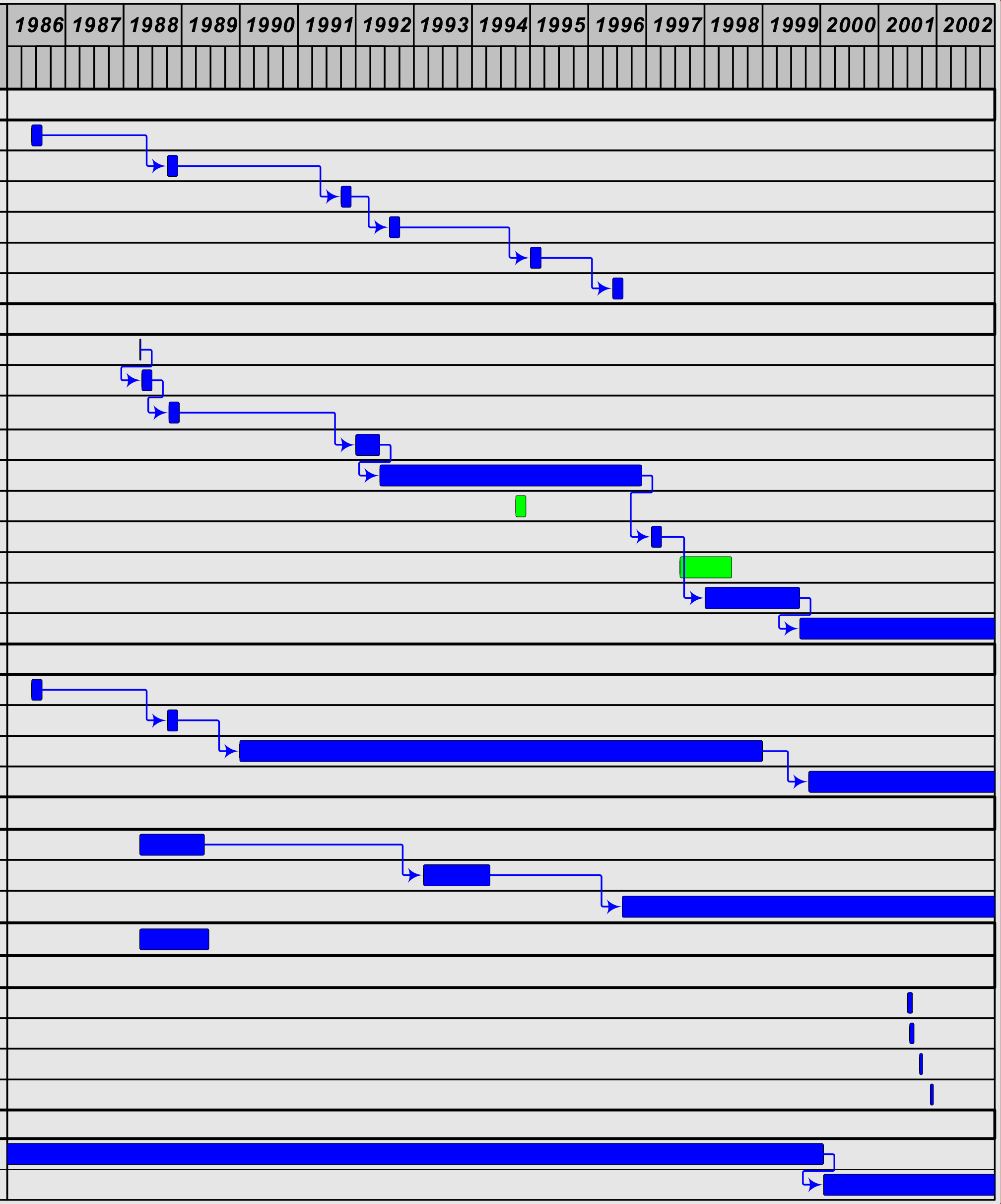
Litigation - In mid-1998, the Commission determined that certain Church Rock and Crownpoint residents and other environmental activists who requested a hearing had standing to raise certain objections to the license. An NRC Atomic Safety Licensing Board administrative law judge and his technical staff from the U.S. Geological Survey conducted a hearing in 1999. The hearing was broken into 9 distinct briefing subjects including performance-based licensing, liquid waste disposal, surface water protection, cultural resource issues, air emissions issues, HRI qualifications in training and experience, groundwater protection, adequacy of financial assurance, EIS and environmental justice considerations.

License Upheld - Following the hearing the administrative law judge found that the project was safe and denied the opponent's request that the license be rescinded. The opponents then appealed the administrative law judge's ruling to the full Commission. On July 10, 2000, the Commission denied the opponents appeal, stating their arguments "unpersuasive" and found that "Intervener's have identified no "clearly erroneous" factual finding or important legal error etc,." The Commission found that there was no reason to question the administrative law judge's finding that HRI was a qualified company and that the project was environmentally safe. With regard to groundwater quality, on January 31, 2001, the Commission concurred with the technical, substantive and legal findings of the administrative law judge's (i.e. that the project as planned safely protects groundwater resources).

Abeyance Denied – Along with the Commission concurring with the technical, substantive and legal findings of the administrative law judge, they also denied abeyance and instructed HRI to proceed with the hearing process for all properties including Crownpoint or amend the License and remove them.

Table XII. GANTT chart of primary tasks in licensing

ID	Task Name	Start	Finish
1	**A. Property Acquisition:**	**6/2/1986**	**8/7/1996**
2	Church Rock Sec. 8	6/2/1986	8/6/1986
3	Crownpoint	10/3/1988	12/6/1988
4	Crownpoint Unit One	10/1/1991	12/3/1991
5	Crownpoint Addition	7/31/1992	10/3/1992
6	Church Rock Sec. 17	1/2/1995	3/11/1995
7	Checkerboard Agreement - Santa Fe	6/3/1996	8/7/1996
8	**B. NRC Licence Application & Litigation:**	**4/13/1988**	**1/1/2020**
9	Initial Submittal of Environmental Report	4/13/1988	4/19/1988
10	Application for Source Material License	4/25/1988	6/28/1988
11	Addendum to Application	10/12/1988	12/16/1988
12	New ER to Accommodate Expansion	1/1/1992	5/31/1992
13	Environmental Impact Statement Process	6/1/1992	12/2/1996
14	Draft Environmental Impact Statement	10/3/1994	12/6/1994
15	Final Environmental Impact Statement	2/3/1997	4/6/1997
16	Consolidated Operations Plan	8/1/1997	6/22/1998
17	License Issued: Litigation Phase	1/5/1998	8/23/1999
18	NRC License Upheld	8/24/1999	1/1/2020
19	**C. Water Rights:**	**6/2/1986**	**3/24/2014**
20	Priority Applications - Church Rock Sec. 8	6/2/1986	8/6/1986
21	Priority Applications - Crownpoint	10/3/1988	12/7/1988
22	Legal Preparation	1/1/1990	1/1/1999
23	Approved for ISL Mining; Church Rock Sec. 8	10/19/1999	3/24/2014
24	**D. Discharge Plans:**	**4/13/1988**	**1/1/2020**
25	DP-558; Church Rock Sec. 8	4/13/1988	5/23/1989
26	Church Rock Mod. 1	3/1/1993	4/23/1994
27	Timely Renewal of Chuch Rock Sec. 8	8/2/1996	1/1/2020
28	**E. Aquifer Exemptions: Church Rock Sec. 8**	**4/13/1988**	**6/21/1989**
29	**F. Restoration Action Plans:**	**7/2/2001**	**12/11/2001**
30	Church Rock Sec. 17	7/2/2001	8/1/2001
31	Church Rock Sec. 8	7/16/2001	8/11/2001
32	Crownpoint Unit One	9/14/2001	10/4/2001
33	Crownpoint	11/21/2001	12/11/2001
34	**G. Navajo Uranium Mining Moratorium:**	**1/3/1983**	**1/1/2020**
35	Uranium Mining Sanctions	1/3/1983	1/19/2000
36	Sanctions Lifted for ISL Mining Only	1/20/2000	1/1/2020



As required, on April 30, 2000, HRI notified the Commission of its intent to move forward with the Crownpoint hearing. Immediately, the administrative law judge contacted all parties and required a schedule be negotiated for the remainder of the hearing. On May 25, 2000, the administrative law judge approved the negotiated hearing schedule that required that HRI provide Restoration Action Plans for the Section 17, Unit 1 and Crownpoint location over the remainder of 2001 and litigation resumption in early 2002.

On Nov. 21, 2000, HRI submitted the requested Restoration Action Plan for the Church Rock Section 8 site. It was approved by NRC and is currently under review by the administrative law judge. On July 24, 2001, HRI submitted the Restoration Action Plan for the Church Rock Section 17 site that NRC approved on August 22, 2001. On September 17, 2001, HRI submitted the Restoration Action Plan for Crownpoint Unit One that NRC approved on October 16, 2001. On November 21, 2001, HRI submitted the Restoration Action Plan for Crownpoint that NRC approved on December 20, 2001.

Settlement - In November 2001, with the concurrence of all parties, the NRC appointed a special judge to attempt to facilitate settlement among the parties that, if successful, would end the hearing process. No settlement agreement has been reached. This settlement process is expected to be finalized in October 2002.

UIC Permits

Primacy - The Federal Safe Drinking Water Act ("SDWA") created a nationwide regulatory programme protecting groundwater, which is administered by the U.S. Environmental Protection Agency ("EPA"). To avoid the burden of dual federal and state (or Indian tribal) regulation, the SDWA allows for the permits issued by the UIC regulatory programmes of states and Indian tribes determined eligible for treatment as states to suffice in place of a UIC permit required under the SDWA. A state whose UIC programme has been determined sufficient for this purpose is said to have been granted primary enforcement responsibility or "primacy," and a UIC permit from a state with primacy suffices in lieu of an EPA-issued permit, provided the EPA grants, upon request by the permitting state, an aquifer exemption modifying the permitting state's UIC programme. New Mexico has been granted primacy for their UIC programme and NMED has jurisdiction under the New Mexico Water Quality Act to regulate UIC activities within the State of New Mexico.

Jurisdictional issues - The Navajo Nation claims regulatory jurisdiction over a significant portion of HRI's development properties. These claims subject the development of those properties within the area claimed as Indian Country to uncertainties, including a potential for delays in UIC permitting. For certain properties not permitted by the EPA at the time a Navajo regulatory programme is promulgated and accepted by the EPA for a determination of primacy, HRI would then apply to the Navajo EPA for its UIC permits. Although a Navajo UIC programme may adopt unique application, permitting, and enforcement procedures, it would, nonetheless, be required to impose virtually the same substantive requirements as HRI is prepared to satisfy under existing New Mexico and EPA UIC programmes.

Church Rock Section 8 - On April 13, 1988, an application for a State discharge plan was submitted at the same time the NRC License was initiated. Discharge plan DP-558 issued on November 2, 1989, which authorized ISL recovery at the Church Rock Section 8 location, was approved by the New Mexico Environment Improvement Division (now NMED). Prior to expiration of amended DP-558 on October 31, 1996, HRI made timely application to renew the permit for both of HRI's Section 8 and Section 17 properties. This timely application for renewal holds DP-558 in force until final NMED action on the application.

Church Rock Section 17 - In March of 1993, HRI submitted an application to amend DP-558 by adding the Section 17 property. The Navajo Nation, which claimed UIC regulatory jurisdiction over the site based on the fact that the Navajo Nation owns the surface estate, contested the permit for Section 17. A public hearing began in October of 1993 on the amendment and continued from time to time thereafter. The amendment was approved by NMED on October 7, 1994. The EPA, acting as an advocate for the Navajo Nation, has asserted the Navajo Nation's claim and has refused to amend its previously issued aquifer exemption covering Section 8 to add the portion of the Church Rock facility on Section 17.

Aquifer Exemption - An important component of the federal Safe Drinking Water Act is the legal authority that allows ISL mineral development in portions of geologic strata, which are also shared by drinking water supplies.

EPA must issue an Aquifer Exemption for each mine site before any ISL recovery can occur. On June 21, 1989, EPA, acting on the request of the State, modified New Mexico's EPA-approved Underground Injection Control (UIC) programme by designating the portion of the mine zone aquifer underlying HRIs Section 8 property to be an exempted aquifer within the meaning of that term under the SDWA. No aquifer exemption has been granted for Section 17, Crownpoint or the Unit 1 site.

II.1.5. Water rights

Jurisdiction over water rights may become an issue when an Indian nation, such as the Navajo Nation, objects to the State Engineer's authority to grant or transfer a water right or to award a temporary water right, claiming tribal jurisdiction over Indian Country. This issue could result in litigation between the Indian nation and the state, which may delay action on water right applications, and, depending on who prevails as to any particular property, could result in a requirement to make applications to the appropriate Indian nation and continuing jurisdiction by the Indian nation over use of the water.

Church rock water rights

HRI acquired mineral leases on Sections 8 and 17 from United Nuclear Corporation and, in connection therewith, acquired certain water rights that were obtained during the years of conventional mining. Applications to use these water rights have been the subject of extensive administrative proceedings and litigation with the New Mexico State Engineer and the Navajo Nation over the nature and extent of United Nuclear Corporation's water rights.

Crownpoint applications

HRI holds a number of unprotested senior water rights applications that when approved would provide sufficient water for the Crownpoint operational life.

Navajo uranium mining moratorium

Executive Order - The Navajo Nation Executive Order of 1992 was a moratorium on all uranium-mining activities on Navajo lands. It stated that "The Navajo Nation shall not approve any exploration, development, mining, milling, or transportation of uranium ore within the jurisdiction of the Navajo Nation unless and until the responsible party is able to certify and prove that the proposed activities will not contribute directly or indirectly to any further radioactive or heavy metal contamination of Navajo air, water, soil, vegetation, wildlife, or livestock." The moratorium was placed on uranium mining activity until such a time that the Navajo people can be assured that all safety and health hazards related to such activity can be addressed and resolved.

Navajo Nation Policy on Uranium Solution Extraction - On January 19, 2000, after completing a review of open pit mining, underground mining, and ISL recovery, the Navajo Nation Tribal Council Resources Committee found that open pit and underground mining caused significant waste and mill tailings that are not associated with the ISL method. The Resources Committee stated that they would not allow uranium extraction by open pit and underground mining methods. At the same time the Resources Committee announced that the Navajo Nation Policy on Uranium Solution Extraction superseded the Executive Order of 1992.

The Policy specified requirements that a applicant or responsible party certify that a solution extraction activity protect Navajo air, water, soil, vegetation, wildlife and livestock through the mandatory compliance with Navajo laws, rules and regulations before a permit could be considered by the Resource Committee of the Navajo Nation Council. It requires compliance with the Navajo Nation Solid Waste Code, the Navajo Nation Pesticide Act, the Navajo Mine Land Reclamation Code, the Navajo Energy Development Policy, the Navajo Nation Environmental Policy Act, the Navajo Air Pollution Prevention and Control Act, the Navajo Safe Drinking Water Act, the Navajo National Discharge Elimination System Act, and Federal environmental laws that, when the Executive Order of 1992 was issued, were not yet approved.

The Navajo Nation Policy on Uranium Solution Extraction Activity on the Navajo Nation also required that an Environmental Impact Statement be required for a Uranium Solution Extraction Permit within the Navajo Nation by an inter-agency committee from the Nuclear Regulatory Commission, Bureau of Indian Affairs and the Bureau of Land Management. The Resources Committee of the Navajo Nation Council committed to review and approve Environmental Impact Statements that deal with oil and gas, uranium, coal, geothermal, or other energy or non-energy mineral resources production and related activities on Navajo lands.

II.1.6. Summary *(Table VII)*

In the U.S., a prospective uranium producer must deal with numerous strategic elements, including: acquisition of a land position with reasonably assured, high quality, uranium resources; acquisition of associated intellectual data as part of the land position to support the resource base and future developmental activities; ore that is demonstrated to be amenable to development by modern, socially accepted, competitive production technology; maintenance of technical expertise; and pursuit of necessary permits and licenses, with the core authorizations in place when market prices allow production to begin.

HRI is in the advanced stages of a 10 plus year permitting campaign for a significant portion of the New Mexico resource properties. The FEIS process has been completed for all of the Crownpoint Project areas. The licensing of the Crownpoint Uranium Project has been the subject of a lengthy administrative review by a number of State and Federal regulatory agencies. The Church Rock Section 8 property, which represents the first step in HRI's incremental development plan, is licensed. Water right precedents have been established to allow for the needed water to conduct ISL operations at HRI's other locations. Relations with the Navajo Nation are good. Future permitting and licensing, is well advanced, so that after the first stage of production, the additional phases can be brought on incrementally to meet sustained production requirements.

II.1.7. Conclusion

As international requirements for mining operations become more uniform over time, companies will be required to develop compatible policies that clarify and guarantee environmental responsibilities and commitments as well as environmental justice for stakeholder groups. As stated in the ISO 14000 standards, policy commitments include legal compliance, environmental protection, pollution prevention, and continual improvement in performance. These company commitments include environmental performance evaluation, life cycle assessment, environmental auditing, quality assurance (ISO 9000) as well as a continual process of planning, implementation, checking, and corrective action.

As these objectives are implemented world- and industry-wide, licensing requirements will become more uniform and careful strategic planning will be required to optimize the critical path required for licensing. As demonstrated in this paper, in the United States, this licensing process requires a significant outlay of company resources and time. Future uranium recovery projects, regardless of location, will be licensed under comparable standards. The international community and the customers for the product will demand it.

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APPENDIX III. ENVIRONMENTAL PROTECTION AT AKDALA DEPOSIT — KAZAKHSTAN

III.1.1. Introduction

The Akdala uranium deposit is located in the northern portion of Shymkent province in South Kazakhstan. Current plans call for the extraction of uranium by in situ leaching (ISL) methods from Cretaceous sandstone at an average depth of 185m. Annual production capacity for the project will be 500 t U. Although the project is located in a desert region and the quality of groundwater is unsuitable for human consumption, evaluation of the potential environmental impacts of the project is given a high priority, equal to that assigned to other projects such as Kanzhugan, Moyinkum, Karamurun, Mynkuduk, Uvanas.

The baseline environmental conditions at Akdala have been characterized and are described in the following sections.

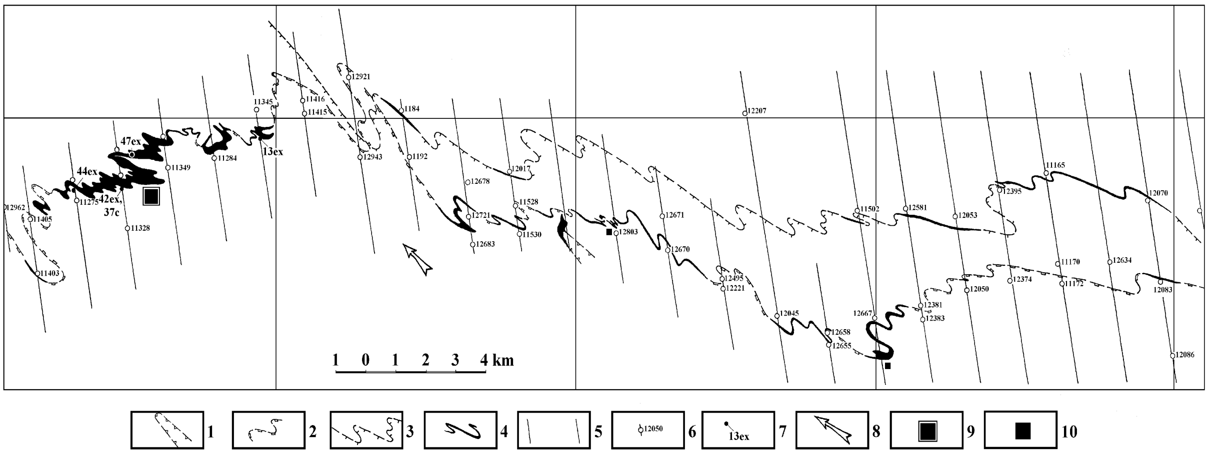

FIG. 13. Map of Akdala uranium deposit.
Legend: 1-3) fronts of redox zones in subaquifers: 1) Intymak (K_2^{2-3}), 2) Zhalpak (K_2km-m), 3) Mynkuduk (K_2t1-st); 4) an orebody; 5) exploratory cross-sections; 6) a well and its number; 7) a hydrogeological well, letters in figures mean as follows: ex–experimental, c–central in a cluster of wells; 8) the direction of groundwater flow; 9) a milling complex (industrial and auxiliary zones); 10) a milling complex without auxiliary zones.

III.1.2. Characteristics of the impact sources

Two basic production complexes, mining and milling, are considered separately as each has distinct impacts on the environment. It is assumed that ore will be mined with typical mining complexes (TMC). Each complex will have an annual production of 150 to 500 t U.

A typical mining complex includes:

- A typical acid unit (TAU),
- A network of operating (injection and recovery) and monitoring wells,
- A network of pipelines for production, pregnant and residual solutions, and compressed air,
- A network of temporary gravel roads along pipelines.

The area of a TMC is 48 to 80 ha depending on a uranium cutoff uranium grade in the orebody. Mining disturbs soil cover, potentially contaminating it with radionuclides and chemical components. Mining also has a strong direct impact on aquifers, particularly in the ore horizon. The life of a TMC is 4-5 years.

The milling complex includes industrial and auxiliary zones. The industrial zones include the followings:

- 2 facilities for treatment of uranium bearing production solution,
- 2 facilities for uranium adsorption on site located 1 km and more from the industrial zone,
- 2 ponds (20×60×2.5 m^3) for production and residual solution,
- Acid storage,
- A facility for decontamination of equipment and transport units.

Facilities within the industrial zones will be constructed and used for 35 years including periods of exploitation and decommissioning. It is expected that there will be 3 milling complexes: a basic complex and two additional complexes (Fig. 13). Additional milling complexes will be designated only to adsorb uranium from productive solution. Due to installation of black top surfaces around facilities and impermeable lining at the bottom of ponds, radioactive and chemical contamination of soils is unlikely. However, radioactive and chemical contamination of the air surrounding the industrial zones is possible, and soil cover will be destroyed during construction.

The auxiliary zone includes the followings:

- Fuel storage,
- Heating facility,
- Energy supply facility,
- Mechanical workshop,
- Garage with different cars,
- Local sewage system.

Operations within the auxiliary zone have the potential contaminate air, soil and the upper aquifer with different chemical components.

III.1.3. Media and types of basic impact

The Technical-Economic Substantiation[1] (TES) or Environmental Impact Assessment does not consider any impact on flora and fauna due to the small size of the deposit in comparison with the ecosystem of the Betpakdala steppe (less 1%). Electromagnetic and noise impacts were not considered due to strict adherence to relevant equipment instructions. Because of the absence of significant surface drainage, impact on surface water was not considered. Only air, groundwater, ore formation, land and social media will be exposed to the proposed industrial activity.

Air will potentially be affected by radioactive and chemical impacts from mining and milling complexes. Groundwater will be affected by radioactive and chemical impact from mining

[1] Determination of the optimal uranium grade on boundaries of ores, and justification of the future uranium production, subject to compliance with all environmental requirements and standards.

complexes and chemical impact from the auxiliary zone. Land (soil and ground) will be affected by mechanical, radioactive and chemical impact from mining and milling complexes. Surface and air contamination will be possible from uranium and technical water extracted from the mineralized formations. Radiation safety standards will be required for personnel working at the sites as well as the general population.

III.1.4. An impact assessment on air

III.1.4.1. Brief characteristics of physical-geographic and climatic conditions

The climate around the site is defined using data collected at the nearest meteorological station (Table VIII).

Table VIII. Accepted meteorological data for calculations of air contamination

Characteristics	Symbol	Units	Magnitude
The factor of air stratification	A	-	200
The factor of relief (change of height is less 50 m around 1 km)		-	1
Average maximum temperature of outdoor air in June	t	ºC	+43
Average maximum temperature of outdoor air in the coldest month	t	ºC	-35
Wind direction:			
North		%	7
North-east		%	18
East		%	36
South-east		%	9
South		%	5
South-west		%	7
West		%	11
North-west		%	7
Wind rate which repetition is 5% (on average for many years data)	V	m/s	3.8-4.6

Climatic conditions of the region are favourable for dispersion of contamination in air.

III.1.4.2. Data of impact calculations in air

Impact on the air was assessed using methodology, mathematical programmes and models accepted by regulatory bodies of the Ministry of Bioresources (now Ministry of Environmental Protection), and standards on maximum permitted concentrations (MPC's) of chemical and radioactive constituents in the air. All impact sources were separated as organized or non-organized. Organized sources are characterized by the system of effluent gathering, purification and disposal. Such sources are facilities for treatment of production solution and for uranium adsorption, the heating facility, the mechanical workshop and the garage. Effluent components are carbon monoxide and dioxide, hydrocarbons, carbon-black, lead, benzapiren, aerosol of nitric and sulphuric acids, nitric dioxide and sulfurous anhydrite. By considering a toxic class of each component, a generalized volume of effluents was calculated (Table IX).

Primary air contamination will result from motor transport (1 212.9 t/y or 95.7% of total contamination). Effluents from stationary sources are insignificant (about 4.3%), and their concentration in the air near the ground will possibly exceed MPC's in some separate points within industrial zones, but not over 0.1 MPC of any contaminated substance on the perimeter of the sanitary protective zone (SPZ) that is located 1.0 km from facilities emitting highly toxic substances such as radioactive contaminants.

Table IX. Generalized volume of effluents

Source of effluents	Specific effluents, t/y*
Mining complexes	195.1
Industrial complexes	0.7
Auxiliary zones	53.5
Beyond the site	1 017.8
Total	1 267

* Mass of each pollutant was multiplied by its toxic factor (0.9÷1.7).

III.1.4.3. Measures for a period of unfavourable meteorological conditions

Unfavourable meteorological conditions can occur in calm or still weather, which is unusual on the site. During such conditions some protective measures are applied as follows:

- Stopping or shortening shipments and storage of loose and friable materials,
- Prohibition of blowing off and clearing off equipment, pipes.

III.1.5. Impact assessment on groundwater

III.1.5.1. Characteristics of current conditions of groundwater

There are two types of permeable groundwater layers: the upper layer with low hydraulic head, and the lower one with high relative hydraulic head. Uranium ores occur in the middle of the lower permeable strata (Fig. 14). Everywhere the groundwater is salty, TDS is 4 to 5 g/l, pH = 7.4 to 8.1, U = 0.1 up to 100 Bq/l within orebodies and less than 0.1 Bq/l beyond orebodies. Hydraulic head is at a depth of 67-70 m. The filtration rate is 0.0032-0.0011 m/d and the flow rate is 4 m/y. Beneath the ore bearing zones are thin, discontinuous impermeable layers. As a result, the first horizon under the ore horizon is vulnerable to the penetration of productive and pregnant solution during the ISL process. Thickness of the upper permeable horizons is up to 60-70 m, including many small impermeable layers of clay and argillite.

III.1.5.2. Water supply and sewage

The magnitude of the project’s impact on groundwater depends on the volume of water supply and sewage and loss of solution in the uranium recovery process.

Drinkable water will be delivered by trucks from the nearest settlement (Kyzymchek located 65 km to the south-east). The quality of water is satisfactory with Sanitary requirements 3.01.067-97 “Drinkable water”. Specific consumption and expenditure are shown in Table X.

Table X. Average daily supply and usage of drinkable water in cubic meters

No.		Daily supply	Daily usage
1.	Workers and officers	2.68	2.41
2.	Showers	15.0	15.0
3.	Technology processes	0.08	---
4.	Evaporation	---	0.35
	Total	17.76	17.76

To provide sanitary conditions for the water supply, and to decrease water loss, networks for cold and hot water supply will be constructed using galvanized pipes. The networks will periodically be replaced and updated.

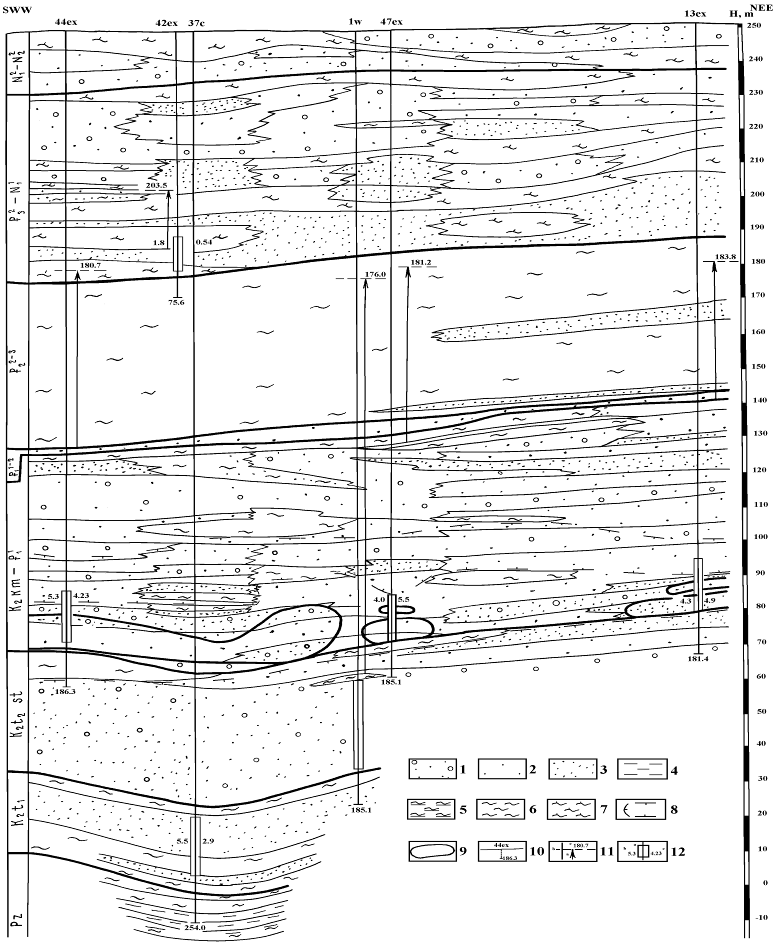

FIG. 14. Hydro-geological cross-section of Akdala uranium deposit.
Legend: 1-7) lithological composition: 1) coarse sand with gravel, 2) medium sand, 3) fine sand, 4) aleurite, 5) clayey aleurite, 6) clay, 7) lime clay; 8) front of the redox zone in Zhalpak aquifer; 9) orebody; 10-12) characteristics of a hydrogeological well: 10) common data: a-a) number of a well (letters mean a type of hydrogeological well: ex-experimental; c) the central well in a cluster of hydrogeological wells); b) depth of a well; 11) potentiometric data: a) head of groundwater, b) an absolute level of the water head, c) figures of the absolute level; 12) basic data of groundwater; a) location of a filter; b) TDS; c) yield, l/s.

Septic facilities, with a total volume of 54 cubic meters will be installed underground. After mechanical and biological treatment, sewage will be disposed of into 6 filtration wells (diameter is 2 m and depth is 2 m).

Process water will be pumped out of the bottom of the lower permeable layers. Specific supply and usage are given in Table XI.

The volume of process water supply is not sufficient to have an influence on the horizon from which the water will be withdrawn. Conventional radioactive sewage (8.53 m^3) will be collected and disposed of in a pond designated for residual or production solution. Conventional non-radioactive sewage will be collected and disposed of into aforementioned septic facilities (1.23 m^3).

Table XI. Average daily supply and usage of technical water in cubic meters

No.		Daily supply	Daily usage
	Conventional non-radioactive in the auxiliary zone		
1.	Hydro cleaning of floors	1.08	--
2.	Dust suppression on roads and other active sites	2.62	1.23
3.	Fire prevention measures	0.08	--
4.	Evaporation	--	3.35
	Total	4.58	4.58
	Conventional radioactive in industrial zones and TMC's		
5.	Hydro cleaning of floors	7.50*	7.09*
6.	Dust suppression on roads and other active sites	5.23*	--
7.	Decontamination	0.44*	0.44*
8.	Fire prevention measures	0.42*	--
9.	Evaporation	--	6.06*
	Total	13.59*	13.59*
	Over total	18.17*	18.17*

* By using additional facilities for uranium adsorption the magnitudes increase by 50%.

III.1.5.3. Heavy rain and melt water

The area of the first industrial zone is 1.89 ha and the auxiliary zone is 1.40 ha. Run-off of heavy rain and melt water from the industrial zone will be directed into a pond of production or residual solution, and from the auxiliary zone into the septic facilities. The maximum level of precipitation is 62 mm/y (Building climatology, Standard 2.04.01-98). The volume of run-off to be directed into the ponds is 868 m^3/y and 1 172 m^3 into the septic facilities.

The area of the additional milling complexes for uranium adsorption is 1 ha. Run-off to be directed into ponds for productive and residual solution is 620 m^3/y.

III.1.5.4. Predicted impact on groundwater near surface

Volume of sewage discharged into septic facilities during the life of uranium production is estimated to be:

Drinkable water:	17.76 m^3/day × 365 days/year × 35 years:	227 000 m^3
Technical water:	1.23 m^3/day × 365 days/year × 35 years:	16 000 m^3
Rain and melt water:	1 172 m^3/year × 35 years:	41 000 m^3
	Total:	284 000 m^3

If we assume that the thickness of the upper permeable layer is 5 m and that the effective porosity is 0.3, the total area that the sewage can occupy will be 284 000/5/0.3 = 189 300 m^2 or 18.9 ha. As the sewage will be mechanically and biologically treated, and its TDS is less than TDS of the natural water, no adverse impact is predicted on natural water.

III.1.5.5. Predicted impact on groundwater around the ore aquifer

For the full period of ISL processing on a TMC, the concentration of sulphuric acid is 20 g/l at the beginning (2-3 months before active leaching), 10 g/l at the beginning of active leaching, 2 g/l at the end of active leaching (a period of active leaching is about 3-4 years) and 0.5 g/l after washing (2-3 months after active leaching). The extent of impact on the ore aquifer depends on confining layers underlying and overlying the above orebodies. The authors of the TES considered some variations in the cutoff grade of the mined area, from

0.02; 0.04; 0.06 and 0.08% U. The higher the cutoff grade is, the less the impact of sulphuric acid solution on the aquifer will be. As a result of economic calculations, including financing of environmental measures, the variation with a cutoff grade of 0.06% U is optimal.

Geotechnological parameters characterizing the impact on the environment during ISL processing are as follows:

• Average ore thickness	5.9 m,
• Average width of the orebody	1000 m,
• Total length of the orebody	3450 m,
• Area of the ore blocks	345 ha,
• Available upper confining layers	37%,
• Available lower confining layers	59%,
• Thickness of the underlying permeable horizon	up to 38 m.

Oxidation from *in situ* leaching is expected within and beyond the orebody: expanding laterally over 10% of the width of the orebody; above the orebody over 20% of its thickness when the overlying horizon is not impermeable; and over the full thickness of the underlying horizon when there is no confining layers. The total volume affected by the leaching process would be:

Volume of the orebody	$3\,450\,000 \times 5.9 = 20.36\ 10^6 m^3$
Lateral extension	$3\,450 \times 1000 \times 5.9 \times 0.2 = 4.07\ 10^6 m^3$
Upper extension	$3\,450\,000 \times 0.63 \times 5.9 \times 0.2 = 2.56\ 10^6 m^3$
Lower extension	$3\,450\,000 \times 0.41 \times 38 = 53.75\ 10^6 m^3$
Total volume	$80.8 \times 10^6 m^3$

Natural concentration of the sulphate ion is about 2.5 g/l, so the increase resulting from ISL mining is only 20%, which need to be considered safe for the host formation aquifer. Washing requires treatment of recycled water by precipitating sulphate with slack lime. It will be used for the final TMC i.e. for 1/33 of total volume affected by leaching:

$$80.8 \times 10^6 \times 1/33 = 2.45 \times 10^6 m^3$$

If it is assumed that the active porosity is 30% and reduction in concentration of sulphate ion is 1.5 g/l, then the amount of precipitated sulphate will be:

$$2 \times 2.45 \times 10^6 \times 1.5 = 7.4 \times 10^6 \text{ kg} = 7\,350 \text{ tonnes.}$$

(where 2 is the average density -t/m^3- of the rocks).

III.1.5.6. Measures to remediate the impacts on groundwater

As noted, there are measures for mechanical and biological treatment of sewage and for treating contaminated groundwater from leached orebodies. Moreover it is clear that there must be strict operating procedures that would prohibit over-injection into well field polygons, cells and wells. This will prevent polluting the underlying permeable horizon and up to 60% of the thickness of the leached orebody, and the contaminated are would be

$$3\,450\,000 \times 0.41 \times 5.9 \times 0.6 = 5.0 \times 10^6 m^3 \text{ (instead of } 53.75\ 10^6 m^3\text{).}$$

Sound operating practices will result in reducing the volume of contaminated area by $48.8 \times 10^6 m^3$. Thus the amount of precipitated sulphate would be only:

$$(80.8 – 40.8) \times 10^6 \times 1/33 \times 2 \times 1.5 \text{ kg} = 3\,600 \text{ tonnes.}$$

III.1.6. An impact assessment on soils and grounds

III.1.6.1. Calculations of possible impact on soils and grounds

Soil cover will be totally destroyed over an area of 4.29 ha occupied by industrial and auxiliary zones. This surface area will be covered with a protective asphalt seal, blacktop. This cover isolates the soils from exposure to potential hazardous materials which may spill from the various sources (ponds, facilities for treatment and sorption of productive solution, fuel storage, the garage, etc). Thus, any heavy chemical and radioactive contamination of soils and grounds is avoided.

On TMC's, a 10% mechanical disturbance is expected as a result of construction of roads, wells and pipelines. The area is 34.5 ha. Radioactive and chemical contamination is expected because of disturbance of locking, plugging, retaining and shutting-off devices on pipelines. Previous experience shows that the area of the contamination will likely limited to 30% of the total area i.e. 10.35 ha.

Depth of contamination depends on the composition of the soils and sub-surface. Considering engineering-geological conditions of the site, loamy soils spread over 70% and sandy loam spreads over 30% of the total area. Average thickness of loamy soils is 0.65 m, and sandy loam is 0.55 m. Moreover in 50% of cases, sandy loam covers clayey ground. Based on these maximum depth (1 m) of contamination is expected on 27.5% of the contaminated area (i.e. 2.85 ha), a contaminated depth of 0.55 m on 2.85 ha and a contaminated depth of 0.15 m on the rest of the area, i.e. 4.65 ha.

Thus total volume of radioactive and chemical contamination is as follows:

$$28\,500 \text{ m}^2 \times 1.0 \text{ m} + 28\,500 \text{ m}^2 \times 0.55 \text{ m} + 46\,500 \text{ m}^2 \times 0.15 \text{ m}$$
$$= 28\,500 + 15\,700 + 7\,000 = 51\,200 \text{ m}^3.$$

Total area of mechanical disturbance will be 4.29 ha + 34.5 ha = 38.8 ha.

III.1.6.2. Measures for protection of soils and grounds

To decrease radioactive and chemical contamination several safeguards will be instituted for warning, localizing and preventing any emergency. One of the safeguards is traps of slack lime for intercepting production, pregnant or residual solution from pipeline ruptures and malfunction of various devices. These measures will limit the volume of radioactive and chemical contamination by a factor of ten (Table XII).

Table XII. Calculation of the volume of radioactive waste connected with contamination of soils and grounds

No.	Parameters	Units	Magnitude
1.	Volume of possible radioactive and chemical contamination	m^3	51 200
2.	Average salinity	%	1.3
3.	Density of soils and grounds	t/m^3	1.8
4.	Mass of slack lime required for prevention against leakage	T	1 400
5.	Mass of contaminated soils and grounds in the case of preventing traps	T	5 100

III.1.7. Waste

III.1.7.1. Non-radioactive technological waste

Maintenance of mining equipment and transportation vehicles will generate waste of lubricants and wiping/rubbing cloth (rags), scrap metal, etc. Absence of a system of gathering, storing, transporting and localizing such waste would result in cluttered areas with negative impacts on soils and flora. Proper design of such a system will mitigate any adverse impact of such waste on the environment.

The list of waste, its characteristics and technical measures for environmental protection are shown in Table XIII. Total volume of waste, for all periods of activities, is calculated by multiplication of working time including 3 years of decommissioning by the annual volume of each type of waste.

Table XIII. Types of waste, their possible impact on environment and measures of prevention

No:	Types of waste	Annual/total volume, t	Impact on environment	Impact assessment	Technical measures	Results of measures used
1.	Oils used (viscous and inflammable fluids)	4.6/161	Disturbance of soil structure; adverse impact on self-refinement in soil; clutter around the site	Weak	Arrangements for gathering oils used in special containers; its shipment for regeneration	It excludes impact on environment
2.	Wiping / rubbing cloth	0.46/16.1	Clutter around the site	Very weak	Arrangements for gathering used wiping and rubbing cloth in special containers (boxes), its storage in special places, its shipment to incineration	It excludes impact on flora and soil
3.	Common scrap	35.8/1253	Clutter around the site	Very weak	Arrangements for gathering it in special containers, its burial into special permitted places near the site	It excludes impact on flora and fauna
4.	Metal scrap	3.2/112	Clutter around the site	Very weak	Arrangements for gathering it, its storage on a special place, its shipment to the smelter	It excludes impact on environment

III.1.7.2. Radioactive process waste

In addition to contaminated soils and grounds (Table XII) waste will be generated in the industrial zone (Table XIV).

Table XIV. Volume of radioactive waste in the industrial zones

No.	Types of waste	Units	Magnitude for a year / 35years
1.	Destroyed resin	t	5.7/200
2.	Equipment, metal scrap, if decontamination is not sufficient	t	8/280
3.	Tailing in ponds	t	350/12 250
	Total	t	363.7/12 730
	Total including additionally radwaste from TMC's.	t	-/17 830

The volume of radioactive and non-radioactive waste, for all period of exploitation, will be determined from results of radiological surveys before decommissioning and on inventory data after decommissioning the site.

III.1.8. Protection of the underground

The objective of the ISL operation is to achieve 90% extraction of uranium from confirmed reserves, or 16 246 t U. This will be accomplished by implementing rigorous operating procedures; documented by annual inventory of extracted uranium from the ground; and verified by post-mining drilling and sampling within TMCs.

III.1.9. Social environment

Work at the Akdala project will positively influence the social environment of the nearest region, as workers and specialists from the local population will be employed after additional training.

III.1.10. Environmental monitoring

Professional environmental monitoring will be conducted according to the "Act of Environment Protection".

The aim of monitoring is to provide satisfactory information on the industrial impact on the environment, possible changes of the impact and unfavourable and dangerous situations.

The professional monitoring system is designed to allow observation of the operations, data gathering and analysis and evaluation of the project's environmental status such that corrective measures can promptly be instituted for the timely prevention, curtailment and elimination of any adverse environment impact at the site.

The programme of professional monitoring includes the following basic directions:

- Control of effluents in air,
- Control of effluents in groundwater,
- Control of contamination of soils and grounds and
- Personal dosimetry.

The nature of the monitoring is periodic under normal conditions and continuous (active) for emergencies. Safety equipment and radiation instruments will be used for monitoring. The staff includes a deputy chief engineer for safety and radiation equipment, a radio-chemist and two dosimetrists.

III.1.10.1. Control of effluents in air

Air samples will be taken at working areas within all facilities. Background concentrations of sulphuric aerosols are measured each week, for one month prior to the start of the ISL process, monthly after starting, and daily during unfavourable meteorological conditions, and at control points near a diesel electric power station and a compressor set working in an emergency regime. Sampling of air on SPZ will be conducted semi-annually (winter and summer) in the direction of effluent plumage. Daily sampling is recommended when barometric pressure is low and wind is moderate, as effluent plumes are localized near or at ground level. Basic chemical parameters to be controlled include carbon, nitric and sulphuric oxides.

III.1.10.2. Control of effluents in groundwater

Pollution in the upper permeable aquifers will be monitored with a group of three wells around septic facilities. Water will be sampled for measurement of TDS, pH and bacteria.

The stability of the fluid level in the process ponds will be the primary monitoring parameter. Periodically, shallow wells installed around the ponds will be sampled to check for soil and subsurface contamination. The samples will be analysed for pH, radionuclides and sulphate ion.

Pollution and dynamics of groundwater in lower permeable horizons will be monitored with a group of 5-6 wells around each TMC within, above, under and laterally beyond the ore aquifer for sampling water in the most vulnerable parts of the aquifers. In the case of observed contamination (three times over background measured before leaching), then an additional number of monitoring wells will be installed. Measured parameters are sulphuric and nitric ions, pH, Fe^{++}, Fe^{+++}, Al_2O_3 and water head. Frequency of the sampling will be monthly.

III.1.10.3. Control of contamination of soils and grounds

Annual radiometric surveys will be conducted with permanent hearing headphones at grid points located 100 m by 100 m. Detected anomalies (more than 30 μR/h over background) will be detailed on a 1 m by 1 m grid. Contaminated soils and grounds will be sampled and analysed for pH, gross alpha-activity and specific contents of soluble chemical components. If the pH is less than 5, gross alpha-activity is 1200 Bq/g above background value, or contents of soluble chemical components are 0.6 g/cm^3 above relevant background, decontamination will be performed. If the decontamination is limited, it still must meet the permitted level of Ambient Dose Rate, ADR = 100 μR/h.

Moreover early inventories of waste and radioactive waste will be conducted followed by analyses of all means to curtail its generation.

Also each unit of shipment, equipment and transport leaving the site will be monitored and controlled.

III.1.10.4. Personal dosimetry

Personal dosimetry will be conducted for each worker and specialist by using the Harsh dosimetry system. It is expected that an annual personal dose will be less 5 mSv in normal conditions and 10 mSv when participating in decontamination measures.

III.1.11. Sanitary Protective Zone (SPZ)

The radius of the Sanitary Protective Zone (SPZ) is defined by Sanitary standards SSP-77, part V, for facilities producing radioactive materials. Its radius is 1000 m.

III.1.12. Economics of environment protection

Article 26 of the "Act of environmental protection" establishes the following economic approaches:

- Planning and financing measures for environmental protection,
- Payment for consumed natural resources,
- Payment for contamination of environment,
- Payment for protection and reproduction of natural resources,
- Economical stimulation of environmental protection,
- Environmental insurance,
- Creation of funds for the protection of the environment.

III.1.12.1. Planning and financing measures for environmental protection

Measures for environmental protection will be carried out in three stages:

- During construction,
- During exploitation,
- During decommissioning.

During construction the following facilities will be created:

- Additional storage reservoirs for sulphuric acid,
- Additional local treatment facilities for sewage.

During exploitation the following measures will be carried out:

- Current rehabilitation of groundwater,
- Current rehabilitation of soils and grounds on TMC's,
- Monitoring of contamination in upper and lower permeable layers,
- Current management of radioactive and non-radioactive waste,
- Timely replacement of settling vessels under acid tanks,
- Preventative maintenance of equipment and facilities,
- Development and introduction of advanced processing methods that decrease the volume of waste and the consumption of natural resources.

During decommissioning the following measures will be completed:

- Radiometric-ecological surveys within and around the site,
- Verifying of measures for full rehabilitation of the site,
- Full rehabilitation of groundwater and soils,
- Creation of a monitoring system for the restoration of environmental components.

III.1.12.2. Payment for used natural resources

The act "The tax and other obligatory payments to budget" establishes special payments for used surface and subsurface (bonus and royalty).

III.1.12.3. Payment for contamination of the environment

There are rates for environmental payment for effluents and radioactive and non-radioactive waste.

III.1.12.4. Environmental insurance

The sum of environmental insurance was calculated according to the cost for conducting the complete decommissioning of the site.

III.1.12.5. Other payments

Other payments have not been developed yet.

III.1.13. Conclusion

By following the measures stipulated in the TES towards the protection of the environment at Akdala, uranium *in situ* leaching will not significantly impact the environment, including the flora, the fauna and the groundwater.

APPENDIX IV. DESCRIPTION OF AN ALKALINE ISL PROJECT SMITH RANCH ISL URANIUM FACILITY, WYOMING, USA

The following is excerpted from a paper by Dennis E. Stover, USA. The paper was presented at the IAEA Technical Meeting on "Recent developments in uranium resources and production with emphasis on in situ leach mining", Beijing, China, 18 to 23 September 2002.

IV.1. Introduction

The Smith Ranch Project is an uranium *in-situ* leach (ISL) mining operation located in eastern Wyoming about 40 kilometres (km) northwest of Douglas, Wyoming and about 80 km northeast of Casper, Wyoming. The Smith Ranch Project utilizes alkaline ISL technology to extract uranium from permeable uranium bearing sandstones located at depths ranging from 140 to 325 metres. Once extracted, the uranium is recovered by ion exchange. Periodically, the ion exchange resin becomes saturated with uranium. Uranium is removed from the resin by contact with a salt water solution (elution). The ion exchange resin, stripped of uranium, is recycled to recover additional uranium. The eluted uranium is precipitated, washed to remove impurities, dried, and packaged for shipment.

The Smith Ranch facility was constructed by Rio Algom Mining Corp. in 1996-1998 at a cost of US$ 42 million. It has a demonstrated production capacity in excess of 770 tonnes U per year and operating flow capacity of 380 liters per second (L/s) through two ion exchange plants.

In mid-2002, the project was acquired by Cameco Corporation, which continues to operate the facility through its wholly owned subsidiary, Power Resources, Inc. (PRI).

IV.2. Production and reserves

Commercial production was initiated in late 1997 and the facility achieved its design production rate in early 1999. Production was cut back to 430 tonnes U in 2000 and 2001 due to the soft uranium market and the decision to only sell into its existing contracts. By the end of 2001, Smith Ranch had produced nearly 2000 tonnes U and 850 tonnes of recoverable U remain in existing well fields under well patterns. Smith Ranch resources at December 31, 2001 were 15 000 tonnes U with reserves of 10 300 tonnes. The property adjoining Smith Ranch on the north, Reynolds Ranch, contains an additional 6 900 tonnes U of resources.

IV.3. Permitting and licensing – overview

IV.3.1. Introduction

Uranium mines in the U.S. operate in a highly regulated environment. There are several levels of regulatory agencies that place demands on corporate and facility performance through Environment, Health, Safety, and Health Physics regulations. The agencies often have conflicting policies and regulations, and there is often little effort to achieve compatibility between agencies. The primary regulatory agency may be at either the Federal level or the State level, depending on the activity.

At the Federal level, the primary regulatory agency is the U.S. Nuclear Regulatory Commission (NRC). The NRC regulates all of the Environmental, Health Physics, and Safety at the uranium mill and ISL facilities. Occupational Safety is regulated through the federal Mine Safety and Health Administration (MSHA). Environmental programmes are regulated through the U.S. Environmental Protection Agency (EPA) using Agreement State programmes and Memoranda of Understanding (MOU's) with NRC. Transportation activities are regulated through the U.S. Department of Transportation. The U.S. Bureau of Land Management is often a landowner and has its own regulations.

At the state level, Smith Ranch is regulated by the Wyoming Department of Environmental Quality, (Land, Water, Solid & Hazardous Waste and Air Divisions) (for environmental compliance), and the Wyoming State Mine Inspector (for occupational safety).

Significant differences do exist between the desires and objectives of the various Federal and State agencies, and as a result, there are issues of compatibility and how to meet the requirement of the various agencies that regulate uranium operations. For all EPA environmental programmes, the State agencies are required to be compatible with EPA regulations. At the Federal level, both EPA and NRC accept risk-based approaches to some regulatory compliance issues. Wyoming does not accept risk-based approaches and relies solely on inspection and enforcement for compliance. MSHA has specific procedures and regulations that are very prescriptive in nature and relies primarily on inspection and enforcement.

IV.3.2. Current status of license and permits

In Wyoming, all required permits from the State of Wyoming are in place, and these include the permit to mine, two deep-well injection UIC (Underground Injection Control) permits, two exploration drilling notification permits, individual monitor well permits, well field block permits and several other lesser permits. All of the permits are current and approved with respect to operating conditions and surety. With respect to the U.S. Nuclear Regulatory Commission, the source material license was renewed on May 8, 2001. The Wyoming operations are now under a NRC "performance-based" license. The concept of this new license is to shift the bulk of the responsibility for routine compliance reviews and operational changes onto the licensee rather than on NRC staff.

IV.3.3. Safety and environmental consideration

Smith Ranch has an excellent Environment, Health and Safety (EHS) Management programme as demonstrated by its employee safety record (no lost time accidents or fatalities as of this writing, January, 2003) and by the state and federal reports on regulatory compliance inspection which includes inspections on workplace safety, employee exposures, environmental compliance, and programme documentation. Smith Ranch operations are frequently inspected by both State and Federal regulatory agencies as part of their compliance assurance programme with many of the inspections being unannounced.

IV.3.4. Reclamation/decommissioning

The NRC and most state agencies required sureties be put in place as a condition of the license. Most of these are secured by insurance company bonds and letters of credit. The amounts of these various financial instruments are reset on an annual basis. Each year forward or remaining reclamation, restoration and decommissioning liabilities are re-estimated based on current costs with credits taken for work completed during the preceding year and debits added for newly incurred liabilities. Based on closure cost estimates prepared by the project staff and approved by both the NRC and WDEQ, financial surety in excess of US$ 8 million is provided to assure that complete restoration and reclamation of the site can be accomplished.

IV.4. Production capacity

Although Smith Ranch was originally designed and licensed as a 380 L/s – 770 tonnes per year facility, it was conservatively designed and constructed such that with additional well fields it is believed that flow rates through existing ion exchange facilities could be increased to 510 L/s or more and that with minor modifications and a small capital expenditure, the Central Processing Plant production capacity could be increased to 1 150 tonnes per year. This in-place capacity together with existing resources will allow PRI to respond quickly to increasing market requirements.

With a view to this potential, the recent NRC license renewal increased Smith Ranch's licensed capacity to 760 L/s and 1 348 tonnes U per year. To utilize all of this additional authorized capacity, PRI will build another ion exchange plant and expand the central processing plant elution facilities in addition to installing new well fields.

IV.5. Well fields

In 1996 and early 1997 the first commercial well field was installed and production has been continuous since June 20, 1997. The well fields consist of arrays of monitor wells, recovery wells and injection wells, which form patterns and flow systems to measure and control flows of lixiviant and gaseous oxygen. The basic pattern for the Smith Ranch well fields has been a square pattern (5-spot) with a 22 metre spacing between injectors and producers.

Well fields have been installed as individual "Mine Units", also referred to as "monitor well rings". Each monitor well ring surrounds groups of production patterns, including the mining zones and aquifers immediately above and below the mining zone. The injection and recovery wells are installed to effectively cover the orebodies such that flows from injectors to recovery wells traverse ore deposits and produce high concentrations of uranium in the production fluid.

In groups of approximately 20 patterns, all the recovery and injection wells are connected with piping and a piping manifold into a common field meter and flow control station, or a "Header House". Each Header House contains flow measurement devices and throttling valves for each well, motor starters for each submersible pump, oxygen mixing/injection devices, and shutdown (fail safe) instrumentation for lixiviant and oxygen trunk lines. Gaseous oxygen is fed to each Header House from one of two liquid oxygen storage tanks and fluid flows to and from the IX Facility are in large polyethylene flow lines, which connect with either one or both of the IX Facilities.

Well field mining unit concept

The well field areas are divided into mining units for scheduling development and for establishing baseline data, monitoring requirements, and restoration criteria. Each mining unit or well field consists of a reserve block in the range from 8 to 24 hectares. Approximately twenty such units will be developed. Two to three well fields are in production at any one time with additional units in various states of development and restoration. A mining unit is dedicated to only one production zone and typically has a flow rate in the 190 L/s range. Aquifer restoration of a mining unit will begin as soon as practicable after mining in the unit is complete. If a mined out unit is adjacent to a unit being mined, restoration of a portion of the unit may be deferred to minimize interference with the operating unit. The size and location of each mining unit is defined based on final delineation of the ore deposits, performance of the area, and development requirements.

Well field design concepts

The well field pattern is the five-spot pattern. However, it is selectively modified to fit the shape of the orebody. The cell dimensions will vary depending on the formation and the characteristics of the orebody. The injection wells will be spaced from 23 to 46 meters apart. All wells are constructed to serve as either injection or recovery wells. This allows flow directions to easily be changed to optimize uranium recovery and groundwater restoration.

In each mine unit, more lixiviant is produced than injected. This creates a localized hydrological cone of depression or pressure sink. This pressure gradient provides containment of the lixiviant by causing natural groundwater movement from the surrounding area toward the mine unit. The over production or bleed rates ranges from 0.5% to 1.5% of the production flow rate from any given mine unit.

Production zone monitor wells are located approximately 150 meters beyond the mining unit perimeter with a maximum spacing of 150 meters between wells. Monitor wells are also completed in the aquifers directly overlying and underlying the production zone. Such monitor wells are uniformly distributed within the mining unit area with one overlying and one underlying monitor well for each 1.6 hectares of well field.

Each injection and recovery well is connected to the respective injection or recovery manifold in an enclosed flow controlled station. The manifolds route the leaching solutions to pipelines, which carry the solutions to and from the ion exchange facility. Flow meters, control valves, and pressure gauges are installed in the individual well lines to monitor and control the individual well flow rates. Well field piping is high-density polyethylene pipe, PVC and steel. The individual well lines and the trunk lines to the recovery plant are buried to prevent freezing. The use of flow control stations and buried lines is a proven method of protecting pipelines. Both Smith Ranch pilot programmes employed this method and operated continuously through the winters without freeze-ups or other significant weather related problems.

Well completion

Monitor, production, and injection wells are drilled to the top of the target completion interval with a truck mounted rotary drilling unit using native mud and a small amount of commercial viscosity control additive. The well is cased and cemented to isolate the completion interval from all overlying aquifers. The cement is emplaced by pumping it down the casing and forcing it out the bottom of the casing and back up the casing-drill hole annulus.

The well casing is SDR-17 PVC, which is available in 6 meter joints. Typical casing has a 127 mm nominal diameter with a minimum wall thickness of 6.55 mm, and a pressure rating of 1480 kPa.

Three casing centralizers located approximately 10, 30, and 45 meters above the casing shoe are placed on the casing to ensure it is centered in the drill hole and that an effective cement seal results.

The cement volume for each well is 110% of the calculated volume required to fill the annulus and return cement to the surface. The excess is to ensure that cement returns to the surface. Occasionally the drilling may result in a larger annulus volume than anticipated and cement may not return to the surface. In this situation the upper portion of the annulus is cemented from the surface.

After the cement has cured, the plug is drilled out and the well completed. The well is then air lifted to remove any remaining drilling mud and cuttings. A small submersible pump is used for final cleanup and sampling. If sand production or hole stability problems are expected, Johnson wire wrapped screen or a similar device may be installed across the completion interval.

Well casing integrity

After a well is completed and before it is operational a Mechanical Integrity Test (MIT) of the well casing is conducted. In the MIT, the bottom of the casing adjacent to or below the confining layer is sealed with a down hole packer, or other suitable device. The top of the casing is then sealed and a pressure gauge is installed inside the casing. The pressure in the sealed casing is increased to a minimum of 20% above the maximum anticipated operating pressure, the well is closed, and all fittings are checked for leaks. After the pressure is stabilized, pressure readings are recorded at two minute intervals for ten minutes.

If a well casing does not meet the MIT, the casing will be repaired and retested. If a repaired well passes the MIT, it will be employed in its intended service. Also, if a well defect occurs at depth, the well may be plugged back and recompleted for use in a shallower zone provided it passes a subsequent MIT. If an acceptable MIT cannot be obtained after repairs, the well will be plugged. A new well casing integrity test will be conducted after any well repair using a down hole drill bit or under reaming tool.

Monitor wells are drilled and constructed in the same manner as production and injection wells and all three types of wells must pass MIT.

IV.6. Commercial development

Designing the initial commercial well field can be a highly uncertain process because of the absence of sufficient large scale test data. This was not the case at Smith Ranch where two back to back pilot well fields were operated beginning in 1980 and continuing until 1991. Both used mild alkaline lixiviants and uranium recovery via ion (anion) exchange resins. Test objectives were (1) to obtain hydro-metallurgical information for economic analysis of ISL and (2) to satisfy Wyoming Department of Environmental Quality requirements of commercial licensing. The results of these multi-pattern tests were the basis for developing the production model, which became the basis for the commercial well field operations. The production history for the first of these pilots is shown in Figure 15.

The original production forecast anticipated a staged development of the Project with an initial installed ion exchange capacity of 190 L/s available on April 1, 1997. Installation of a second, identical unit in the first half of 1998 provided for the availability of full capacity (380 L/s) on July 1, 1998.

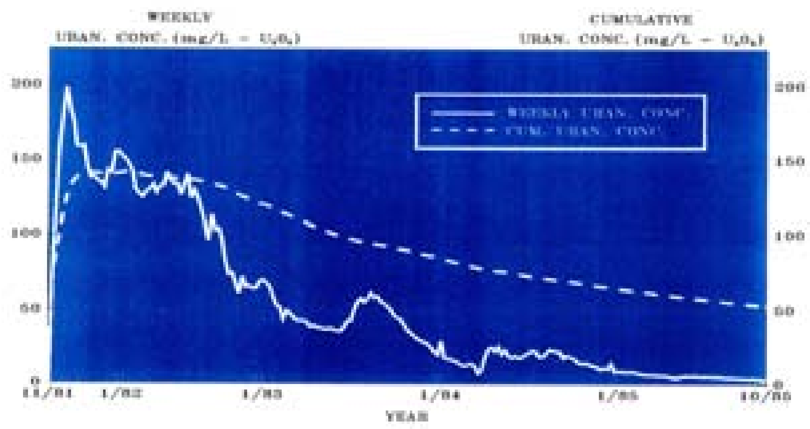

FIG. 15. Q-Sand production history.

The drilling plan for 1996 began promptly in January with installation of monitor wells for the first production areas. Baseline sampling and testing of these wells were completed during the spring and the results submitted to the WDEQ for review and approval. During the summer and fall, four drilling rigs were employed to install operating wells for over 385 tonnes of recoverable reserves.

This campaign positioned the project for the steady, ongoing phase of well field construction, which accompanies commercial operation. Cased well drilling in support of the second ion exchange facility began in late 1997 with installation of initial monitor wells. At full production (770 tonnes U) and an average recovery of 3.55 tonnes per pattern, the annual consumption of cased wells is the equivalent of 217 patterns. Replacement of depleted reserves requires installation of 20 new patterns per month (11 working months per year) and 70 new monitor wells per year. At least nine full-time drilling rigs were employed at all times to meet this need.

Additional drilling rigs were required to sustain the well field development and ore delineation programmes which serve to identify commercial sized ore deposits and provide the detailed geologic data necessary for planning the layout of well patterns for future well fields.

The narrow sinuous shape of the uranium role fronts at Smith Ranch increase the drilling density requirements for both ore delineation and well field development. Since 1996, as many as four drilling rigs have been assigned to ore delineation programmes with an additional four drill rigs committed to well field development. Further, much of the lands within the Smith Ranch Project and adjoining Reynolds Ranch project had not been fully explored. Aggressive exploration programmes were conducted on both properties from mid-1997 into early 2000. During this period, the total drilling rig count at the site averaged more than 20 and reached as high as 26.

The basis for this massive drilling effort was driven by the planned production rate, the production model, and the resulting depletion of well field areas. This situation is typical for the larger ISL operations in the U.S. where well patterns are relatively quickly depleted of uranium. To plan, coordinate, and administer four different drilling programmes (exploration, delineation, development, and well installation) in the midst of an operating ISL facility with ongoing installation of well field flow lines requires close coordination between geologists, engineers, logging operators, casing and piping crews, and operations personnel.

Well field operations

During the production phase of a well field's life, the key objective is to maximize the rate of uranium production from each recovery well in service. However, an environmental consideration, the loss of lixiviant into surrounding aquifers, must be avoided. An escape of lixiviant or excursion into unauthorized aquifers requires immediate attention and, if not promptly remediated, can result in a shut down of the facility by regulatory authorities.

As a result, well field management at Smith Ranch emphasizes the importance of flow balancing. At no time is the injection rate allowed to exceed the recovery rate in any individual well pattern or a well field as a whole. Balancing on a pattern by pattern basis can be difficult, when the injectivity of some wells markedly decreases. Maintenance of individual well flows is an important aspect of day-to-day well field management. A separate work crew and supervisor are dedicated to this task at Smith Ranch. Swabbing accompanied by air lifting has been very successful in restoring well injectivity and enabling pattern flow balancing. No acidizing of wells has been employed during commercial operations at Smith Ranch and no excursions of lixiviant have occurred.

Well field restoration

The decision to discontinue leaching of a particular pattern or well field at Smith Ranch has been based on the general mine plan. If the ion exchange facilities are operating at maximum fluid flow capacity, older, low productivity wells are shut-in to create flow capacity to accommodate new patterns and well fields. A simple criterion to cease leaching is reached when the value of uranium produced from a pattern or well field is less than its direct operating cost. In many cases, marginal production can temporarily be sustained in a depleted well field area by rearranging wells within the area to redirect fluids through areas containing residual ore. As shown in Figure 16, this rearrangement programme was successful in both pilot and commercial well fields at Smith Ranch. Such a programme does require a dedicated effort by well field operating personnel to understand the operating history and ore reserve distribution within the subject area.

The final phase of an effective well field management programme is that associated with the groundwater restoration of a depleted well field. The Smith Ranch team is now moving into this phase. The techniques and methodologies employed during the production phase can be brought to bear on the management of the groundwater restoration effort.

Because of anisotropic reservoir properties such a highly directional permeabilities, bedding plane discontinuities, and uranium roll front characteristics, it is not readily possible to fully displace the nature lixiviant with a second, clean fluid. (Nor is it possible to recover 100% of the uranium). Isolated pockets of lixiviant will remain even after restoration. Much like the production phase, a restoration programme is intended to maximize the removal of contaminates in the minimum time. Building on the knowledge gained during production, an intensive management programme will include frequent monitoring of water quality and flow rates, numerous well flow reversals to maximize contaminate removal, and addition of a strong reductant to reduce and reprecipitate dissolved metals.

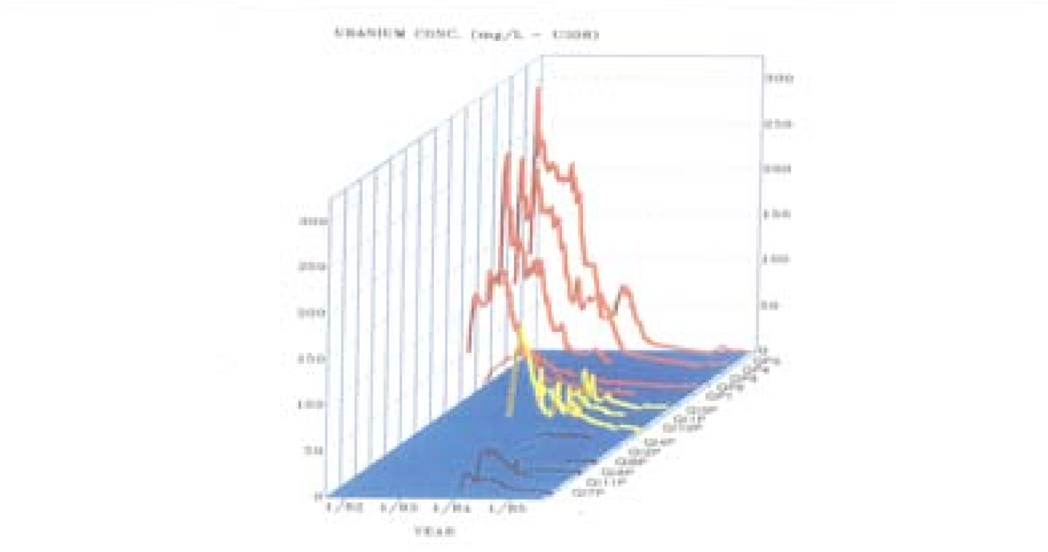

FIG. 16. Q-Sand production history – Individual well data.

IV.7. Processing plant design concepts

The processing plant at Smith Ranch consists of two Ion Exchange Recovery Plants and a Central Processing Plant. One Ion Exchange Recovery Plant (IX Facility #1) is located next to the Central Processing Plant. While the second is a satellite unit (IX Facility #2) located 1 600 meters to the west. Schematics, which illustrate the major process flow paths in the Ion Exchange Recovery Plant and the Central Processing Plant are presented in Figure 17.

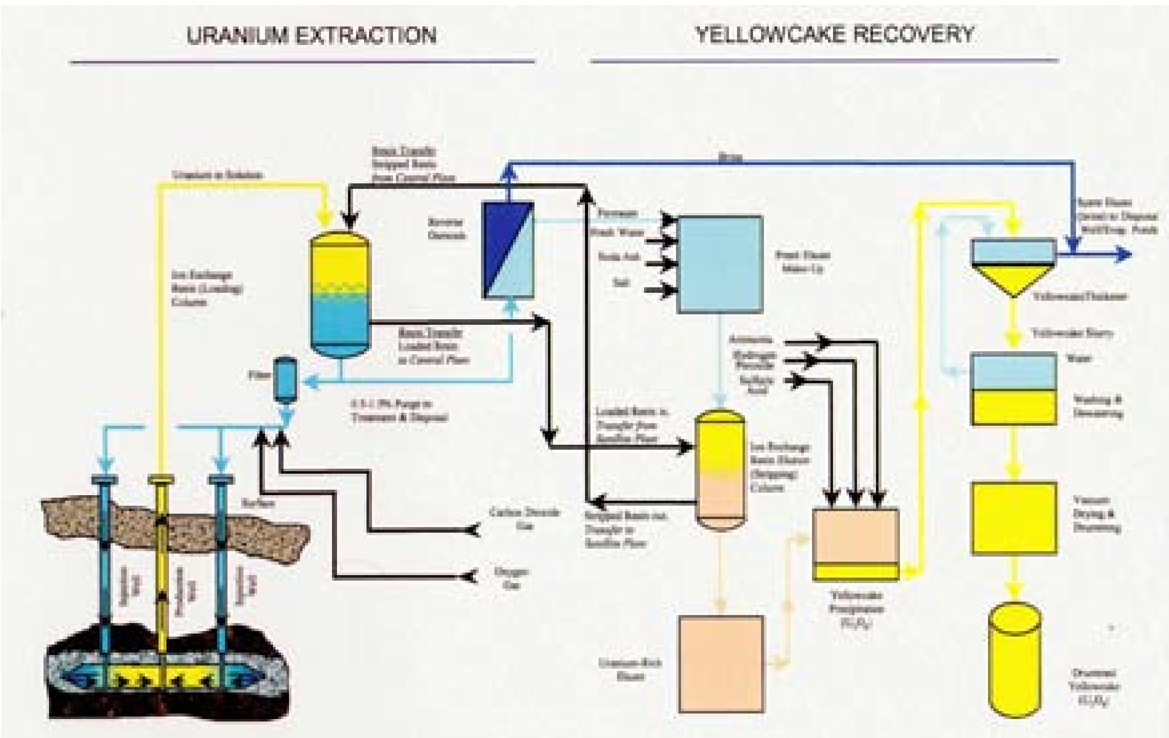

FIG. 17. Process flow-sheet.

Uranium recovery at Smith Ranch involves the following processing circuits:

Resin loading,
Well field bleed treatment,
Resin elution,
Product precipitation,
Yellowcake product filtering, drying, and packaging.

The IX Facilities are equipped with resin loading and well field bleed treatment circuits. Each facility can process 189 L/s (3000 gpm) of lixiviant. Ion exchange resin is transferred by pipeline between IX Facility #1 and the Central Processing Plant. Truck trailers are used for IX Facility #2. The Central Processing Plant elutes resin from both IX Facilities. The precipitation, product filtering, drying, and packaging circuits can process more than 2.15 tonnes (5 600 pounds) U_3O_8 per day or 770 tonnes (2.0 million pounds as U_3O_8) per year.

Resin loading

The resin loading circuit in each IX Facility consists of six pressurized vessels, each containing 14.2 m^3 (500 cubic foot) of anionic ion exchange resin. These vessels are configured as three parallel trains for two-stage down flow loading. Booster pumps are located upstream and downstream of the trains.

As the pregnant lixiviant enters the IX Facility, the upstream booster pumps pressurize the fluid to 791 kPa (100 psig). The dissolved uranium in the pregnant lixiviant is chemically adsorbed onto ion exchange resin. Any sand or silt entrained in the pregnant lixiviant will be trapped by the resin bed like a traditional sand filter. The barren lixiviant exiting the second stage will normally contain less than 2 mg/L of uranium. This fluid will be pressurized to 791 kPa (100 psig) by downstream booster pumps and returned to the well field for reinjection.

The lixiviant is composed of native groundwater, carbon dioxide and oxygen. Carbon dioxide can be added in the IX Facility, both upstream and downstream of the resin vessels. Oxygen is added to the barren lixiviant at the well field header houses prior to the injection manifold. The lixiviant concentration of carbon dioxide is maintained at approximately 1 200 mg/L while the oxygen concentration approximates 250 mg/L.

Well bleed treatment

To control the movement of lixiviant within the ore zone, a fraction of the barren lixiviant is continuously removed. More fluid is produced than injected. This bleed or blow-down creates a hydrologic cone of depression within the ore zone causing natural groundwater from the surrounding area to flow toward the ore zone. This negative pressure gradient holds or contains the lixiviant within the desired ore bearing region and prevents the unwanted excursion of lixiviant away from the ore. This also minimizes the dilution of lixiviant by uncontrolled fluid movement. Based on hydrologic studies, the bleed rates range from 0.5% to 1.5% of the production rate for a given mine unit.

The bleed fluid is treated to remove residual uranium normally contained in the barren leach solution. Uranium removal is accomplished by additional ion exchange treatment in a single train of two-stage down flow vessels. The treated bleed fluid is mixed with other waste waters for disposal into deep (3000 metre) naturally saline formations via specially designed injection wells.

Elution circuit

When resin in a first stage IX vessel is loaded with uranium, the vessel is isolated from the normal process flow. The resin is transferred in 14.2 m^3 (500 cubic foot) lots to the Central Processing Plant (CPP). In IX Facility #1, the transfer is hydraulic utilizing dedicated transfer piping. For Satellite IX Facility #2, a bulk tank trailer is used. At the CPP, the resin passes over vibrating screens with wash water to remove entrained sand particles and other fine trash. It is gravity fed into pressurized down flow elution vessels for uranium recovery and resin regeneration.

In the elution vessel, the resin is contacted with an eluate containing about 90 g/l sodium chloride and 20 g/l sodium carbonate (soda ash), which regenerates the resin. The eluted resin is rinsed with fresh water and returned to an IX vessel for reuse.

Using a three-stage elution circuit, 170 cubic metres (45 000 gallons) of eluate contact 14.2 m^3 (500 cubic feet) of resin to create 57 m^3 (15 000 gallons) of rich eluate, which contains 10 to 20 g/l U_3O_8. The fresh eluate, 57 cubic metres (15 000 gallons) per elution, is prepared by mixing quantities of saturated sodium chloride (salt) solution, saturated sodium carbonate (soda ash) solution, and water. The salt solution is generated in salt saturators (brine generators). Saturated soda ash solution is prepared by passing warm water, < 41ºC (< 105ºF), through a bed of soda ash.

Precipitation circuit

In the elution circuit, the uranyl dicarbonate ions are removed from the loaded resin and converted to uranyl tricarbonate by a small volume of strong sodium chloride/soda ash solution. The resulting rich eluate contains sufficient uranium for economic precipitation.

Sulphuric acid is added to the rich eluate to break the uranyl carbonate complex, which liberates carbon dioxide and frees uranyl ions. The acidic, uranium rich fluid is pumped to agitated tanks where hydrogen peroxide is added (0.2 kg $H_2O)_2$/kg U_3O_8) in a continuous circuit to form an insoluble uranyl peroxide compound. Ammonia is then added to raise the pH to near neutral for digestion. The uranium precipitate (slurry) gravity flows to a 11.6 metre (38 foot) diameter thickener. The uranium depleted supernate solution overflows the thickener to surge tanks for disposal via a deep injection well.

Product filtering, drying and packaging

After precipitation, the settled yellowcake is washed, filtered, dried, and packaged in a controlled area. Washing removes excess chlorides and other soluble contaminants. Filtering and dewatering is done in a filter press. The filter cake is then moved to holding tanks located above the yellowcake dryers.

The yellowcake is dried in one of two low temperature, < 121ºC (< 250ºF), vacuum dryers which are totally enclosed during the drying cycle. The off-gases generated during the drying cycle are filtered and scrubbed to remove entrained particulates. The water sealed vacuum pump also provides ventilation while the cake is loaded into drums. Compared to conventional high temperature drying by multihearth systems, this dryer has significantly lower airborne particulate emissions.

By operating at low temperatures, < 121ºC (< 250ºF), and under a vacuum, no measurable quantities of insoluble uranium solids are produced, further reducing environmental and occupational risks. This drying technology requires a high purity feed stock because operating temperatures are not sufficient to volatilize contaminates.

The dried yellowcake product is packaged into 208 litre (55 gallon) steel drums for storage and shipment by truck to another licensed facility for further processing. All yellowcake shipments are made in compliance with applicable regulations. The vacuum pump system is employed during packaging to minimize airborne particulate emissions.

Instrumentation

For control and monitoring purposes, the instrumentation philosophy provides for two separate control systems. Each system is fitted to accommodate the steady state or batch flow nature characteristic of the following process flow streams:

1. STEADY STATE
   Well field/Resin Loading Circuit — Precipitation

2. BATCH
   Bleed Treatment — Elution
   Product Filtering, Drying and Packaging

Since the well field/resin loading circuit operates at a steady state, small deviations from the normal operating flow rates and pressure profiles (10% or greater) indicate major operating upsets. An automatic Emergency Shut Down (ESD) system consisting of pressure and flow rate switches is provided for this circuit. If an automatic shut down occurs, an alarm notifies the operator of the situation. Once the major upset is identified and corrective action taken, only then can the circuit be manually restarted. This type of control system provides the best protection against major spills. Backup for the automatic ESD system is provided by local displays of the same flow rates and pressures that the ESD system monitors.

The Elution, Product Filtering, Drying, and Packaging Circuits operate in a batch mode. These circuits are controlled by Programmable Logic Controllers (PLC), which automatically open and close the appropriate valves once the processes are manually initiated. The PLC provides closed loop feedback control of the flow rates in the elution and precipitation circuits. All automatic valves have manual control override. Local indication of pressures, levels, flow rates, pH and temperature are provided for complete manual control of these circuits as required.

IV.8. Summary

The Smith Ranch ISL Uranium Facility was designed, developed, and now operates under a stringent environmental regulatory regime. A key aspect of this successful project is the continued planning for final closure as well as ongoing production and groundwater restoration. Plans for all three phases are updated, at a minimum, annually. Simultaneously, cost estimates for each are updated to reflect both remaining restoration and final closure liabilities. The information and plans formulated for the original EIA continue to serve as the basis for these annual updates.

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APPENDIX V. DESCRIPTION OF AN ACID ISL PROJECT: HONEYMOON URANIUM PROJECT, SOUTHERN CROSS RESOURCES, AUSTRALIA PTY LTD

The following project description is excerpted from a paper by M.C. Ackland and T.C. Hunter of Southern Cross Resources Pty Ltd. The paper was prepared for the IAEA meeting in Beijing, September 2002.

V.1. Introduction

Southern Cross Resources Australia Pty Ltd (SXR) obtained access to the Honeymoon uranium deposit and nearby sedimentary uranium prospects in 1997 when it acquired various leases, licenses and assets in the Curnamona region of South Australia from Mount Isa Mines Limited and Sedimentary Holdings NL.

Since that time, the company has progressed the project through a 30 month demonstration phase, a comprehensive joint Commonwealth/State EIS and all government approvals are now in place. Honeymoon is poised for a formal project commitment which will result in it becoming South Australia's third uranium producer and the fourth Australian producing facility. It will join the Heathgate Resources' Beverley project as an Australian user of the acid *In Situ* Leach (ISL) process.

The Honeymoon site is located 75 km northwest of Broken Hill and some 61 km by road from Cockburn on the New South Wales-South Australia border as shown on Figure 18. The area within a 25 km radius of the site is an almost featureless plain, covered mainly with saltbush and bluebush, with trees confined to the few ephemeral watercourses that drain the area towards Lake Frome, 100 km to the northwest. Kalkaroo Station is one of a number of similar pastoral properties in the region carrying mainly sheep and some cattle.

FIG. 18. SXR Project Location Map.

V.2. Development strategy and plans

The main strategy was to develop, after a demonstration field leach trial and regulatory approval process, a commercial ISL uranium recovery operation, based initially on the adjacent Honeymoon and East Kalkaroo Uranium Deposits. Yellowcake would be produced as uranium peroxide (UO_4 $2H_2O$) at a nominal rate of 850 metric tonnes per annum U equivalent and wholly exported for use in the electric power generating industry.

The initial step was to prepare a Declaration of Environmental Factors (DEF) and to obtain the necessary approvals to undertake demonstration-scale ISL recovery of uranium (Field Leach Trial). Following the DEF approval, SXR refurbished existing infrastructure, particularly the demonstration plant and pilot well field. The company also re-established supporting infrastructure, including an office complex, accommodation camp and electricity generation facilities. Subsequently it recommissioned and operated the pilot well field and demonstration plant at an initial rate of 6 L/s during the last six months of 1998. In early 1999 SXR augmented the pilot well field with new wells and increased the feed to the demonstration plant to the design rate of 25 L/s. The company has also undertaken additional technical, environmental, financial and marketing studies and prepared a proposal for the construction of a commercial production facility.

V.3. Regulatory requirements

The dominant approval process is through the Environmental Impact Statement (EIS) and involves both the South Australian State Government and the Australian Commonwealth Government. The initial step in the EIS process was the release of draft guidelines for public comment in late 1997. The resulting comments were considered in finalizing the guidelines, which were agreed to by SXR and the relevant Federal and State authorities. The draft EIS document was then prepared by SXR taking into account these guidelines and incorporating the wide variety of expert reports commissioned by the company and the information gathered by the Field Leach Trial. The draft EIS was issued for public comment in mid 2000 and there were a number of public consultation mechanisms. The comments from the public, NGOs, Government agencies and interested parties were incorporated into the company's Response Document, which was formally published in November 2000. The two documents formed the basis for the formal review by the State and Federal authorities. Prime approval is given by the Commonwealth Environment Minister with consequent formal actions for the Commonwealth Resources Minister and the State Mines Minister.

In February 2001, the Environment Minister gave conditional project approval whilst requiring that additional work be undertaken, primarily in the areas of palaeochannels and hydrology characterization and modelling of groundwater. This field and office work was completed and submitted in July 2001 and formal final approval by the Commonwealth Ministers followed in November 2001. State approval to issue Mining Leases was given in December with the mining leases being formally granted in February 2002. A range of other plans relating to radiation, environment and management will be agreed prior to commercial production.

V.4. Geology

The Honeymoon deposit occurs in unconsolidated sands in buried palaeovalleys. The palaeovalleys are incised into Mesoproterozoic basement rocks of the Curnamona Craton. The basement includes gneisses and schists of the Willyama complex as well as intrusive and anatectic granites.

Uranium mineralization at Honeymoon occurs predominantly within sands of the Basal Aquifer of the Eyre Formation towards the outer margin of a major bend in the Yarramba Palaeovalley. The uranium occurs as uraninite coatings on pyritic quartz sand. The distribution of mineralization within the aquifer system is characteristic of roll front type mineralization with observable zonation relating to oxidation-reduction interfaces. The uranium is considered to be derived from weathered granitic basement. Uranium is dissolved and transported in solution by migrating oxidized groundwater along the palaeovalley aquifer system. The interaction of this groundwater with reduced sediments results in the re-precipitation of uranium minerals. The deposition of economic mineralization at Honeymoon is thought to be strongly influenced by a combination of factors including: the coincidence of a sharp bend in palaeovalley with a basement bar which dramatically changes the hydrological flow regime; the convergence of two tributaries resulting in fluid mixing; and a possible change in the reduction potential of the basement lithology.

Uranium mineralization is not entirely confined to the Basal Aquifer and also occurs in the overlying Middle and Upper Aquifers. However, this mineralization is more sporadic and tends to be of lower grade. Currently SXR is only intending to mine from the Basal Aquifer System. Mineralization at Honeymoon extends for nearly 1000 m along the channel margin, is 400 m wide at its maximum and averages 5 m in thickness. The pyrite content is high (~7%) and total organic carbon averages 0.3%. In the Basal Aquifer, the salinity of the formation groundwater ranges from 16 000 mg/L to 20 000 mg/L TDS.

Resources have been estimated from historical and recent data, which has been reinterpreted to develop a sedimentological model. Sand and clay units in the model were then used to constrain the estimation of mineral resources. Equivalent uranium grades are calculated from gamma logging and a grade-variable disequilibrium factor was applied prior to the application of a cutoff grade. Mineral resources were estimated between upper and lower digital terrain modeled surfaces, within a selected minimum grade×thickness (GT) contour. Grade allocation was by inverse distance weighting of all available grades within a 100 m search radius.

For the Basal Sands resource estimation, a minimum grade cut-off of 0.0085% U and a GT cut-off contour at 0.17 m% U equivalent was applied. Current resources for Honeymoon are tabulated below (Table XV).

Table XV. Honeymoon uranium resources

Deposit	JORC Category	Avg. Thick. (m)	SG	Tonnes (Mt)	Avg. Grade (%U)	Avg. GT (m% U)	U (t)
Honeymoon	Indicated	7.1	1.9	2.8	0.10	0.71	2 800

The results of two hydrological testing programmes indicated that groundwater level, flow direction, and hydraulic gradient are similar in all three aquifers. Thus, the water bearing layers are at or near hydraulic equilibrium, and flow is restricted to within the palaeochannel in a generally northeast to southwest direction.

The analysis of all the test pumping data, using a number of techniques provided convincing evidence of a hydraulically laterally constricted channel that is bounded to the north and the south by impermeable boundaries. A leaky strip aquifer was simulated using analytical models derived from the well equations. Further, the groundwater hydraulic evidence for laterally impermeable boundaries was in good agreement with concurrent programme of stratigraphic drilling.

The rate of flow (average linear velocity) was calculated to be in the range from 10 to 16 m/y for the Basal and Middle Sand units and was similar to that determined in the 1982 work. A flow of less than 1 m/y in the Upper Sand unit was determined in the more recent work. Aquifer throughflow was calculated using cross sections and indicated that the volume of water flowing through the palaeochannel may be in the order of 90 ML/y.

A multi layered numerical groundwater flow model was constructed, calibrated and tested using all available geomorphologic and monitoring data to represent the conceptual model of aquifer geometry and flow conditions. This model was used to simulate the effects on the groundwater regime from start up of a commercial operation. It incorporated an ISL well field array and disposal of reverse osmosis plant (RO) reject brine and ISL barren solution bleed at various alternative locations. The extraction of raw water from the system for RO plant feed was also introduced. An important element in the analysis was the estimation of inter-layer leakage induced by pressurization and dewatering effects due to injection and extraction stresses.

A numerical solute transport flow model was also constructed and was based on the calibrated flow model, to incorporate advection-dispersion and simplified adsorption processes. This model was used to carry out a robust sensitivity analysis on the assumed solute adsorption coefficients to "bracket" expected solute migration. The analysis was based on the production of breakthrough curves showing time-variant water quality concentrations at particular locations for chemical species of interest.

Another objective of the modeling was to enhance the current state of knowledge concerning solute migration from the Honeymoon operations, which were based previously on advection and dispersion only using a conservative species approach. The numerical solute transport flow model was used to simulate transient changes in the distribution of contaminant concentration.

In addition to simulating the advection and dispersion of the chemical compounds, linear sorption theory was used to account for the likely adsorption of dissolved solute to the mineral surfaces of the receiving aquifer. An extensive literature review was conducted to obtain linear sorption values representative of the Yarramba palaeochannel system. A concentration contour of 1% variation was adopted to assess the migration of disposal solutions. This contour represents 1% of the difference between the baseline concentration of a source compound in the natural groundwater and the concentration of the same element in the disposal fluid. This was used to track the progress of the solute plume resulting from the disposal of waste solutions.

It is unlikely that the conservative solute case with an adsorption value of zero is at all representative of actual conditions in the basal aquifer. It is far more likely that partial sorption would occur between the source solute ions and minerals in the aquifer material.

In cases where higher sorption characteristics were assumed, only minor differences between the baseline concentration in the natural groundwater and the concentration of the same element in the disposal fluid were reported at the monitoring locations over the time periods considered. This result shows pronounced localization of the solute plume within a 125 m radius of the disposal points.

The removal of contaminants was determined to be rapid and residual concentrations confined to the immediate vicinity of the injection wells. It is reasonable to expect, therefore, that disposal solutions will equilibrate to natural background levels well within the proposed seven-year monitoring period following cessation of operations.

V.5. Demonstration phase

The Field Leach Trial was authorized by the relevant South Australian authority in March 1998 and commenced in the following month. Initially, use was made of the refurbished original three patterns from the 1982 trial and throughput was limited to 6 L/s. Subsequently the decision was made to install a new five-pattern trial well field using the same sizing and equipment planned for the commercial phase. This was completed in May 1999 and was operated under varying well field and plant conditions until 8 August 2000.

The demonstration plant and well field were operated up to the design rate of 25 L/s, developing additional technical, financial and environmental data for use in final feasibility, engineering and design studies for the project. The radiation and environmental information collected will form the basis for radiation and environmental monitoring and management plans being developed for the commercial operation.

The recovery of uranium by solvent extraction methods is used worldwide, though it has never been commercially applied with highly saline water. Much of the technology had only been tested in the laboratory and during limited small-scale pilot testing at Honeymoon in 1982. The Field Leach Trial was designed to test the technology under field conditions at a scale that provided a high degree of confidence in the design and operation of a commercial plant.

The operation employed 22 people during this period and was operated with the full range of management, geological, metallurgical, analytical, environment and radiation skills.

The trial was essential to the development of the project and formed a firm basis on which the planned commercial phase can be confidently developed.

V.6. Commercial development

The commercial development at Honeymoon is planned to feature (Fig. 19):

- A new solvent extraction based metallurgical plant producing up to 850 tpa U equivalent as drummed product.
- A number of well fields operating at a nominal average uranium concentration of 64ppm U at 340 L/s to the plant with associated monitoring, bleed disposal and development wells.
- Upgraded road access and telecommunications facilities and a 5 MVA capacity 65 km long 22 Kv power line from the existing infrastructure near Broken Hill.
- Upgraded and expanded camp and support facilities.

Development philosophy is to initially concentrate production on the Honeymoon field and then move to the east to East Kalkaroo. An ongoing exploration effort will be undertaken to identify further economic deposits within the Yarramba palaeochannels and within economic pumping distance of the Honeymoon plant. Appropriate investigation and regulatory approval procedures will be put in place as necessary to ensure continued operation.

V.7. Well field

During the Demonstration phase, an upgraded five-pattern trial well field with associated monitoring, well field control centre and necessary plumbing was installed using techniques specifically designed for Honeymoon (Fig. 20). This well field provided a reliable input for the demonstration plant and was central to the development of *in situ* leach conditions. One of the individual patterns was in continuous operation from August 1999 until the shutdown of leaching (a year later), with an average uranium content exceeding 64 mg/L and a flow rate of approximately 8 L/s. Other wells were in operation for shorter periods of time as they were brought into production progressively and used for differing testing. Flow rates and grades varied from production well to production well and demonstrated the variability of the deposit.

The equipment and materials used during the installation of the demonstration well field and ancillary plant were identical to those proposed for the commercial operation (Fig. 21). Consequently, there is no need for further scale-up. This equipment and material included:

- Well casing — selected to be of a suitable pressure rating that would accept the standard 150 mm down hole pump selected;
- Corrosion resistant down hole pumps — the 150 mm down hole pumps are intended to be used during the operation of the commercial well field; and
- Injection and recovery lines — selected to match the performance of the down hole pumps, and will be used in the operation of the commercial well field.

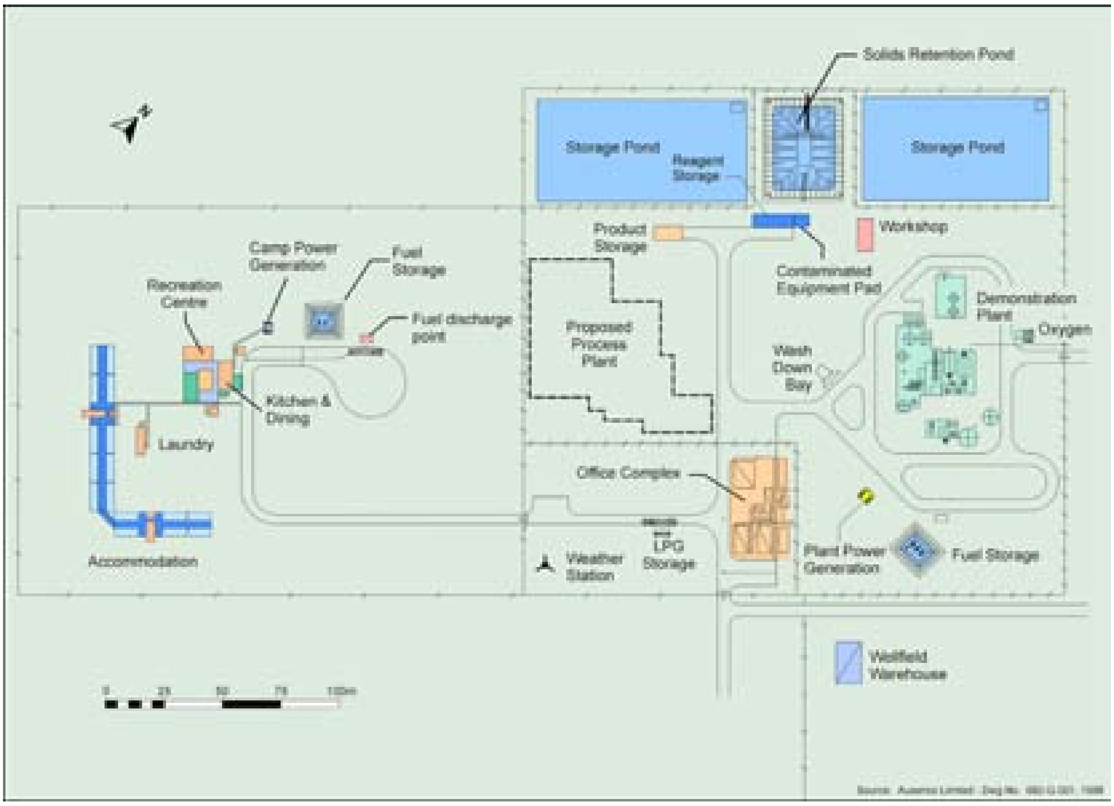


FIG. 19. Honeymoon planned layout.

The determination of the optimal leaching conditions for uranium extraction and the management of the regeneration of the circulating leach solution was an integral part of the Field Leach Trial. This enabled the successful trial of a number of leaching agents under a variety of operating conditions and resulted in an optimization process. There is, therefore, a high degree of confidence in the commercial viability of the ISL process proposed for use at Honeymoon. Optimum trial leaching conditions involve operating at relatively high pH levels (pH 2.2 – 2.5), resulting in much reduced sulphuric acid input, and the use of oxygen and sodium chlorate as oxidizing agents.

Operation of an ISL pattern is characterized by an initial rise in solution grade, as easily mobilized uranium is contacted with leach solution. This is followed by a gradual reduction of solution grade over time.

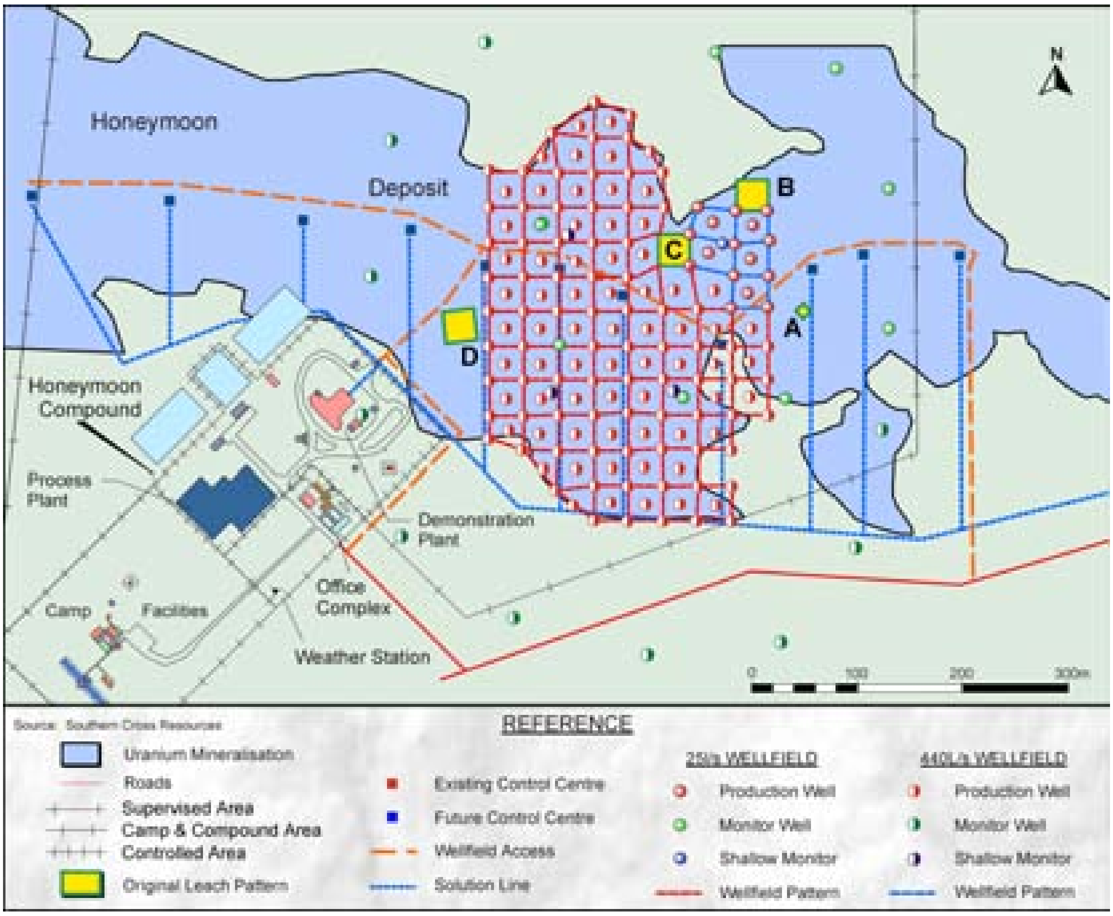


FIG. 20. Honeymoon well field.

V.8. Metallurgy

The high salinity of the groundwater (TDS 16 000 to 20 000) in the Basal Sands aquifer of the Yarramba paleochannel at Honeymoon sets it apart from other ISL operations and metal recovery plants using ion exchange recovery techniques. The water quality is a determining factor in the selection of a processing route for the recovery of the uranium.

Acid leaching has proved more effective than alkaline leaching at Honeymoon. Laboratory column leach tests demonstrated that uranium leached more rapidly with acid leach than with alkaline leach, and the overall recovery was greater. The time required to recover 80% of the uranium by alkaline leach was approximately four times that required for acid leaching.

The measured differences in leach rates for the two leaching methods would have a significant impact on the size of the well field needed to support a commercial operation. The Field Leach Trial demonstrated the effectiveness of acid leaching at Honeymoon, with lower than expected acid consumption.

There are two methods for recovering uranium from ISL solutions; resin ion exchange and liquid ion exchange (commonly referred to as solvent extraction). Each of these recovery methods works effectively under different conditions.

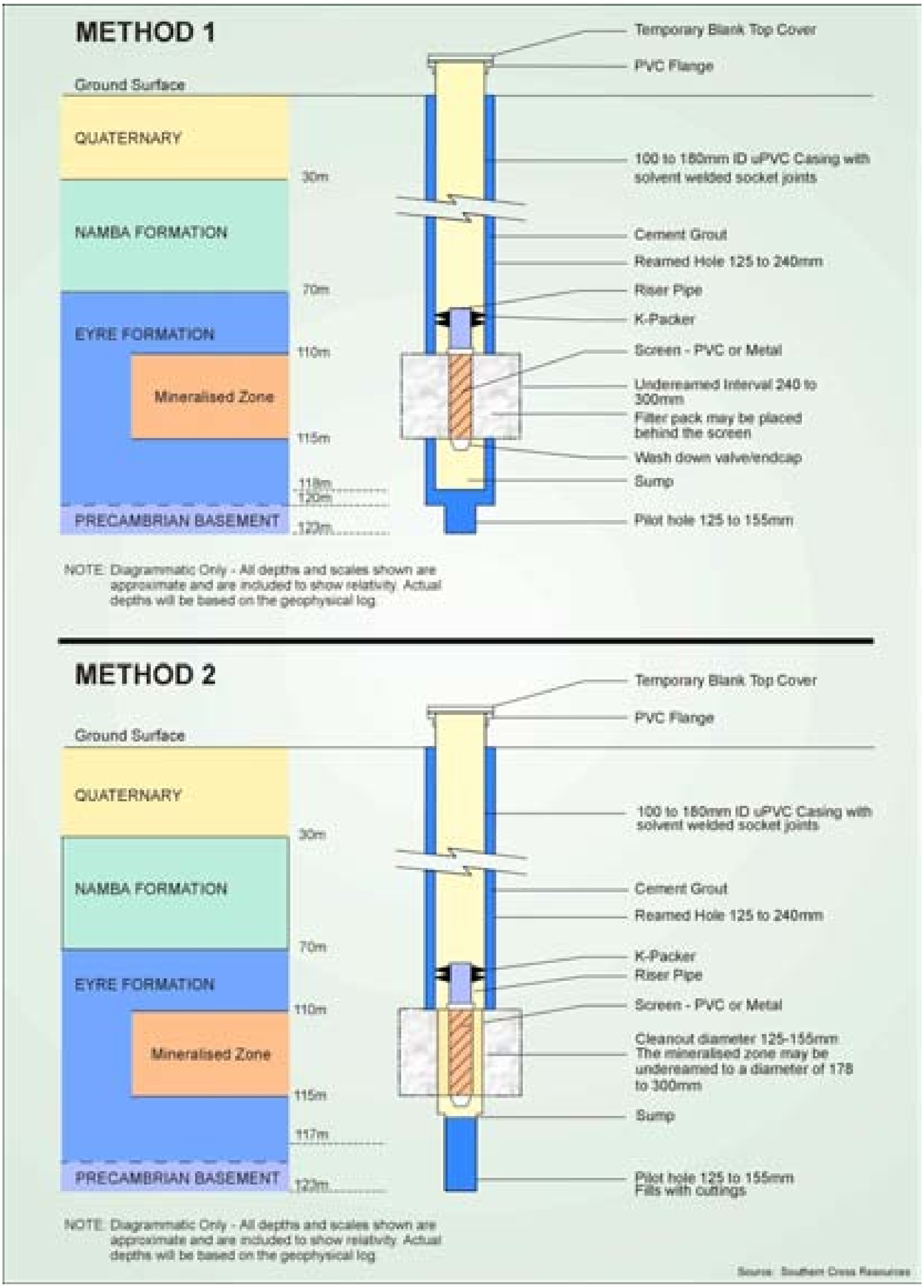


FIG. 21. Well construction.

Recovery of uranium by resin ion exchange, using commercially available resins, is effective where the groundwater contains less than 3000 mg/L dissolved chloride. However, with chloride concentrations greater than 3000 mg/L, the efficiency of recovery decreases markedly because chloride ions in the leach solution displace uranium ions from the resin.

The Basal Sands groundwater at Honeymoon has chloride levels in excess of 7000 mg/L. Under these conditions, ion exchange with commercially available resins will not work efficiently and solvent extraction is the only option. Solvent extraction is a well-proven method for uranium extraction and proved effective at Honeymoon during the Field Leach Trial.

Uranium solvent extraction plants around the world use a tertiary amine and isodecanol combination in the organic phase. This chemistry is not suitable for the high concentrations of competing ions in the Honeymoon saline pregnant solutions. An alternative chemistry was therefore developed to obtain high uranium recoveries and high solution grades from pregnant solutions.

The successful alternative organic reagent suite was comprised of di-(2-ethylhexyl) phosphoric acid (DEHPA), tertiary amine and tributyl phosphate (TBP) dissolved in high flash point kerosene. These organic extractants were able to achieve uranium recoveries from pregnant solutions of 97%. There were no problems with jarosite formation or excessive scale build-up in the plant.

The organic extractants were submitted to long-term tests under continuous operating conditions over a range of uranium concentrations in the feed solutions. The data generated from these trials has been used in the design of the commercial plant.

V.9. Approval process experience and issues

The Honeymoon approval process formalities are detailed earlier and the project benefited from the proximity in timing and largely similar Beverley development, which preceded it through the approval process. There was a heightened degree of education about ISL and the important hydrological and bleed stream disposal characteristics amongst the authorities. Particular attention was paid to hydrological and stratigraphic characterization and to examining all options for bleed stream and process liquid disposal. The operation of the Field Leach Trial for an extended period also enabled comprehensive radiation monitoring to be undertaken, adequately understood, well documented and passed onto the relevant technical agency.

The conditional approval by the Commonwealth Environment Minister also raised the need for additional work in the areas of geological confirmation of the palaeochannel margins in some sectors, positive hydrographic measurements by pump testing to prove margin impermeability and further modeling work to show the benign effects of the planned commercial bleed stream re-injection into the Basal Aquifer. This had the practical effect of involving the expenditure of considerable funds and making the practical “approval” date some nine months later than had been provided for in original planning.

All authorities displayed a high degree of professionalism, rigorous scientific knowledge and adherence to agreed formal procedures and timing commitments. SXR also appreciated the coordinated approach whereby one agency and its nominated person acted as the prime point of contact, action and information.

V.10. Summary

The Honeymoon project is proceeding towards a positive formal commitment decision. The company has built up a strong land position in the Curnamona area in South Australia and has now, through the trial and approval process, built up a strong basis for commercial operation. The market position for yellowcake is improving and there is a considerable gap between demand and mine production. The Honeymoon project economics are robust and there is high confidence in being able to achieve low operating costs and the tonnage production targets.

The project will be the first commercial ISL operation using solvent extraction from saline groundwater.

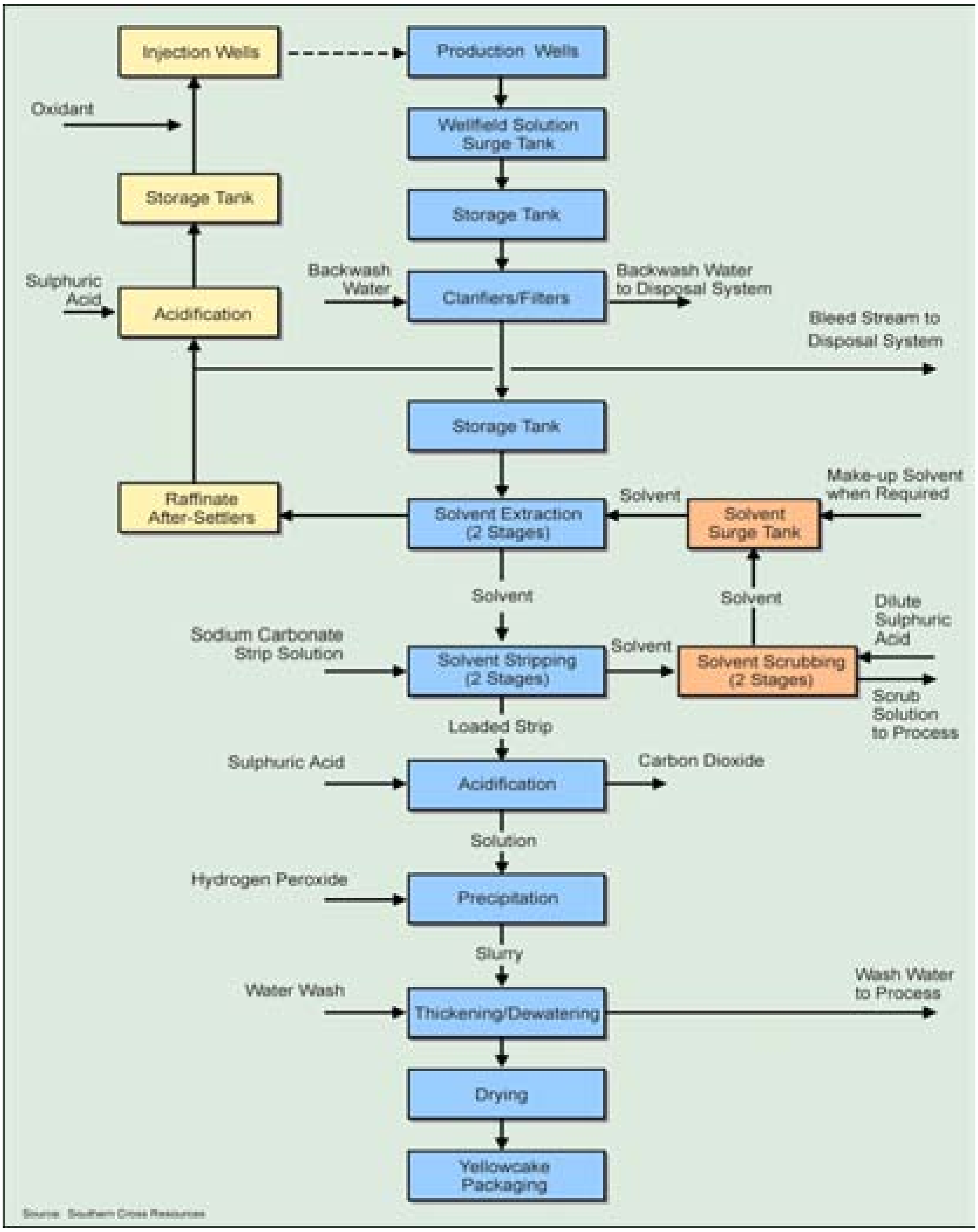


FIG. 22. Flow sheet.

APPENDIX VI. KANZHUGAN ENVIRONMENTAL REHABILITATION AFTER CLOSURE

VI.1. The status of ISL uranium production in Kazakhstan

In Kazakhstan, about 72% of uranium reserves are suitable to recovery by a progressive technology — *In Situ-Leaching*. ISL has been used in Kazakhstan for more 20 years, and at present time it has replaced traditional mining methods, i.e. underground and open pit mines. Uranium production is entirely associated with five ISL production centres, Tsentralnoe, Stepnoe, No.6, Katco and Inkay, with a total production capacity of 4000 tU/year. Tsentralnoe, Stepnoe, and No.6 mining companies are controlled by the State Company Kazatomprom. The Inkay and Katco companies are joint operating companies with Cameco and COGEMA, respectively, as partners. In the near future, additional centres are planned at the Irkol and Zarechnoe deposits. Planned production capabilities will grow to 4–5 thousand tU/y by 2005 (Uranium, 1999 [1]). The basic production is based on large and unique deposits, characterized by an average uranium grade of 0.04–0.07%U, and high productivity 3–7.5 kgU/sq. m (Yazikov, 2001 [2]), such as Karamurun, Kanzhugan, Uvanas, Mynkuduk, Inkay (Fig. 23).

VI.2. Basic issues of the production

Using sulphuric acid allows the extraction of up to 90% of the uranium from orebodies. However, acid leaching leads to the appearance of a great amount of other chemical elements and compounds in the productive solution at the same time (Petchkin, 1998 [3]). Additionally, there are some positive and negative aspects of ISL production. ISL methods transform some peculiarities of epigenetic uranium deposits such as high water encroachment and weak lithification, which are unfavourable for conventional production, into favourable qualities that allow production of uranium and by-products without the extraction of large quantities of ore, rock waste and overburden on the surface. Therefore it reduces important adverse impact to the environment (Yazikov, 2001 [2]). Moreover, some by-products (rhenium, selenium and molybdenum) can be extracted in addition to the basic product.

Adverse characteristics of uranium deposits amenable to *in situ* leach mining (sandstone type deposits) need to be considered in an EIA as follows:

- Absence of ore retainers (aquicludes) especially underlying the of orebodies,
- Location of orebodies at the top of an ore horizon,
- Low uranium productivity of orebodies,
- Very low ratio of ore's thickness to the thickness of the ore horizon,
- High depth of orebodies,
- A high percentage of fine grains in ore sand,
- Very narrow ore bands,
- High degree of heterogeneity of ore sand and ore layers.

In addition to the above characteristics, geochemical peculiarities of the ore stratum need to be considered. First the consideration is which part of a redox zone (roll front) is involved in the production plan. Frequently at the beginning of the oxidized zone, uranium is absent and radium and its progenies are the sources of the radioactivity in the place. The fact that some uranium deposits, such as Kanzhugan, Moynkum and Karamurun, are located in aquifers, which are used for water supply is important to planning an operation. So one requirement of Sanitary Rules for recovery of ISL polygons, i.4.2.2, says that water quality after processing must correspond to water quality before mining.

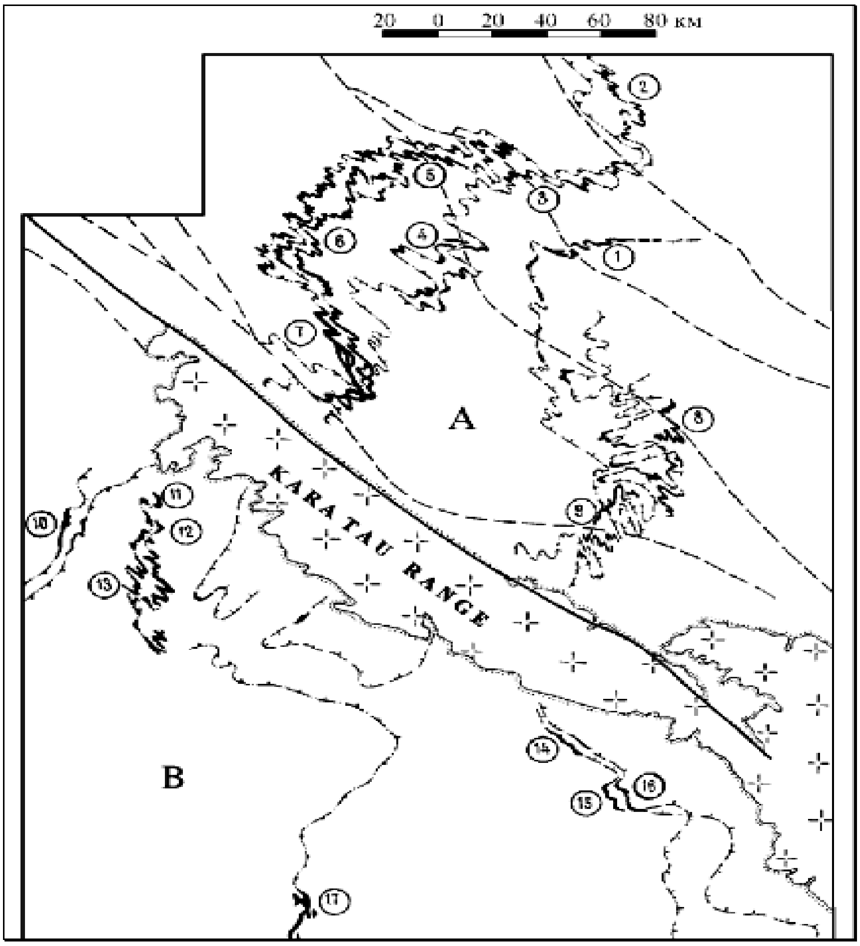


FIG. 23. Location of uranium deposits in basic hydrogenous uranium provinces.

*Legend**:** 1) Outcrops of Paleozoic and earlier sediments; 2) faults; 3) ore units of uranium; 4) Chu-Sarysu uranium province; 5) Syr-Darya uranium province; 6) fronts of redox zones in Cretaceous sediments; 7) fronts of redox zones in Paleogen sediments; encircled figures names of uranium deposits: 1) Uvanas; 2) Zhalpak; 3) Akdala; 4) Sholak-Espe; 5) Mynkuduk; 6) Inkay; 7) Budenovskoe; 8) Moynkum; 9) Kanzhugan; 10) Irkol; 11) North Karamurun; 12) South Karamurun; 13) Charasan; 14) Kyzhylkol; 15) Lunnoe; 16) Chayan; 17) Zharechnoe.*

VI.3. Basic directions of geological investigations

The list of basic necessary data is in Kazakhstan government guidebooks for preparing environmental impact statements (Temporary guidebook, 1993 [4]) and environmental audit (Temporary guidebook, 1996 [5]). The practice of performing an EIA requires that detail geological surveys of landscapes and modeling of hydrodynamics of aquifers and mass transfer are necessary to determine the sustainability and the reactions of the natural spheres (hydraulic, lithologic, pedologic, faunal and floral) against the influence of mining and milling.

VI.3.1. Regional

The basis of an ecological prediction or evaluation are the characteristics (attributes) of landscape structure, a measure of its incongruity and hydroclimatic indices (Orazymbetova, 2001 [6]). Determination (specification) of the parameters on detailed geological surveys is based on studying and mapping some landscape units with detailed data about soil, its hydrological regime, its salinity, vegetation and animals.

It is common to find a zone of natural geochemical and hydrochemical anomalies, characterized by high content of heavy metals and radioactive components and elements, practically throughout all geological cross-sections in hydrothermal and hydrogenous deposits. The presence of these anomalies in sandstone deposits is one evidence among others, that refers to its hydrothermal genesis (origin) (Aubakirov, 2000 [7]), though the majority of uranium geologists refer to some epigenetic changes in strata connected with the flow of water through it. Another line of evidence, which support the first point of view, is that there are radioactive anomalies in air particles (aerosols), washed from leaves of plants, which grow in the contour of the horizontal projection of each uranium deposits (Tcaritcyn, 1987 [8]). However more intensive anomalies spread within ore bearing aquifers that include stratum-infiltration uranium deposits (Berikbolov, 1998 [9]). These horizons often provide local populations with juvenile water, and sometimes this water is the only source in some dry regions of Kazakhstan. Therefore we need to limit use of the water supply near and within ore fields during operations, and to tie the definition of sustainability of an ore bearing aquifer to mining's influence on the water supply especially after uranium production has ceased. Non-sanctioned human activity within an ore bearing aquifer leads to a negative impact on hydrosphere and soils. Today more 110 artesian wells, surrounded by radioactive contaminated soils, are known in the area.

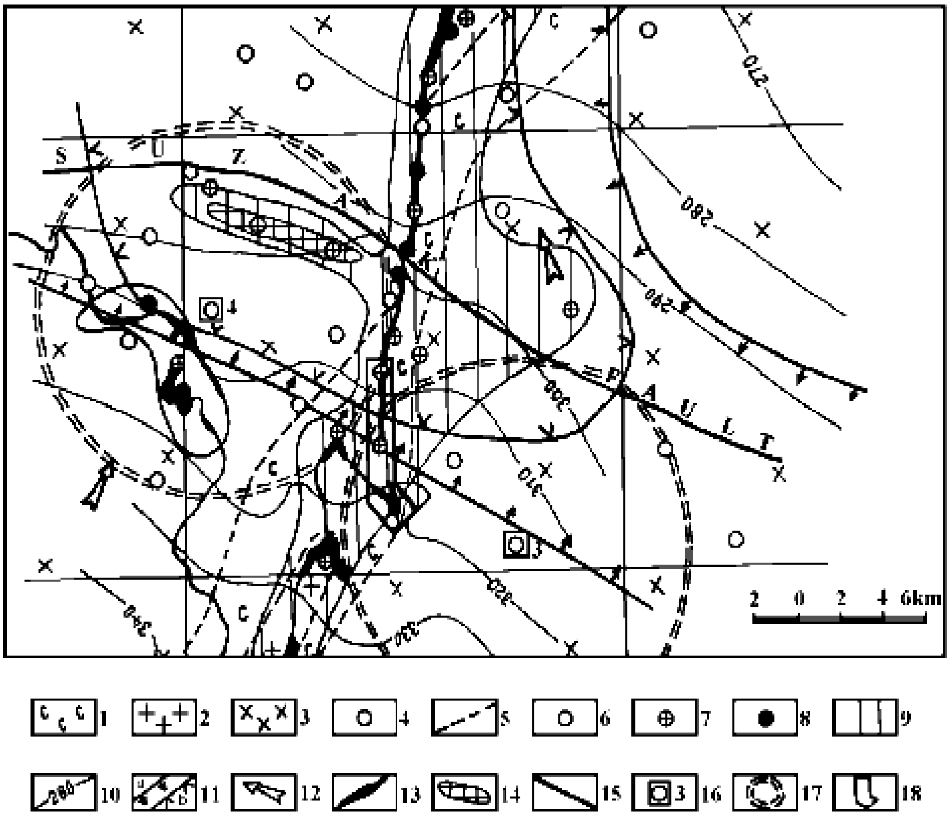


FIG. 24. Radiohydrogeochemical scheme of Uyuck aquifer ₽^{2}uk.

1-3) Chemical composite of water: 1) Sulphate-carbonate-sodium; 2) Hhydrocarbonate-chloride-sodium; 3) Hydrocarbonate-sulphate-sodium; 4) A hydrogeological well; 5) A boundary of spreading groundwater with different chemical composite; 6-8) Content of Ra-226 in groundwater that divided by the safe save standard [6]: 6) Lower 1; 7) From 1 to 5; 8) More 5; 9) A projection of halo of Radium-226 which concentrate is higher the safe standards in the groundwater [6]; 10) A equal level of a groundwater table; 11) an extending of artesian wells: a) in 1983; b) in 1989; 12) a main direction of the groundwater flow; 13) a uranium ore (a complex of uranium orebodies); 14) a local uplift of host rocks; 15) a fracture; 16) a water supply and its number; 17) a zone of water supply influence; 18) an active in-situ leach site.

A water use limitation near ore fields is possible after specifying the use boundary on the basis of radiogeochemical studies and a re-estimation of groundwater resources where the use boundary crosses boundaries of ore fields. In that case we need to consider a sustainability of natural geochemical barriers (stratum redox zones) and lixiviant halos formed by ISL production sites. The sustainability could be simulated using a hydrodynamic, a mass transfer process and different data before, during and after the ISL processing or/and available water supplies located near the production site (Fig. 24).

Therefore the size of the final impact on the environment is determined considering a broad range of environmental parameters — landscapes, geomorphologic, geological, biological, etc. As there is a close relationship between these parameters and the environment, the studying of the geological structure including a deposit will be enough for an environmental assessment of mining activity.

VI.3.2. Local

Laboratory tests need to be made on permeable rocks within and surrounding the orebodies, which might be affected by residual solutions. The tests will provide an assessment of the sorptive characteristics of such materials as montmorillonites, zeolites, allophane, oxides of iron and aluminum and thin dispersed quartzes (Kayukov, 2000, [10]). More detailed studies of the uranium ISL process show that the process goes through many stages, and that variation in the process needs to be considered during uranium production, which would increase production efficiency and decrease expenditure of a leaching reagent – sulphuric acid (Berikbolov, 2000 [11]) and finally decrease the level of impact on ore horizons (Fig. 25).

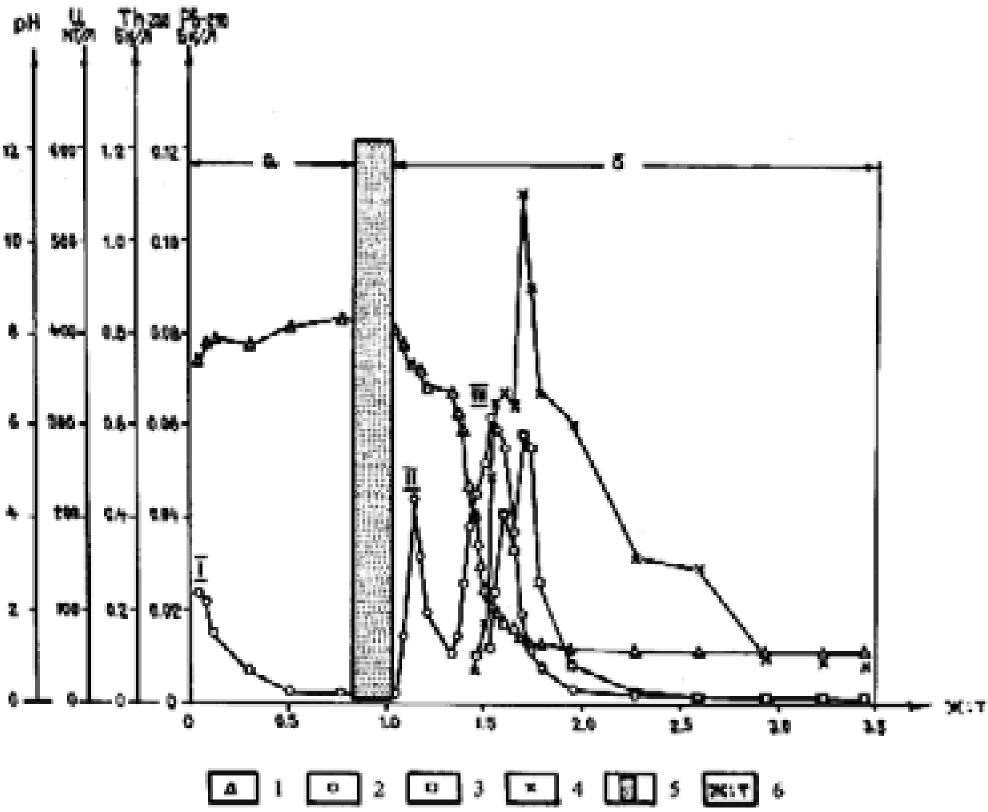


FIG. 25. Changing pH, uranium content and activity of Th-230 and Pb-210 as a result of a technological experience of uranium leach from ore sand of Kanzhugan deposit: a) by distilled water; b) by solution of sulphuric acid (10 g/l).

There are three stages of uranium leaching in Fig. 25:

I. Leaching by distilled water due to difference between hydrodynamic conditions of the experiment and natural conditions, however the basic difference is the pH of distilled water is 5.5,

II. "Alkaline" leaching before changing a rock status from alkaline to acidic,

III. Acidic leaching, direct forcing by acidic solution on uranium minerals.

Using each stage in practice would allow the optimization of the production process with a minimal amount of sulphuric acid and would decrease the adverse influence on the environment.

Assessing the regional stability of the region after completing uranium processing is the first step in a post operational evaluation. Second it must be shown that the inner characteristics of rocks near leached ores are satisfactory to retain the lixiviant halo, and then attenuate it to a desirable level due to sorptive attributes and multiple water changes.

VI.4. Reclamation

One important task of reclamation is the rehabilitation of the disturbed environment within and around an ISL-site. While the recovery of contaminated soils is considered essential, the restoration of affected groundwater is not indisputable (Yazikov, 2001 [2], Grutsynov, 2000 [12]). In fact "a substantial portion of groundwater restoration technology has its roots in the ISL process" (Pool, 2000 [13]):

- The introduction of a reductant, such as hydrogen sulfide, into the depleted well field regime can precipitate and immobilize a variety of metal ions,
- Reverse osmosis technology and electrochemical water treatment methodologies are finding increasing application in a variety of clean-up situations,
- Reactive chemical barriers are now in use as a means of reducing groundwater contamination,
- Bioremediation,
- A three-stage process of ion exchange, lime neutralization and filtration.

Also the author noticed the positive attributes of natural attenuation as he observed: "Even the US Environmental Protection Agency, one of the world's most conservative environmental regulators, has adopted this approach at a number of abandoned uranium mill sites in the USA where contaminated groundwater is unlikely to pose an active threat to the environment."

In Kazakhstan, there are some ISL sites where mining was completed more than 10 years ago, and some of them are located in the Kanzhugan uranium deposit. The stratum-infiltration (epigenetic, sandstone) Kanzhugan deposit is situated on the south-east side of the Chu-Sarysu sedimentary basin (Figs. 23 and 24). Some characteristics of the deposit are shown in Table XVI. Under the framework of an EIA, grant some investigations were conducted in 2000 on already leached blocks of the deposit, to study the post-leach environmental status. The following tasks were achieved:

- Determination of maximum possible impact range of ISL-processes on the ore and overlying and underlying horizons,
- Definition of maximum consequences of residual solution (lixiviant) spreading in the horizons,
- Determination of possibility of natural recovery (attenuation) in the disturbed horizons.

The goals were reached by using:

- Data from professional monitoring observation from a network of hydrogeological wells,
- A group of exploratory wells drilled with core through lixiviant halos in leached ore horizons at Uyuck and Kanzhugan,
- Mathematical modeling,
- Laboratory investigations.

Table XVI. Basic geological-hydrogeological parameters of Kanzhugan deposit

No.	Parameters, units	Uyuck ore layer	Kanzhugan ore layer
1.	Depth of ore, m	240	285
2.	Average permeable thickness of an ore layer, m	30	30
3.	Average thickness orebodies, m	6.7	6.7
4.	Average contents of uranium, %	0.038	0.038
5.	Uranium minerals	Pitchblende, coffinite	Pitchblende, coffinite
6.	Carbonate grade of ores, %	0.05-0.10	0.12-0.15
7.	Filtration coefficient, m/day	9.1	7.1
8.	Groundwater head, m	-127 ± 25.8	- 51.7 ± 30.6
9.	Temperature of groundwater, ºC	20-21	23-25ºC
10.	TDS of groundwater, g/l	0.5-0.7	0.5-0.7
11.	Chemical composite of groundwater	Sulphate-hydrocarbonate-calcium-sodium	Sulphate-hydrocarbonate-calcium-sodium
12.	Direction and rate of groundwater flow, m/y	NE, 17.5	NE, 14.0
13.	Availability of upper groundwater	Sporadic	
14.	TDS of upper groundwater, g/l	0.6-0.7	
15.	Thickness of upper aquiclude, m	0-20	0-15
16.	Thickness of lower aquiclude, m	0-15	0-20

VI.5. Mathematical modeling

In our modeling, it is stipulated that some of the changes are caused by the following processes:

- Convection,
- Hydrodynamic dispersion,
- Physico-chemical interactions between compounds in a system of groundwater and rock.
- A model allows for infiltration feeding of groundwater, discharge through sources and drainage (Fig. 26). Such models are useful for studying the dynamics of groundwater on a regional scale. First the current status of aquifers are determined (Fig. 27), then using obtained trends, a prediction of groundwater behaviour is considered for the next 30 years. The modelling effort yielded the following predictions:
  - Groundwater head in Uyuck and Kanzhugan aquifers will be recovered in full for 30 years,
  - Filtration regime approaches stability for that period.

Results of mass transfer of pollutants were not accepted due to lack of physio-chemical characteristics of the geological media. To begin with available natural and leaching induced geochemical barriers, the former had formed the uranium occurrences the latter has been created as a result of an impact of sulphuric acid solution on the rocks due to newly generated sorptive minerals: pseudomorphous hydroxides of calcium, iron and aluminum and silicates of aluminum. In this case it is not sufficient to know only the full list of minerals participating in the physio-chemical processes, as properties of sulphuric acid components, especially crystal-hydrates, have not been studied enough to calculate the balance of minerals in the processes (Fedorova, 1985 [14]).

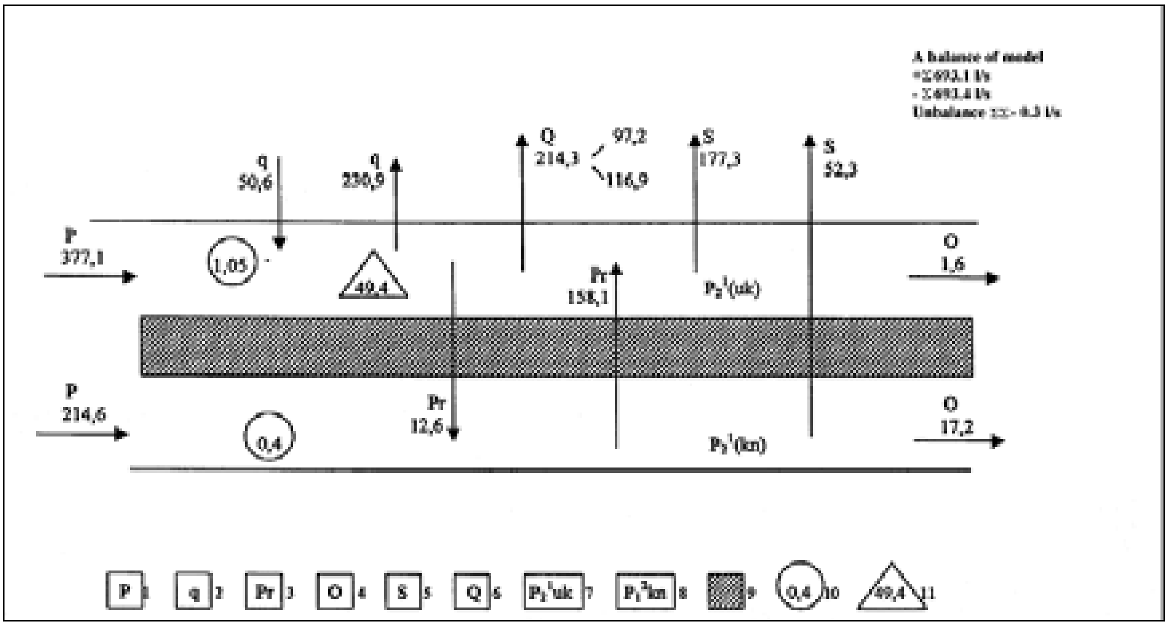


FIG. 26. A balance of groundwater for 1977–2000.

Legend: *Elements of a groundwater balance: 1) inflow of groundwater; 2) interflow; 3) cross flow; 4) outflow; 5) self-flowing; 6) water supply; 7, 8) indices of geological layers; 9) aquitard; 10) depletion of recoverable reserves; 11) recoverable reserves.*

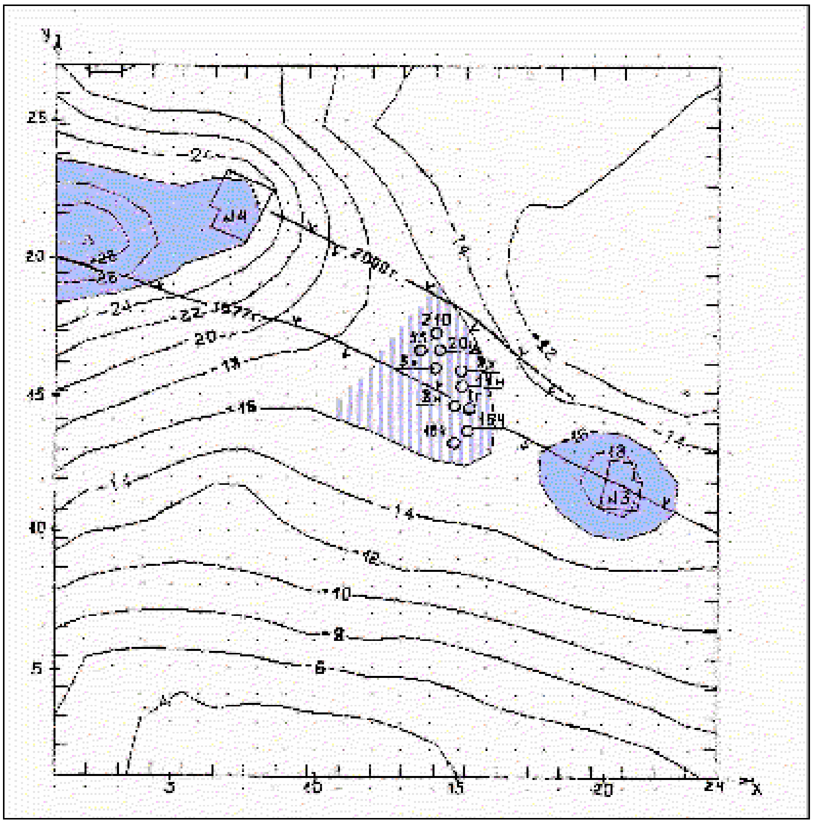


FIG. 27. Scheme of descent of the groundwater head for the 1977–2000 period, for Uyuck horizon, m.

VI.5.1. Direct geological study

During previous field investigations, lithologic facies analyses of rocks had been performed for Uyuck and Kanzhugan aquifers within ore units 3y (Uyuck) and 1k (Kanzhugan) where ISL processing was completed more than 10 years ago. Contours of the most permeable sandstone and then contours of sulphuric acid solution spreading were determined. Along the determined channels of the most affected sandstone four wells were drilled:

- The first one — at the margin of a leached block, at the entrance of fresh groundwater,
- The second one — at the centre of a leached ore unit,
- The third one — at the margin of a leached block, at the outlet of pollutant solutions,
- The fourth one — beyond polluted blocks groundwater flow direction.

The Uyuck cross-section through the lixiviant halo is given in Figure 28. Geophysical and geological investigations did not reveal any sign of ISL induced oxidation of rocks in the second and third wells. However mineralogical-petrography investigations discovered weak intensity of a sulphuric acid solution impact on rocks; there is a small difference in magnitude and width of a challenge from montmorillonite on roentgen graphics for well 1yc (in well 1yc the magnitude is less and width is greater, than in well 4yc). There are also some small changes in mineralogical samples: brown-yellow dry "covers" of decomposed biotite and green-gray assemblies of hydrobiotite. Well 2yc shows full ISL induced oxidation of the sand at depths between 199.5 and 227.0 m, where the ore had been completely leached. Changes appeared in the shape of thick swollen packages of green-gray mica transmitted to fragile "covers" of yellow-brownish hydrobiotite, feldspar with changed surface to sericite. These changes are noticeable on the roentgen graphic of montmorillonite from the well. Since well 1yc and well 3ykc crossed the weakest changes in sand geophysical logging did not reveal any changes in the rocks.

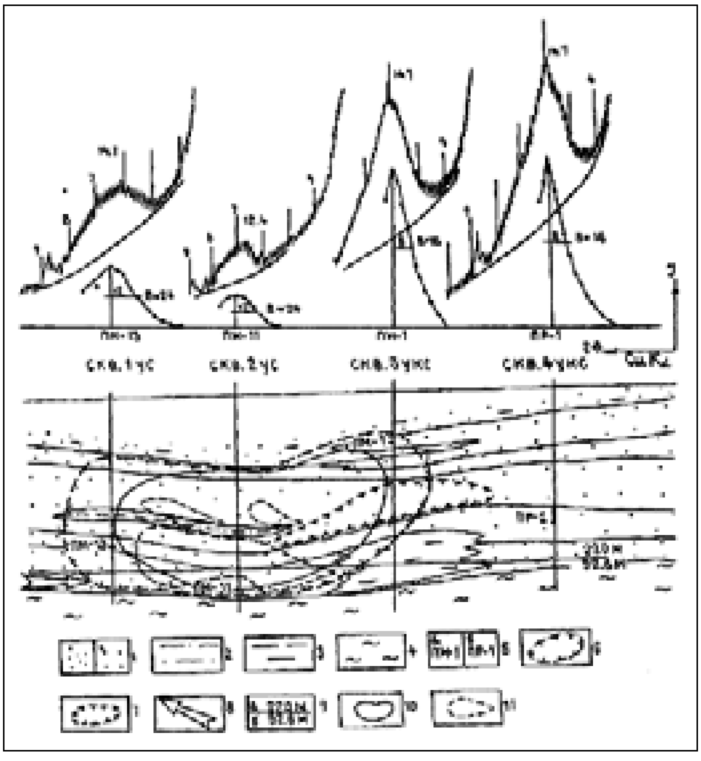


FIG. 28. Diffractometer's challenges of montmorillonite of samples selected from wells drilled through the lixiviant halo in unit 3y of Uyuck horizon.

On the top of the figure: a – a roentgen graphic registered by diffractometer DRON-3, b – half width of a difractometer's challenge.

On the bottom of the figure: 1) sand: a) fine-grained, b) medium-grained; 2) aulerolete; 3) aleurite; 4) clay; 5) points of sampling; 6) front of influence of lixiviant solution; 7) front of redox zone; 8) direction of groundwater flow; 9) zone of residual ISL induced oxidation; 10) contour of orebody before ISL-processing.

Observed physical-mechanical characteristics of sand from the lixiviant halo are not significantly different from those sampled in well 4ykc (Table XVII).

Table XVII. Physical-mechanical characteristics of the most permeable sand of Uyuck horizon

Characteristics, units	Magnitude				
	Before ISL (1977)	After ISL (2000)			
		1yc	2yc	3ykc	4ykc
Porosity, %	41.2	43.3	46.6	44.2	44.4
Specific weight of sand, g/cub. cm	1.91	1.80	1.72	1.82	1.74
Specific weight of sand skeleton, g/cub. cm	1.58	1.48	1.40	1.45	1.44
Natural humidity, %	19.1	21.7	23.0	25.6	21.0
Content of soluble minerals, %	--	0.04-0.20	0.02-0.20	0.06-0.20	0.08-0.32
Active diameter d_{60}, mm	--	0.20	0.20	0.17	0.28
pH, medium and deviation standard	--	6.0±2.0	6.3±1.1	7.8±1.1	8.6±0.8

The absence of a significant difference in content of soluble minerals between the leached and non-leached areas is surprising as a greater difference has been predicted. With an active porosity of 30% with a maximum TDS of productive solution –20 g/l, the expected content of soluble minerals would be 0.3×0.020×1.91 = 0.011 g or 0.6%. Moreover the pH of the sand shows that restoration of the sand is nearing completion.

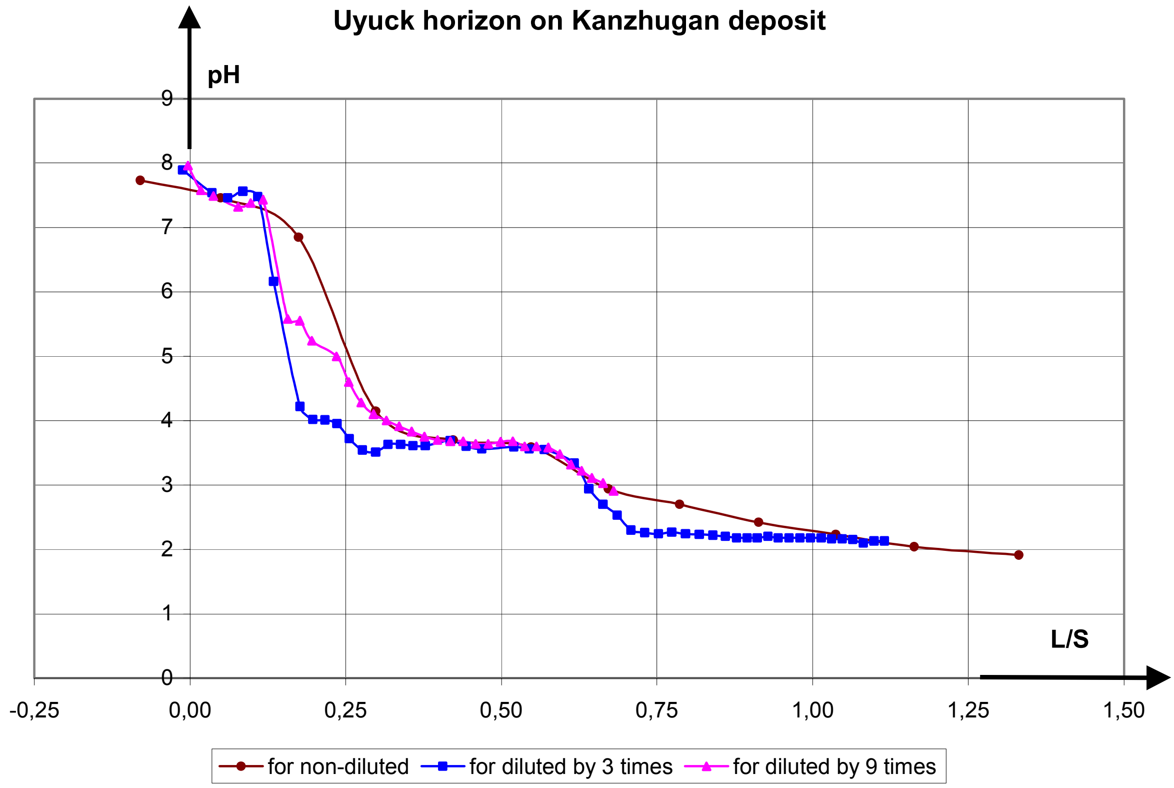
VI.5.2. Laboratory experiments

Laboratory experiments were conducted to determine the sorptive characteristics of the most permeable sand in dynamic and static regimes. The sorptive characteristics were determined for the sand sampled from core taken in well 4ykc, which was not exposed to sulphuric acid solution. The sand was packed tightly into three plastic columns (l = 0.5 m, Ø = 32.4 mm). Then residual solution from the ISL plant located on the Kanzhugan deposit was diluted 3 and 9 times by usual running water (to simulate a neutral solution between oxidized groundwater that entered the orebodies and groundwater that flowed downstream in the recovered zone). Then 3 tests were carried out. One was with non-diluted residual solution, second was with 3 times diluted residual solution, and third was 9 times diluted residual solution. After the tests running water was passed through each column for stabilizing the hydrodynamic regime (routine). The outlet filtrate was sampled for studying:

- Sorption indicators: pH, Eh,
- Basic chemical compounds: U, Fe, Al, sulphate ion and silicate ion.

Current observations allowed calculation of the dynamic conditions of experiments and filtration coefficients. Analytical outcomes were used to determine the sorptive coefficients.

Contents of the columns were studied with granulometric (fractional) and petrographic methods. The detail data of experiences are omitted here as analogous ones were mentioned in a previous article (Kayukov, 2000 [10]). For all practical purposes the shapes of the curves for each parameter were similar. All data were normalized by dividing the value in abscissa by the degree of dilution of each studied solution (Fig. 29). In general compared graphics of pH show the same interactive processes between solution and sand minerals. However dilution of the initial residual solution leads to delaying some processes such as buffer states and



accelerating contents of the sulphate ion in initial portions of a filtrate.

FIG. 29. Graphics of pH changes normalized by the degree of dilution of the initial solution.

Notes: *1. For diluted solutions ratio L/S is normalized as follows: the data in abscissa are compressed by 3 times for solution diluted 3 times, and by 9 times for solution diluted 9 times,*

2. Data on a negative abscissa refer to filter of liquid used for achieving a dynamic balance.

In a static regime, a method of filtration of the residual solution into the sand was used, which allows study of the full chemical composition of the obtained filtrate, and involves more complicated processes than those occurring in nature. A fresh drop of groundwater enters a pore and reacts with elements of the pore (fluid and minerals), then the changed drop of that pore enters an adjacent pore and so on. So if we take groundwater from the oxidized zone and some samples of leached sand from lixiviant halo along groundwater flow, and then mix groundwater with the first sample of sand, filtrate of the first mixture mix with the second sample and so on, at last we analyse all filtrates and create a model that simulates processes that would be useful for an impact prediction in an aquifer. Such experiments were produced only for leached sand from the Mynkuduk deposit, which showed that even sand oxidized by sulphuric acid solution possesses sorptive property.

Buffer states ("stairs") are manifested strongly in a dynamic regime and weakly in a static regime. In the latter case the graph of pH is smoothed out, as mixing of solution with minerals promotes its interactions. However final results of both types of experiments are similar according to sorptive quality of sand. Though the list of basic minerals of the sand is short (quartz, common feldspar, montmorillonite, kaolin, hydromica, chlorite, which represent 95% of the total mass), the variety of chemical components in production or residual solution is very wide, as each basic mineral can be altered to form new minerals. Due to hydrate and sulphate ions the list of components can be enlarge many times. Some newly formed components were observed on precipitation from solution by using roentgen films. Dramatic changes of montmorillonite and kaolinite were observed also on roentgen films (Ref. again Fig. 28). They first react with sulphuric acid solution and give additional material to a fluid system K_2O-Na_2O-Al_2O_3-H_4SiO_4-H_2O. So montmorillonite and kaolinite are dispersed and destroyed to mica, oxides and hydroxides. Due to these changes active adsorptive centres appear and promote processes of chemical sorption and hydration. Three types of centres are as follows (Osipov, 1989 [15]):

- Ordinary and double hydroxide groups at silica atoms in tetrahedral net,
- Incomplete atoms of oxygen on a frontier tetrahedral and octahedral layers, and
- Incomplete double hydroxide groups at aluminum atoms in octahedral net.

In acidic media, active centres of the first type act create oxygen and hydroxyl surfaces of clayey minerals, i.e., active centres are able to adsorb water molecules on the surface due to hydrogen links. Active centres of other types arise on a frontier of two nets and broken faces of octahedral nets, which are able to participate in reactions or exchanges and influence the magnitude and sign of superficial charge on the faces. By attaching a hydrogen atom an active centre of the second type receives a surplus positive charge. Active centres of the third type create a stronger influence on a superficial charge. In acidic media due to amphoteric characteristics of aluminum the centres form a layer of positive ions. Thus by destroying clayey minerals their sorptive capacity increases. That is why even leached sand retains some sulphate ions. And effective sorptive capacity on sulphate ions is spent at the first stage of filtration of a pollutant – residual sulphuric acid solution. The capacity depends on different concentrations of sulphate-ion in the groundwater and a pollution plume (Fig. 30). In our case the value changes from 0.26 g/kg for the difference 0.69 g/l up to 1.24 g/kg for the difference 9.33 g/l. The sand for the laboratory experiments was sampled from the natural oxidation zone. Notwithstanding that the sand is able to adsorb pollutants flowing from the lixiviant halo.

VI.5.3. Geophysical and hydrogeological monitoring

A network of monitoring wells is set on each production site to monitor the chemical and radioactive composition of the groundwater within the productive aquifers and the adjacent upper and lower aquifers. Moreover geophysical logging is conducted in the monitoring wells. Direct current logging is used to determine the water level and induction logging is used to determine the oxidation level in the monitoring wells. Geological conditions of rocks are favourable on Kanzhugan deposit as its electrical conductivity changes from first ten up to 700 mSm (miliSiemens). Electrical conductivity of the technological solution is up to several thousand mSm, and electrical conductivity of sand saturated by sulphuric acid solution increases 10-50 times. Most of the monitoring wells are cased with polyethylene pipe favourable for conducting current and induction logging. Geophysical interpretation of the logging data is performed by comparing measurements before and after in situ leach oxidation of the rocks. The difference in the data shows the extent of oxidation in a relevant interval of oxidation (Fig. 31). Results of the interpretation show that the recovery process has been completed in the south-western part of ore unit 1k.

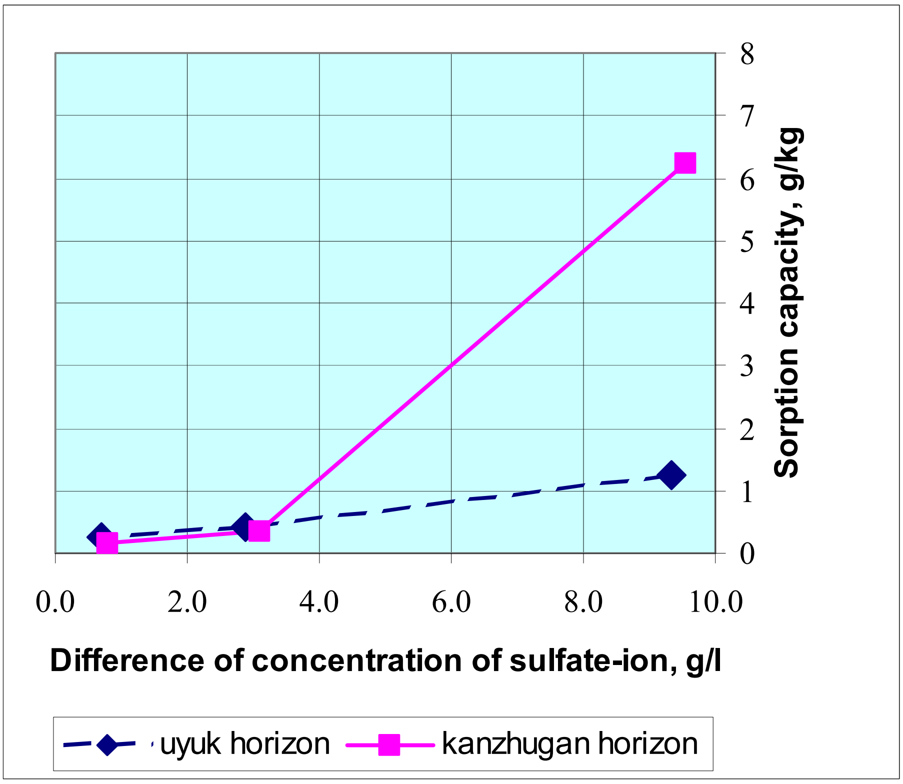


FIG. 30. Graphics of sorptive capacity depending on difference of concentration of sulphate-ion in groundwater and an infiltration.

Outcomes of hydrogeological monitoring are used for an impact assessment of sulphuric acid oxidation of groundwater. After completion of the production process in an ore aquifer, the monitoring shows the behavior of residual solution in the aquifer. Changes in parameters of the solution are noticeable over an extended interval, as in the case of the Kanzhugan deposit where uranium production was completed on unit 3y in 1989 (Fig. 32) and on blocks 8-10 of unit 1k in 1992 (Fig. 33). In the Uyuck aquifer, on unit 3y, concentration of uranium 3.1 Bq/l was not met in monitoring wells 10 years after completing uranium production. At the same time concentration of radium was not over background value. Therefore, TDS and content of sulphate ion decreased significantly and pH increased. It is especially noteworthy for the contour of sulphate ion concentration equal to 1 g/l. It decreased in area by 6 times for Uyuck ore unit 3y and vanished for Kanzhugan ore blocks 8-10 of unit 1k. The north part of unit 1k was completed later and the contour 1 g/l decreased only by 32%.

Comparative values of sulphate concentration are shown in Tables XVIII and XIX for 1988 and 1999. The data indicate that recovery of groundwater is far more advanced at the entrance of fresh groundwater into a unit (upstream), than at the outlet of effluents (downstream). Sometimes a concentration of sulphate ion increases in separate cases as wells 21n, 13n and 14n (unit 3y). However, overall, the tendency is for a decrease in sulphate concentration. The completed recovery of groundwater is achieved over 10-15 years in both units notwithstanding the difference of natural groundwater flows. In the unit 3y, groundwater flows from the natural recovery zone into the natural oxidation zone, and in the unit 1k, groundwater flows from the natural oxidation zone into the natural recovery zone.

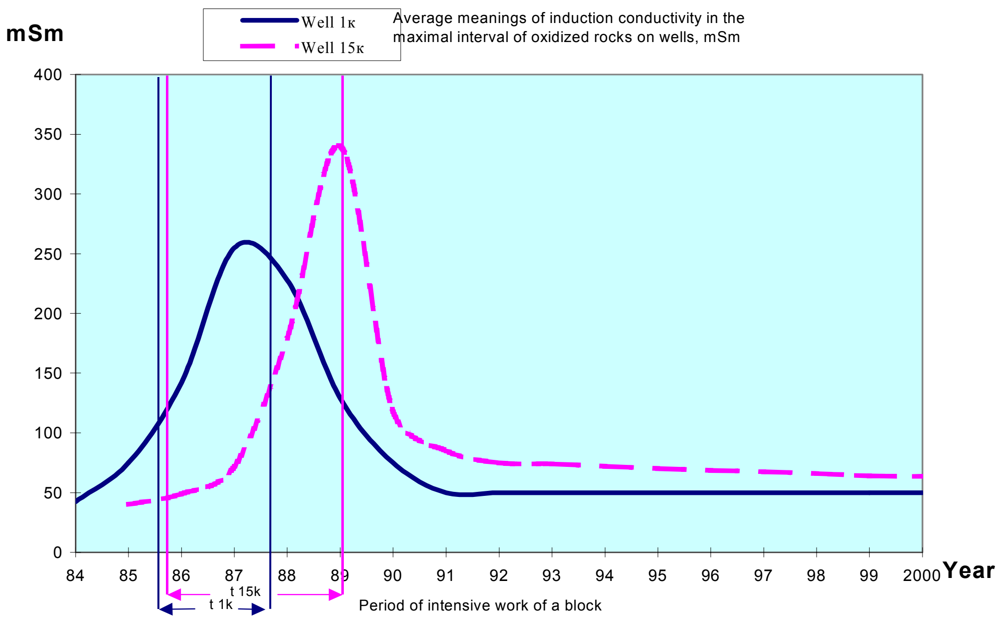


FIG. 31. Graphics of dynamics of technological oxidation-recovery on ore unit 1k.

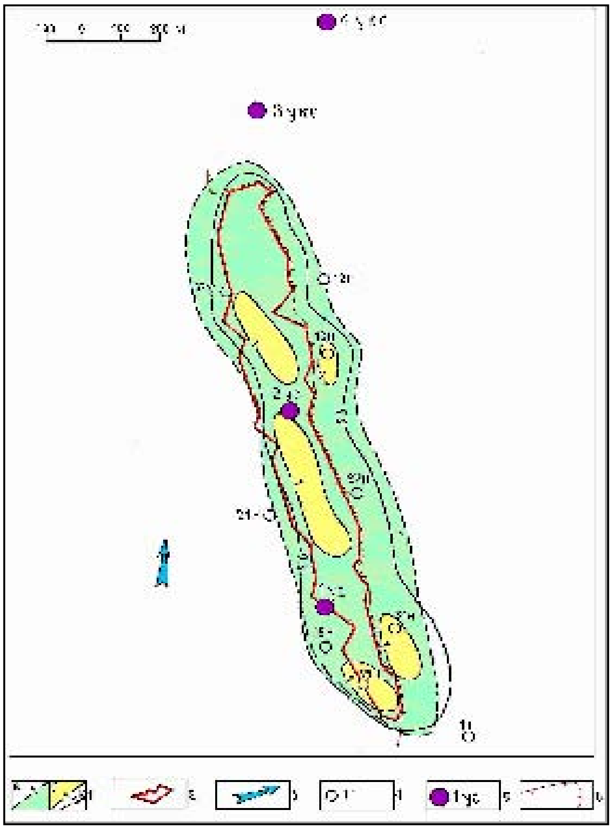


FIG. 32. Scheme of spreading sulphate-ion for period 1988-1999 on ore unit 1k of Kanzhugan deposit.
Legend: 1) isopleths of sulphate-ion concentration (g/l) at the state of 1988 (a) and 1999 (b); 2) contour of ore unit; 3) the direction of groundwater flow; 4) a monitoring well and its number; 5) wells drilled under the EIA project; 6) front of oxidation.

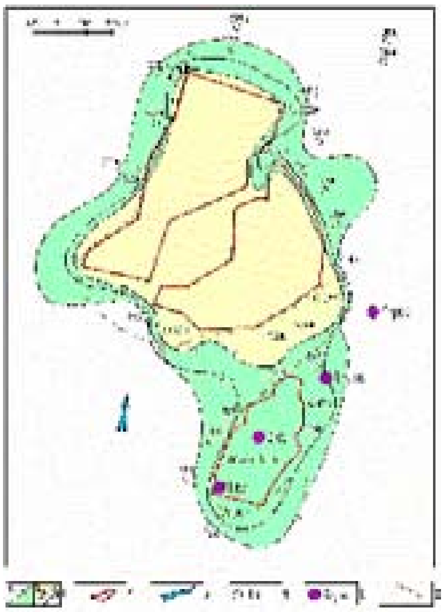


FIG. 33. Scheme of spreading sulphate-ion for period 1988-1999 on ore unit 1k of Kanzhugan deposit Legend: 1) isopleths of sulphate-ion concentration (g/l) at the state of 1988 (a) and 1999 (b); 2) contour of ore unit; 3) the direction of groundwater flow; 4) a monitoring well and its number; 5) wells drilled under the EIA project; 6) front of oxidation.

Table XVIII. Changes of sulphate ion concentration of groundwater in Uyuck aquifer on unit 3Y being leached in 1981–89.

No. of wells	Concentration of sulphate ion, g/l		
	at 01.10.88	at 01.01.99	difference
Downstream after blocks			
42n	0.97	0.32	-0.67
10n	3.42	2.25	-1.17
26n	3.58	1.68	-1.90
20n	5.48	4.48	-1.00
21n	2.71	4.48	+1.77
Mean			-0.59
annual mean			-0.06
within blocks			
30n	4.48	0.74	-3.74
36n	5.54	0.80	-4.74
11n	1.44	0.77	-0.67
12y	4.09	3.20	-0.89
13n	0.90	2.56	+1.66
14n	0.77	7.68	+6.91
15n	7.09	4.48	-2.61
16n	7.17	0.35	-6.82
17n	5.12	0.19	-4.93
22n	4.35	2.24	-2.11
Mean			-1.79
annual mean			-0.18
along flow before blocks			
25n	1.02	0.16	-0.86
19n	1.67	0.79	-0.88
Mean			-0.87
annual mean			-0.09

Table XIX. Changes of sulphate ion concentration of groundwater in Kanzhugan aquifer on blocks of unit 1K being leached in 1985–92.

No. of wells	Concentration of sulphate ion, g/l		
	at 01.10.88	at 01.01.99	difference
downstream after blocks			
14k	4.23	2.56	-1.67
13k	4.70	0.93	-3.77
47k	6.00	0.70	-5.30
Mean			-3.58
annual mean			-0.36
within blocks			
7k	5.12	2.88	-2.24
Mean			-2.24
annual mean			-0.22
along flow before and beside blocks			
35k	4.03	0.76	-3.27
34k	5.12	0.99	-4.13
16k	7.10	0.99	-6.11
15k	7.54	0.32	-7.22
10k	3.43	0.19	-3.24
9k	4.45	0.16	-4.29
1k	4.49	1.30	-3.19
48k	1.47	0.15	-1.32
17k	7.68	1.38	-6.30
Mean			-4.34
annual mean			-0.43

Thus the monitoring confirms the absence of spreading of residual solutions, beyond blocks that have been mined.

VI.5.4. Conclusion

Current investigations of the environment on ISL sites show that notwithstanding some positive signs of natural attenuation of residual solution of sulphuric acid there are some issues that need to be addressed.

First: it is important for current and future ISL projects to consider effects of some outside activity (as public water supply) on extracting water in the production region, and different facilities for water supply need to take into account available redox zones.

Second: monitoring of natural attenuation of residual solution of sulphuric acid is important in order to obtain more definitive data not only for producers but also for authorities and the public.

Third: further refinement and development of the bases of mathematical and laboratory modeling is necessary for creating reasonable and reliable methodology for predicting the impact of ISL production. In particular the modeling needs to include the natural barriers that caused the formation of uranium deposits and preserved them over geologic time.

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APPENDIX VII. THE STRAZ BLOCK ISL PROJECT

VII.1. Introduction

The Straz in-situ leach (ISL) uranium mine is located in the northern part of the Bohemian Cretaceous Basin near the town of Straz pod Ralskem in the Czech Republic (Fig. 34). These uranium deposits were discovered in the early 1960s, when exploration focused on the most promising part of the basin, the Straz block.

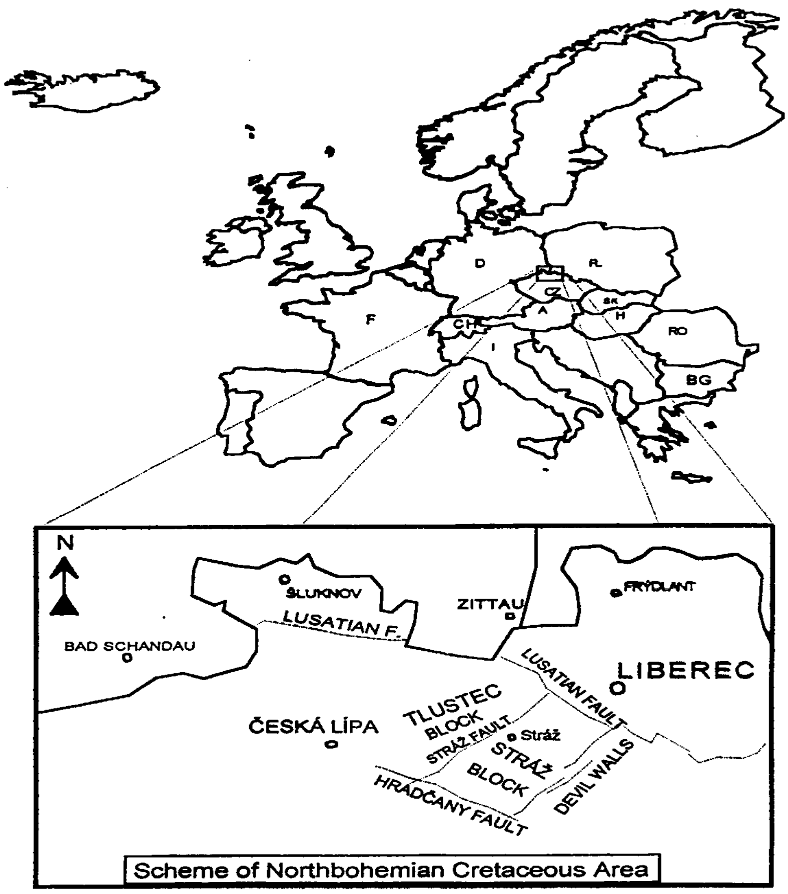


FIG. 34. Location of the project.

There are eight deposits situated in the Straz block — Krizany, Brevniste, Hamr, Osecna-Kotel, Holicky, Straz, Mimon and Hvezdov-Hamr and the Straz deposits being the largest in the area (Fig. 35).

Exploitation development began in the second half of the 1960s. The newly discovered deposits were considered as the most prospective uranium source in the former Czechoslovakia, and were to replace production from classical deep-mined vein type deposits, such as Pribram, Rozna, Zadni Chodov etc.

Because of a questionable strategy in uranium production development (classical underground mine close to ISL fields) and other external influences, uranium production became more expensive and declined in this newest production area in the Czech Republic.

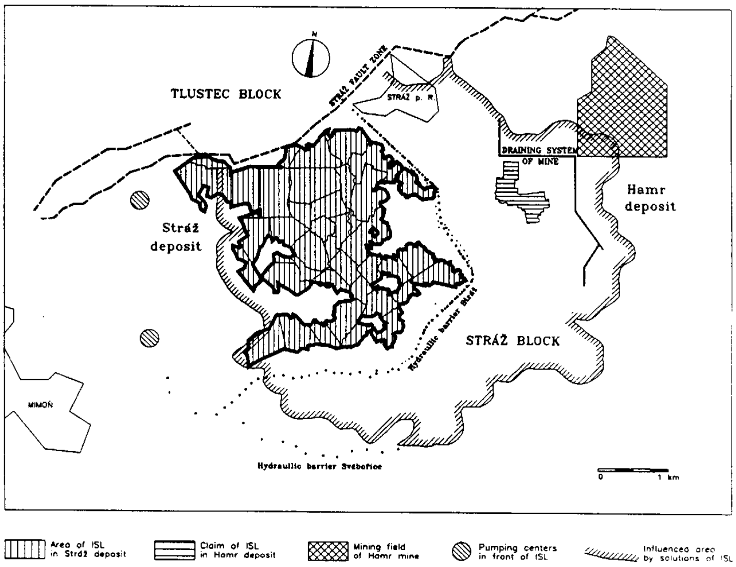


FIG. 35. Location of the facilities in the area.

VII.2. Geology

The Straz block is a geological unit, bordered by faults. The north-eastern border corresponds to the Lusatian fault, which separates the Straz block from crystalline rocks of the Jested mountains complex of lower Palaeozoic and upper Proterozoic age.

The south-eastern border is formed by a belt of Tertiary volcanic dikes called “Devil’s Walls”. Facies changes within Cretaceous sedimentation change in this direction.

The Straz fault forms the north-western border of the Straz block and separates it from the downdropped Tlustec block lying in the north-west direction from it.

The last, south-western border is created by complicated south-eastern continuation of the Ceska Lipa fault zone. Geological conditions of Cretaceous sedimentation do not change in this direction.

The deposits in the area of the Straz block belong to the sandstone-tabular type uranium deposits. They are hosted in the basal part of the Upper Cretaceous sedimentary complex, which overlie crystalline rocks of Proterozoic and Lower Palaeozoic age with some depressions in their paleorelief filled by Carboniferous and Permian sediments.

Cretaceous sedimentation began with fluvial, fluvio-lacustrine and other fresh water sediments of the lower Cenomanian. This sedimentation continued in “wash-out” horizon, which lies between the freshwater and marine sediments. Marine sediments of the upper Cenomanian consist of two main parts - the lower one is called friable sandstones and the upper one fucoid sandstones. Ore is associated with freshwater, mostly argillaceous sediments and especially with the lower part of Cenomanian marine sandy sediments. The thickness of the orebodies sometimes exceeds more than 10 metres, however, the average is about 6-8m. The depth of deposits depends on their position in the Straz block - from about 130 metres in the north-eastern part to about 250 metres in the south-western part.

The whole area has been influenced by Saxon tectonics and Tertiary volcanism.

VII.2.1. Lithostratigraphy

See Fig. 36.

Proterozoic

Proterozoic rocks are developed in the north-western part of the deposit, and consist of grey sericitic phyllites and granitoids.

Palaeozoic

Palaeozoic rocks underlying the deposit are formed by Ordovician, Silurian, Devonian and Permo-Carboniferous sediments. Ordovician rocks are formed by quartzy phyllites (with content of quartz higher than 50%) and sericitic quartzites. Silurian rocks are formed by so-called “variegated series” - graphitic phyllites, sericitic-chloritic phyllites, chloritic phyllites, carbonatic phyllites and quartzy phyllites. Devonian rocks are formed by sericitic phyllites with layers of slightly metamorphosed limestones. Permo-Carboniferous rocks are formed by red sandy- clayey siltstones, melaphyres and quartzy porphyries.

Mesozoic

Mesozoic sediments within the deposit are represented by upper Cretaceous.

Upper Cretaceous

Upper Cretaceous sediments belong to the Lusatian facies area and consist of Cenomanian and Turonian sediments. Their thickness varies between 150m in the north-east and 270m in the south.

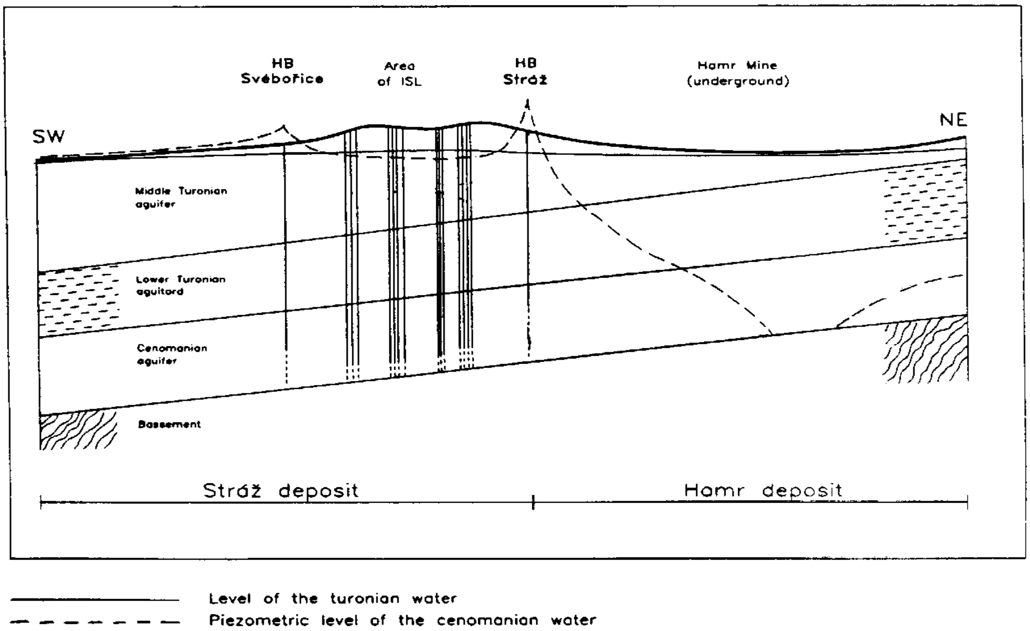


FIG. 36. Schematic cross-section of the area.

VII.2.2. Tectonics

Platform sediments in the area are affected by many fissures and faults. They create four main systems: NE-SW, NW-SE, sub-meridional (N-S) and subequatorial (W-E). The whole complex of Proterozoic, Palaeozoic and Mesozoic sediments is intruded by ultrabasic dikes of Tertiary age.

VII.2.3. Shape of the orebodies

Orebodies were formed in the shape of flat-lying tabular lenses. Their shape is influenced by:

- Lithological homogeneity of the rock environment,
- Volume and character of the reduction agent dispersion,
- Thickness of the horizon,
- Intensity of the layer oxidation and the form of red-ox barrier.

VII.2.4. Mineralogy

The Straz deposit, similarly to other deposits of the Straz block, is characterized by a typical U-Zr-P-Ti suite of elements. Ore mineralization is very fine grained and is present as cementing material in sandstones and conglomerates. Ningyoite [$(U,Ca,Ce)_2(PO_4)_2 1\text{-}2H_2O$] is the most economically important mineral; uraninite and U-bearing hydrozircone are less important. Distribution of the main minerals is quite variable in the deposit; nevertheless the main mineralization can be characterized as U-Zr. Monometallic U mineralization is present very rarely. According to mineral associations, the following mineralization suites can be distinguished:

- Ningyoite – uraninite – hydrozircon,
- Ningyoite – hydrozircon,
- Hydrozircon,
- Ningyoite.

Other minerals within the ore are numerous and variable as to their content, but their occurrence can be characterised as rare or very rare.

VII.3. Hydrogeology

Hydrogeological relationships are very complicated within the Straz block. Two aquifers are developed in the upper Cretaceous sedimentary complex. The lower Cenomanian aquifer has an artesian water level and the upper Turonian aquifer has a free surface water level. [1,2]

Cenomanian confined aquifer

This aquifer is formed by semipervious freshwater sandy siltstones and silty sandstones of lower the Cenomanian, and marine sandstones (friable sandstones) and silty sandstones with fucoidal texture (fucoid sandstones) of the upper Cenomanian.

Middle Turonian aquifer

This aquifer is separated from the Cenomanian aquifer by the lower Turonian aquiclude, which is formed by marlstones, muddy limestones and marly siltstones. It is formed by middle and upper Turonian marine sandy-marly siltstones, marly sandstones and sandstones.

VII.4. Pilot testing

The Straz block deposits were discovered by structural borehole HJ-1 in 1963.

The actual Straz deposit was discovered by geological - exploration borehole profile XXX063 in 1967. The history of uranium production began immediately after its discovery.

Operation of the first leaching test field **(VP-1)** started in 1967. [3] It was situated on the Hamr deposit. Alkaline lixiviant (sodium carbonate) was used during the test and it did not give sufficient results. In retrospect, the lack of success of the alkaline leach test can be attributed to:

- The very primitive conditions given to this test,
- The limited experience with this leaching technology and
- The orientation on sulphuric acid leaching technology used in the former Soviet Union.

Leaching test field **VP-2** was drilled near the new shaft of the Hamr mine and before testing began, it had insufficient groundwater level for its operation because of the drainage of the nearby shaft. Later the decision was made to move future leaching test fields farther from the deep mine area.

Leaching test field **VP-3** was the first test situated in the middle of the Straz deposit. It was drilled in the form of two hexagonal cells with 16 m long side and one well in the centre. It was the first leaching test, to result in uranium production using ISL technology. The first tank of concentrate was sent for processing to the MAPE Mydlovary uranium mill on December 13, 1967 (Fig. 37). It was the real beginning of semi-commercial uranium production using ISL at Straz. Afterwards this leaching test field was extended to 9 ha under a new name **VP-4**.

FIG. 37. Transportation of the first concentrate to MAPE mill.

Leaching test field **VP-5** was situated on the Hamr deposit. It was designed to test the possibility of leaching in the freshwater low permeable sediments in the lowest part of the Cenomanian sediments. The results of test, which used very strong sulphuric acid lixiviant (over 200 g/l), were not sufficient.

The last leaching test field was also performed on the Hamr deposit and was named **VP-6.** It covered an area of 30 ha. Because this field was situated in close proximity to the Hamr underground mine there were many problems with production. It also affected the deep mining area with the inflow of acidic solutions. Many corrective actions were taken, but they were not sufficient.

In 1971, following the government decision regarding the future of the uranium production in the North-Bohemian area, development of ISL fields was accelerated and production started at a commercial scale. The area of leaching fields rapidly increased, especially after the flooding of the Hamr mine in 1972. Increase of the leaching fields area and cumulative production are given in Table XX.

Table XX. Well field area and production development

	Before 1970	1971–1975	1976–1980	1981–1985	1986–1990	1991–1995	1996–2000
Well fields [ha]	9.0	208.3	305.5	439.3	600.7	652.2	652.2
Production [t]	100	2500	4400	3800	3400	2200	1100

Unfortunately this development was done without any consideration for the environment, or for future restoration procedures.

VII.5. Commercial operation

The results of laboratory research and the parallel knowledge obtained from the operation showed very quickly that the conditions for underground leaching in the Straz deposit were extremely difficult. Part of uranium mineralization occurs in rocks with low permeability, often at the contact with permeable layers. There are usually good leachable ores, which unfortunately are only leached under diffusion conditions. Another part of the uranium mineralization, located in permeable rocks is also very difficult to leach. Here the reaction takes place very slowly, and can only be accelerated by higher concentrations of the leaching reagent. [4,5]

Under these conditions only acid leaching can be applied with any success. The main component of the leaching solution is sulphuric acid at an average concentration of about 5% (mg/l). The leaching solution is also enriched by an oxidant. The oxidant consists of nitric acid (HNO_3) and NO_3^- ions.

VII.5.1. Environmental licensing

No separate environmental licensing was demanded at the time of approval. All environmental requirements, which were very limited, were part of mining licensing process.

VII.5.2. Commercial construction

Construction of the commercial mining facilities started in 1968 and was completed in 1969. The facilities can be divided into two major components. The first is the well field, which consists of the injection and recovery wells, monitoring wells and surface equipment. The second component is the processing plant, which includes the buildings and the process equipment. Each of these components will be discussed separately.

VII.5.2.1. Well field design and construction

The long period of activity of the individual well fields also made it necessary to develop very durable well constructions. They must guarantee an almost perfect safeguard against the possible contamination of the upper Turonian aquifer by technological solutions. At the present time, the injection wells go through the Turonian sequence with a double casing - outside steel, inside an acid-resistant casing pipe. Until 1984 extraction was performed exclusively by air-lifts and the construction of both the recovery and injection wells was similar. Since 1985 submersible pumps, with a diameter of 4 - 6" (101.6–152.4 mm), have gradually been put into operation. These pumps require wells with a diameter of 200 mm, cased by stainless steel. The well construction consists of under-reaming, screening and gravel packing, well screen length is between 4 and 10 m.

During the adjustment of the well patterns and the changes of the pumping technology, a number of different patterns have been tested, e.g. polygonal and linear ones. The first well fields were built with a square pattern and the distance between wells was 28 m. The distance between wells was reduced to 20×20 m and even to 14×14 m in areas with rich uranium mineralization. The injection and recovery wells alternated regularly. The newer well fields were built with a parallel pattern 20×50 m based on the better quality of boring and casing and the better knowledge of the leaching process. The last step in the development of well patterns was connected with the application of submersible pumps. The present well patterns are formed by lines of recovery wells with a diameter of 200 mm and by double lines of injection wells with a diameter of 90 mm. The distance between extraction lines is about 100 m, the distance between recovery wells is from 60 m to 80 m and the distance between injection wells is about 12 m. The present network is also optimized with respect to the topographic inequalities in some parts of the deposit. Under favourable conditions it is possible to farm on the agricultural soil between individual well lines during the leaching process.

The pipelines on the surface are built mostly of polyethylene, whereas stainless steel is used only in those sections where higher pressure occurs. For the transport of solutions over greater distances or at places with greater differences in elevation local re-pumping stations are utilized. The pipelines are equipped with a control system to indicate accidental failures.

VII.5.2.2. Processing plant design

The separation of uranium from the solutions at the surface is made with means of classical ion exchange technology with strongly basic anion exchange resins. The original technology with fixed bed adsorption columns was replaced by a semi-continuous sorption and regeneration mechanism in two of the three chemical production plants. The lixiviant flows from the bottom of the adsorption column through the layer of the anion exchange resin and on the top of the column it is separated into several filtering segments. The resin flows down the column, and in regular intervals is released during stops in the sorption process. The lixiviant without uranium is conditioned by addition of sulphuric acid according to the needs of the individual groups of leaching fields.

The anion exchange resin, with the adsorbed uranium, is pumped into the desorption column, in which it is washed free from impurities and the rest of the lixiviant by counterflowing water. The next operation in the following column is a counterflow saturation with nitrate-containing waste solutions. This phase of saturation is followed by the regeneration of the anion exchange resin in a counterflow pulse regeneration column by a regenerative solution containing nitric acid, ammonium nitrate and ammonium sulphate. This regeneration is followed by the desorption of nitrates from the anion exchange resin by sulphuric acid containing ammonium sulphate. Then the solution is returned into the adsorption columns.

The eluate from the regeneration column is neutralized by ammonium and in the following two technologic steps ammonium diuranate is precipitated by increased temperature. The suspension of the uranates is then concentrated in sedimentation tanks. The concentrated suspension is filtered by filter presses and vacuum filters. The overflow from the sedimentation tanks is returned to the anion exchanger regeneration cycle, in which it is used (after being adjusted to the required nitrate concentration by addition of nitric acid) to regenerate the anion-exchanger. The final product of the hydrochemical uranium extraction is a suspension of ammonium diuranate produced by disaggregation of the filter cake. Finally the suspension is dried, packaged and delivered.

VII.5.2.3. Waste water disposal

During the operations of well fields there was no waste water disposal system. The injection and pumping worked in close circuit. A small over production of acid solution (the plant bleed, sulphuric acid) was added to the injected leaching solution. The whole time the well fields were working with overbalance (injection > recovery) at approximately 2%.

VII.5.3. Commercial mining operations

Commercial mining operation continued until 1996, when a remediation programme was initiated. During that time the area of leaching fields increased to 650 ha (6.5 sq. km). The number of wells, both operational and monitoring, reached almost 10 000. Three processing stations were built in the area with total solution capacity of 40 000 m^3/day.

VII.6. Aquifer restoration and decommissioning project

All the remediation and decommissioning works will have to be a long-term process. The first step will be the remediation of the underground (mainly groundwater of both aquifers). Afterwards all the wells (except for some monitoring wells) will be backfilled and decommissioned, in parallel to the decommissioning of abandoned surface buildings. The last step will be decommissioning of the tailings impoundment, which will serve as a final storage of radioactively contaminated materials from the area. [6,7,8,9]

VII.6.1. Special technological regime applied during 1992–1995

After the government decision in 1992, the special technological regime for ISL plants was applied. Solution circulation was decreased to the minimum required to protect the area surrounding ISL fields. It also gave time for the evaluation of the present situation, considering both future production or beginning of remediation. During this period the acidity of solutions was kept at the necessary level to avoid the re-precipitation of dissolved solids in the formation (orebody). During that time substantial research work was done and its results were summarized in the detailed report called Analysis of ISL - III.

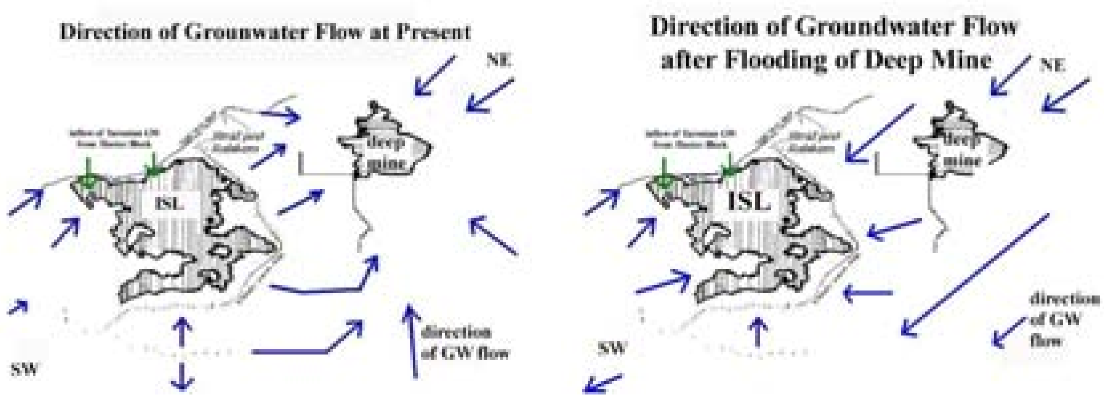
The addition of sulphuric acid to the injection stream was stopped in 1996.

VII.6.2. Restoration project

Over the years the acid solutions and leaching products have spread into a large volume of underground water and it is necessary to clean this contaminated water once uranium production ceases.

The main task of the Straz deposit restoration is to remediate the environmental impacts on the Cretaceous aquifers due to ISL mining.

Extensive laboratory research and geological and geophysical exploration were carried out to help plan the aquifer restoration programme. New mathematical models have been developed for evaluation of hydraulic and hydrochemical conditions within the deposit and for the economical evaluation of the restoration process (Figs. 38 and 39).



FIGS. 38 and 39. Groundwater flow before and after flooding of the deep mine.

This work led to the determination of starting conditions for the restoration project:

a) Contamination of the Cenomanian aquifer
   Volume of contaminated water - 186 mil. m^3, over an area of 24 km^2
   Main contaminants SO_4^{2-} - ca 4 100 000 t (out of which 800 000 t free H_2SO_4)
   NH_4^+ - ca 90 000 t
   Al - ca 400 000 t
   U - ca 1 000 t
   The total amount of TDS - ca 4 800 000 t
b) Contamination of the Turonian aquifer
   Volume of contaminated water - ca 80 mil. m^3, over an area of 7.5 km^2
   Main contaminants SO_4^{2-} - 22 000 t,
   NH_4^+ - 1 300 t.
   The total amount of TDS - ca 25 000 t
c) The risk of the dispersion of the contamination to a larger area and to a higher volume of underground water,
d) The risk of the contamination of the Turonian aquifer, which is the source of drinking water.

The targets of the deposit restoration are as follows:

- To gradually decrease the contents of dissolved solids in Cenomanian water to the environmental limit. Research results show, that the safe concentration of TDS is about 3 g/l.
- To gradually decrease the contents of dissolved solids in Turonian water to the quality given by the Czech water standards, or practically speaking to the pre-operational baseline.

Restoration of the Cenomanian aquifer is planned in two steps. The first one is to achieve hydraulic underbalance in a very short period of time, and to obtain full control of underground contaminated solution. During this step it is necessary:

- To control the ISL process in order to prevent the precipitation of solids in orebody,
- To prepare the well pattern for a new system of pumping and injection,
- To continuously remove uranium from solutions all the time
- To start the evaporation station operation (first stage of desalination plant),
- To inject the concentrate from evaporators back to the central part of deposit.

The second step is to start to remove solids from the underground. This step will include:

- The construction of the second stage of the desalination plant (for the treatment of the Stage I products),
- The controlled pumping of the solution in order to use the full capacity of the treatment plant for 7–10 years,
- Checking and control of changes in underground solution composition,
- The construction of membrane technology units and their operation.

The restoration of the Turonian aquifer will be performed by extraction of the contaminated water by:

(a) Injection of contaminated water to the hydraulic barrier.
(b) Pumping of the most contaminated water to the membrane technology plant. The projected start of operation was in 1996 with a capacity of 2 m^3/min.
(c) Discharge of low contaminated water to the river. This method will be used only during the final phase of restoration.

Desalination plant stage I (Fig. 40)

In February 1994, DIAMO awarded RCCI a contract to clean up the acidic solutions and to produce a pure salt product using a system of evaporators, crystallizers and recrystallizers. The system will treat 6.5 m^3/min of acid solution, recovering 5.5 m^3/min of clean water for discharge to a nearby river and 1.0 m^3/min of concentrated solutions. The start of operation was in April 1996. This technology produces two main products after crystallization and recrystallization of salts from the concentrate:

1. The crystals of ammonia alum, $NH_4Al(SO_4)_2.12\ H_2O$. The assumed production will be about 120 000 t per year for the first 15–20 years of operation or until 2015. Production will decline (3–5% per year) after that 2015.

2. The crystallization filtrate of alum (the so called mother liquor). The assumed production will be about 300 000 m^3 per year. The composition of this solution will change very slightly in the first 15 years of operation. A moderate decrease of individual concentration components is expected during following years. Most of components from the original solution, and practically all of radionuclides will be concentrated in this mother liquor.

FIG. 40. Evaporators and crystallizers building (Desalination plant stage I).

Desalination Plant Stage II

The products of the Stage I are for all practical purposes wastes if they are not further treated and it is necessary to continue their treatment into commercial products or into products, which can be safely deposited in the environment.

A large research programme for solving the problem connected with the underground water desalination is underway in DIAMO at present. The first results show possible ways for treatment of the Stage I products.

There are several technologies (or their combination) for decomposition of ammonia alum:

1) The calcination of ammonium aluminium sulphate to produce $Al_2(SO_4)_3$.
2) The decomposition of ammonium aluminium sulphate by means of ammonia under atmospheric conditions with production of $Al(OH)_3$ and calcination to Al_2O_3 afterwards.
3) The production of so called “restoration materials” by mixing the alum with lime and the use of this product for the restoration of waste pond.

Possible commercial products of these technologies are:

- Al_2O_3, about 10 000 t per year, or
- $Al_2(SO_4)_3$, about 40 000 t per year, and
- Restoration materials 100 000– 150 000 t per year.

The main goal of concentrate treatment has to be the minimization of the amount of solid wastes.

The Desalination Plant Stage II started to operate in 2002, when the production of $Al_2(SO_4)_3$, with capacity of 10 000 t/a, was put in operation.

The operation of classic neutralization stations is planned in years 2006-2030 for the treatment of slightly contaminated solutions pumped from borders of contaminated areas.

VII.7. Conclusions

At the outset it is very important to mention that we cannot judge old projects from the present point of view and under new conditions and requirements. But we always have to be careful when developing new projects that we learn from previous experiences.

The ISL project in Straz was developed under conditions dictated in the 1970s and 1980s. There were many attempts to start remediation actions during the operation, but the main priority was uranium production and at that time any other activity would have only raised the costs of operations.

This is why the remediation solutions at present are and will be very costly. We will have to be very careful to keep the cost at an acceptable level and also leave the environment in acceptable status for the future.

Present evaluation is to spend 40 billion CZK (US$ 1.5 billion) during 40 years of remediation and decommissioning.

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APPENDIX VIII. BEVERLEY URANIUM PROJECT, GUIDELINES FOR AN ENVIRONMENTAL IMPACT STATEMENT

VIII.1. Introduction

VIII.1.1. Background

These guidelines are based on the requirements of paragraphs 4.1. and 4.3. of the Administrative Procedures under the Commonwealth Environment Protection (impact of Proposals) act 1974 (EPIP Act). The guidelines are also based on the requirements for the assessment of proposals under section 75 of the South Australian Development Act 1993.

The former Commonwealth Assistant Treasurer Senator Jim Short designated Heathgate Resources as proponent for the proposal under the Environment Protection (Impact of Proposals) act 1974 on 4 October 1996 in relation to foreign investment approval. The south Australian Minister for Mines and Energy also directed that an Environmental Impact Statement (EIS) be prepared on 15 July 1996 for the proposal under Section 75 of the Development Act 1993.

The object of both Acts is to ensure that matters affecting the environment to a significant extent are fully examined and taken into account in decisions by the Commonwealth Government and the south Australian Government.

The term "environment" refers to all aspects of the surroundings of human beings, whether affecting human beings as individuals or in social groupings. It includes the natural environment, the built environment and social aspects of our surroundings. The definition covers such factors as air, water, soils, flora, fauna, buildings, roads, employment, housing and recreation facilities.

In preparing the EIS, the proponent needs to bear in mind the following aims of the EIS and public review process:

- To provide a source of information from which interested individuals and groups may gain an understanding of the proposal, the need for the proposal, the alternatives, the environment which it would affect, the impacts that may occur and the measures to be taken to minimize these impacts,
- To provide a forum for public consultation and informed comment on the proposal, and,
- To provide a framework in which decision-makers may consider the environmental aspects of the proposal in parallel with economic, technical and other factors.

The proponent needs ensure that the EIS demonstrates compliance with the goals, objectives and guiding principles of Ecologically Sustainable Development as set out in the National Strategy for Ecologically Sustainable Development. The EIS needs to also acknowledge and take into account that the region surrounding the proposal may be culturally diverse (with an associated diversity of values) and ecologically, economically and socially important.

In accordance with the principles contained in the Intergovernmental Agreement on the Environment, and the Australian and New Zealand Environment and Conservation Council (ANZECC) "Basis for a National Agreement on Environmental Impact Assessment", the project will be subject to a joint assessment by the Commonwealth and South Australia. The

South Australian Department of Transport, Urban Planning and the Arts, will take the lead role in the joint assessment process in close consultation with the Commonwealth Department of the Environment, Sport and Territories. However, two Assessment Reports will be prepared, one by each Department.

As there is joint State/Commonwealth assessment of this proposal there may be issues and factors, which fall outside the South Australian Development Act definition of the environment. The South Australian Department of Transport, Urban Planning and the Arts will only consider those factors consistent with the provisions of its Act.

As set out in the following guidelines, the scope of this assessment shall encompass those issues and alternatives directly related to the development of the Beverly Uranium Project and potential impacts upon the region. The EIS will not address policy issues about the appropriateness of uranium mining. The scope of the EIS will also not include broader issues relating to the use of exported uranium in the nuclear fuel cycle. Issues related to the use of exported uranium in the nuclear fuel cycle are beyond the control of the proponent and it would be impractical for Heathgate Resources Pty Ltd to address these issues in the EIS. Issues relating to the use of exported uranium will be considered separately within the overall Commonwealth assessment of the proposal.

VIII.2. General content, format and style

The administrative procedures under each of the EPIP Act and the Development Act provide guidance on the public review and assessment process. Section 46 of the Development Act outlines the contents of an EIS whilst paragraph 4.1. of the Administrative Procedures under the EPIP Act lists the required contents of any EIS (copy at Appendix I). The following guidelines describe in more detail, those matters it is considered need to be addressed in this EIS.

The document is best balanced by giving priority to the major issues associated with the proposal, with matters of lesser concern being dealt with only to the extent required to demonstrate that they have been considered.

It is envisaged that the EIS will be based on the results of available research, studies and data as appropriate, with further studies being conducted where necessary and practicable. By discussing the extent to which the limitations, if any, of available information may influence the conclusions of the environmental assessment, the document fully informs the reader of potential data shortcomings.

In these guidelines the terms "description" and "discussion" are to be taken to include both quantitative and qualitative materials as practicable and meaningful. Similarly, adverse and beneficial effects need to be presented in quantitative and/or qualitative terms as appropriate.

The main text of the EIS should be written in a clear, concise style that is easily understood by the general reader, avoiding technical jargon wherever possible. Detailed technical information necessary to support the main text can be included as appendices issued with EIS so that the EIS is complete and self-contained. Where appendices include results of studies conducted in preparing the proposal, the public availability of the studies need to be indicated.

The documentation needs to include references, a list of individuals and organizations consulted and relevant maps and illustrations. The cost of the EIS to the public should be minimized.

While every attempt has been made to ensure that these guidelines address all of the major issues associated with the proposal, they are not necessarily exhaustive and are not be interpreted as excluding from consideration matters deemed to be significant but not incorporated, or matters (currently unforeseen) that emerge as important or significant from environmental studies or otherwise during the course of preparation of the EIS.

VIII.3. Contents of the EIS

VIII.3.1. Summary

As prescribed by paragraph 5.2 of the Administrative Procedures under the EPIP Act, the EIS must include a concise summary of the matters discussed in the main body of the document to allow the reader to obtain quickly a clear understanding of the proposal and its environmental implications. The summary should include:

- The title of the proposal,
- Name and address of the proponent,
- A brief discussion of the background to and need for the proposal,
- A brief discussion of the alternatives, and reasons for selecting the preferred option,
- A brief description of the proposal,
- A brief description of the existing environment,
- A description of the principal environmental impacts (both adverse and beneficial),
- A statement of the environmental protection measures, safeguards and monitoring procedures proposed, and
- A brief description of the proposed plans for decommissioning and rehabilitation.

VIII.3.2. Introduction

The main body of the EIS should be introduced with a clear definition of the objectives of the proposal, followed by a brief explanation of the scope and legislative basis for the EIS, including the role of the EIS in the governments' decision-making processes. A description of the study area and regional setting for the proposal, including land use, tenure and the potential for application of the Native Title Act 1993, is an integral part of the introduction.

Brief descriptions of the studies/surveys/consultations that have been conducted in developing the proposal and preparing the EIS provide the reader with an overview of the basis for the document. Results of studies and detailed comments resulting from the consultation can be included as appendices. An explanation of the structure of the document will help the reader understand which items are given priority.

VIII.3.3. Background

The EIS needs to discuss the background to the proposal, covering, for example, the following points:

- History of the proposed Beverly uranium mine site including previous studies undertaken by previous lease holders,
- Existing approvals and conditions applying to the Beverley leases where relevant to the proposal,
- Any preliminary planning, design and on-site works (including exploration and field leach trials) which have been undertaken,

- Negotiations with and involvement of government agencies in the assessment, authorization and approval process to date,
- Negotiations with and involvement of traditional owners in the assessment, authorization and approval process to date,
- Planning considerations, regulations, standards etc. governing the design and operation of the proposal, and
- The current status of the proposal, the approvals required in order for the proposal to proceed, and the legislation under which those approvals are required.

VIII.4. Need for the proposal

The EIS will offer the reader a comprehensive explanation of the need for and justification of the proposal, including:

- The specific objectives the proposal is intended to meet including market locations, requirements and trends,
- Expected regional, state or national benefits and costs (including those that cannot be adequately described in monetary or physical terms, e.g. effects on cultural and aesthetic amenity), and
- A summary of environmental, economic and social arguments to support the proposal.

VIII.5. Description of the proposal

Detailed descriptions of all components of the proposal (including the site, processing site, transport corridors etc) from initial installation to decommissioning and site completion (including long-term monitoring or management) will ensure that the project is properly characterized. Alternatives to various components of the proposal need to be outlined, with emphasis given to those components with the most potential for significant short and long-term environmental impacts. When appropriate, technical information may be supported by maps, figures and diagrams. Detailed technical information can be included in the appendices. Underlying assumptions and forecast reliability are important for a full understanding of the proposal.

The description should include (where relevant):

- Location, site, layout and project description including ancillary sites, transport corridors etc.,
- Description of the physical requirements for the proposal including:
    - o Types, total quantities, sources and availability of major construction materials,
    - o Infrastructure requirements, including drainage, retention ponds, fencing, roads transport systems, workshop, stockpiles, machinery, uranium processing facilities, other buildings, communications services, water and power supply, waste treatment and disposal, spill containment etc., and
    - o Off-site infrastructure requirements and community developments required to support the operation of the proposed development including transportation of processed uranium and ship loading, housing and other facilities for employees and families, other services.

- Description of the construction works required, including:

- Timing of work programme, duration of construction phase including lead times,
- Size of construction work force and accommodation requirements,
- The process of extraction and transport of construction materials from off-site sources (specify sources of supply, quantities and types of materials, proposed haulage routes),
- Extent of earthmoving, building demolition/relocation, vegetation clearance and other site preparatory works including arrangements to minimize unnecessary clearance and disturbance,
- Construction standards, techniques and site management arrangements, including for on-site storage and handling of construction and other (e.g. fuel, oil) materials and rehandling basins,
- Arrangements for disposal of construction wastes during and following construction, and
- Arrangements for erosion control and rehabilitation of construction sites.

- Procedures/processes/technologies to be utilized, and the major plant components associated with various operations, including:

  - Review of ISL technology using acid and alkali lixiviant,
  - Operational programmes/plans, estimated life of the proposed development,
  - Nature, quantities and sources of supply of raw materials for processing, feedstock, (if not produced as part of the project) and chemical additives,
  - Review of effectiveness of detection and recovery of leachate excursions,
  - Onsite storage facilities for raw materials and products (location, capacity and design),
  - Processing of uranium liquor, and
  - Packaging of processed uranium.

- Resultant products and waste including:

  - The nature and quantities of processed mineral generated by the development,
  - Origins, quantities and nature (physical, chemical) of solid wastes produced during various project operations and proposals for disposal, including the capacity of proposed disposal sites,
  - Origins, volumes and composition of liquid wastes associated with the project (such as site drainage, process effluents, evaporation basins, upgrading prior to release to environment etc). If there is an objective of "no release", explain how this is to be achieved,
  - Water management and sediment control, runoff from undisturbed areas, runoff from site,
  - Origins, quantities and composition of gaseous emissions from project operations (include chemical and particulate emissions, provide estimates of both total emissions and ground level concentrations),
  - Waste and hazardous substances contingency plans for spills, accidental release and pollution,
  - Any noxious odours emitted by the project,
  - Predicted levels of noise (on-site and at site boundaries) generated by individual plant components and the project overall, and

- Sources, pathways and potential doses of radiation exposure for employees (taking into account documented information on workers in other uranium mines), members of the public and the surrounding ecosystems, including: radon gas and its decay products, radioactive particles in dust, radioactive liquids, gamma radiation, including exposure from ore processing, and transportation and storage of processed uranium.
- Water supplies, including:
  - Requirements in terms of quantity and quality for industrial operations, work force consumption on site, domestic consumption,
  - Proposals for provision of required supplies including source, pipelines from storage or bore fields,
  - The proposed infrastructure and methods for exploitation and delivery to project sites and arrangements for maintenance of water quality; and
  - Proposed recycling and water minimization techniques.

- Energy supplies, including:
  - Quantity for industrial and workforce domestic purposes, types of energy which can be utilized, proportions of proposed energy supply mix, and sulphur content in the case of fuel oil,
  - Proposed sources of energy supplies and transmission nodes (including placement of power lines), and
  - Identification and adoption of measures to minimize energy requirements.

- Transport, including:
  - (for raw materials and products both within and beyond project sites) existing transport networks to be utilized and proposals for upgraded or additional road links, pipelines, conveyors etc. Method and frequency of transport of processed product to port, loading, and shipping within Australian waters, including selection of the transport route, interim storage sites, transfer and loading of material and decommissioning of transportation and storage sites, and
  - Any transport facilities to be provided by project operators linking accommodation site and workplace.

- Required work force, its establishment and maintenance, including:
  - Numbers in various categories of skilled and unskilled workers required at various stages of project development, numbers of part-time, full-time and casual workers and the expected source of labor forces including references to regional availability,
  - Work force establishment and maintenance including predicted increase in total population numbers resulting from direct employment of the project,
  - Requirements for accommodation, and
  - Provision of other service and facilities to support the project work force and families,
  - Health and safety, including project site safety and medical facilities and procedures, measures to prevent exposure to radiation, fumes and dust both at the sites and during transportation and handling for both employees and nearby communities,

- Community liaison and consultation including identification of, and ongoing consultation and negotiations with, traditional owners at all stages of the project, ensuring the full range of community viewpoints are sought,
- The relationship between the management of the mine, surrounding land and Gammon Ranges National Park,
- Access arrangements for the Project Area.

VIII.6. Alternatives

The EIS needs to describe any prudent and feasible alternatives to carrying out the proposed activity, including the "no mine" option, in sufficient detail to make clear the reasons for preferring certain options and rejecting others. The choice of the preferred option(s) needs to be explained, including a comparison of the adverse and beneficial effects (direct and indirect) used as the basis for selection, and compliance with the principles and objectives of ecologically sustainable development.

The alternatives to be discussed may include:

- Not proceeding with the proposed development,
- Inclusion of processing of other materials, including radioactive materials, in the proposal, and
- Other key alternatives to the project configuration.

Discussion needs to include:

- Adverse and beneficial effects of alternatives at national, state, regional and local level,
- Identification of groups and/or areas that are adversely or beneficially affected,
- The comparison of short, medium and long-term advantages and disadvantages of the options, and
- The criteria and their relative importance in comparing options.

VIII.7. Existing environment

A description of the existing environments within the study area, including those areas likely to be affected by processing and transport operations, is required to serve as a baseline against which the impact of the proposal and alternatives can be assessed. The extent of the discussion and description will be guided by the general principles set out in Section A.2.

a) Aspects of the physical environment:

- Geology (of the region, site and mineral deposit), geomorphology, seismic stability, soil types (including erosion potential and ability to store and/or remobilize contaminants) and the pre-mining radiological aspects of the Beverley deposit,
- Topography,
- Hydrology and hydrogeology (surface and groundwater systems including the GAB, catchments, flow and discharge rates, water quality),
- Relevant climate and atmospheric conditions including precipitation and evaporation rates, winds, and temperature, seasonal variability, probability of extreme events, flooding, and storms,

- Existing ambient noise levels in the study area, and
- Existing air quality in the study area.

b) Aspects of the biological environment:

- Describe the habitats, communities and vegetation/fauna species within them, noting significance of the biological diversity (as per the Convention on Biological Diversity), and current condition,
- Conservation status of species or associations to be disturbed by the proposal (including species and communities listed under the Commonwealth Endangered Species Protection Act 1992),
- Other sensitive environments or areas of special significance (breeding sites, seasonal habitats, wetlands, refuges, etc); ecological relationships and interdependencies, including recognized food chains, and
- Radiation dose from existing environment for both the surrounding ecosystems and the local community,
- Insect species of present concern from a nuisance and health perspective,
- Introduced flora and fauna.

c) Areas of natural environment with identified special values including:

- Gammon Ranges National Park,
- Areas listed on the register of the National Estate,
- Areas important to obligations under relevant international agreements to which Australia is a party, and
- Areas of wilderness, wilderness quality, and wild rivers values.

d) Aspects of the socio-economic environment:

- Demographic characteristics,
- Existing communities in the region,
- Social factors (lifestyle characteristics, existing trends, social problems and underlying reasons) including reference to results and recommendations of relevant studies,
- Employment levels and characteristics,
- An overview of the history of land use in the region,
- Regional and bioregional planning strategies and frameworks,
- Relationship to other economic activities in the region,
- Existing and proposed land uses including government land, water resources, infrastructure, pastoral, tourism, mining, national parks, aboriginal land, areas for food gathering and ceremonies, and town planning or zoning considerations, and
- Other physical infrastructure that could be affected by operations.

e) Aspects of the cultural environment:

- Areas listed on the register of the National Estate for indigenous and historic cultural values,
- Any other historic cultural values in the area,
- Sites of significance to the Aboriginal population and culture,

- Information on the Beverley area as a cultural landscape,
- Sites of archaeological and anthropological significance including a description of their anthropological or cultural significance (including sites within the meaning of the SA Aboriginal Heritage Act 1989),
- Areas with other special values (landscape/visual environment, commercial/recreational value),
- Places and objects within the meaning of the SA Aboriginal Heritage Act 1989, and
- Cultural values that are not site specific.

VIII.8. Environmental impacts

A discussion of the predicted environmental impacts expected to result from the proposal and, to the extent appropriate, alternatives is a centerpiece of the EIS. The discussion needs to cover effects on the natural and socio-economic environment in the study area, at a local, regional, state and national level as appropriate. Consideration may be given to the effects during the construction phase and the ongoing operations of the mine. Generally the discussion will use the same indicators and descriptors used to describe the existing environment (Section 7).

Direct and indirect, short-term and long-term, temporary and irreversible, adverse and beneficial effects need to be described and, where possible, quantified. The reliability and validity of forecasts and predictions, confidence limits and margins of error may be indicated as appropriate. Accessibility to underlying data and assumptions is important to the credibility of the document. Interactions between impacts on biophysical and socio-economic environments, individually and collectively need to be covered. Consultations with the groups of people potentially affected by these impacts, particularly those expressing particular concerns will ensure the broadest input into project planning.

While the EIS needs to deal with all issues related to the environmental impacts of the proposal, particular emphasis should be placed on surface water, groundwater, radiation, solid wastes, liquid wastes, access, rehabilitation, transport, cultural values, and the community.

The following sections illustrate the types of impacts that need to be considered:

a) Impacts during construction phase

Description of the impact of construction works associated with the development of the site and associated areas (roads, processing site) needs to include:

- Effects of dust, vibration, noise,
- Effects and extent of earthworks, including potential soil erosion,
- Transport of materials and disposal of construction wastes,
- Changes to hydrology, e.g. drainage patterns, aquifers, sediment loads and effects of water table, and
- Water quality,
- Effects of spills of fuel, oil, etc.,
- Extent of clearing of native vegetation and effects on native fauna, especially rare or endangered species or significant habitats,
- Impacts of constriction on local communities including effects on employment and local economy,

- Visual and aesthetic impacts of construction works,
- Flood mitigation, and
- Impacts of construction on sites of archaeological or cultural significance.

b) Impacts during operational phase

The impacts of the operation of the mine and associated sites should be described, as far as is practicable, from initial operation to the decommissioning and site completion including:

- Dewatering and storage of water (including potential for seepage),
- Residue and process water accidental and scheduled releases and seepage,
- Dust or spillage from transported loads and other mining operations,
- The changes in noise due to the proposal and associated effects,
- The effects of changes in demand for surface access (road),
- Impact of loading, unloading and transport of materials (including radioactive materials) required for project operation and transport of wastes,
- Air quality and atmospheric emissions throughout the mine and processing area,
- The impact of the proposed development on the hydrological and hydro-geological environment needs to be discussed, including,
  - The potential for runoff from the mine, roads and processing areas and the potential for increased flooding or other changes to water flow regimes,
  - Permanent and temporary changes to drainage patterns, groundwater levels and storm water runoff,
  - Changes to water quality, including groundwater quality, sediment loads and the effects of oil or fuel spills, and waste water and storm water discharges,
  - Impact of water storage and treatment systems, and
  - Impact of lixiviant injection.
- Impact of transportation of uranium including transport to port, interim storage loading and shipping within Australian waters.

c) Impacts for all stages and aspects of the proposal

- Potential impacts on National Estate values and other natural and cultural values for all stages and aspects of the proposal,
- Long term effects of disturbance or isolation of species/communities/habitats,
- Cumulative impacts, including the combined impacts of the Beverley and other mines upon the environment and communities of the Beverley region,
- Potential for increases in introduced fauna and flora (introduction and dispersal) and associated impacts upon the environment,
- Impacts of proposal construction and operation on the creation or aggravation of insect breeding sites,
- Other impacts on biological diversity including through fire management regimes associated with mining activities,
- Effects of waste disposal, particularly processing wastes and sewerage,
- Impacts associated with the Beverley camp including:
  - Social issues arising from establishment and operation of the camp,
  - Continued or increased impacts upon the surrounding natural environment,
- Effects of demand for water, and waste disposal and other infrastructure elements,

- Impacts of the mine on communities in the study area and along transport routes, including effects on employment, health and human services, local government services, safety, law and order, the local and regional economy and demography,
- Effects on surrounding land uses and zoning in the short and long term, including government land, water resources, infrastructure, pastoral, tourism, mining, national parks, Aboriginal land, areas for food gathering and ceremonies and town planning or zoning considerations,
- Visual and aesthetic impacts at the site and from vantage points,
- Impacts on significant sites such as archaeological and anthropological sites and values,
- "Greenhouse" gas emissions, including design and procedural measures to reduce such emissions,
- Impacts on the economic regime of the region and broader economic analysis where relevant,
- Adverse impacts of the proposal upon the social and cultural lifestyle of traditional owners and the broader Aboriginal community, including customary practices, resource sharing and food gathering (drawing upon the findings and recommendations of previous studies on the impact of mining upon Aboriginal communities),
- Beneficial impacts through social and cultural benefits for traditional Aboriginal owners and the broader Aboriginal community including improved schooling, housing and opportunities for Aboriginal business enterprises,
- Impacts of mining activity upon Aboriginal values of the region, sites of significance and Aboriginal culture (including views of traditional owners on impacts), and
- Impact upon traditional owners' use of land after the proposed mine has been completed.

d) Risk/safety

- A quantitative risk assessment needs to be undertaken as appropriate to determine individual risk and societal risk, including:
    - Exposure to radiation at all stages of the proposed operation (including transportation and storage) and post operational exposure for employees, and nearby communities,
    - Road transport accidents, and
    - Fire, explosion and blasting hazards.
- Description of predicted radiation releases during and post development and implications to species, ecosystem and traditional foods.

VIII.9. Environmental safeguards, monitoring proposals, environmental management plans and audit and review

This section describes all measures proposed to mitigate the adverse impacts associated with the proposal, and where appropriate, alternatives, and draws together all relevant information mentioned in the text together with a clear statement of specific commitments, which the proponent will make. Any actions required by others to enable the proponent to meet these commitments are identified (e.g. independent oversight of monitoring, safeguards and environmental management). All commitments need to include a statement of the objective to be achieved. A list of commitments should be contained in a separate chapter of the EIS with individual commitments comprehensively indexed and cross-reference to the text.

A clear analysis of the likely effectiveness and secondary effects of all safeguards and monitoring programmes to be implemented provides an overview of the safety of the proposed project. Where practicable, and relevant to the comparison of alternatives, the cost of mitigation measures and monitoring programmes need to be estimated.

The overall management philosophy to be applied to the mine should be enunciated, including an outline of the environmental management plans for the construction and operational phases. Monitoring and quality assurance programmes designed to ensure safeguards are being effectively applied and to identify and measure any differences between predicted and actual impacts need to be described.

Providing a reference to relevant legislation, standards and procedures and any relevant international codes of practice gives assurance to the readers (including regulators) that the document appropriately addresses environmental laws and concerns. The bodies responsible for implementing each of the various safeguards and monitoring programmes need to be identified, and their roles explained. Similarly, making details of proposed environmental management plans and monitoring results public add credibility and transparency to the EIS.

Environmental safeguards

Safeguards to avoid and mitigate effects on the environment need to be discussed, including measures which:

- Control erosion,
- Minimize vegetation disturbance,
- Control bushfires and other fires,
- Control/mitigate changes to groundwater and flooding,
- Prevent or minimize the creation of mosquito breeding sites, and/or adequately manage such sites,
- Control air and water pollution,
- Control exposure to radiation including emanation of radioactive substances,
- Control pollution from slid and liquid waste including options for reuse and recycling,
- Mitigate noise and noise impacts,
- Mitigate any deleterious effects on economic, social, recreational, conservation, cultural, and community activities and resources (in particular, renewable resources),
- Minimize disruption to traffic and disturbance and loss of amenity due to increases in traffic to and from the site,
- Minimize “greenhouse” gas emissions and maximize energy efficiency,
- Avoid, control or minimize impacts on sites and values of environmental or heritage significance (National Estate etc.),
- Control and minimize impacts upon biological diversity,
- Incorporate environmental protection to the design, siting, layout and landscaping of facilities and associated works (e.g. to minimize visual impact),
- Educate employees and construction managers in relation to their environmental protection obligations (e.g. through the incorporation of appropriate clauses in construction contracts), and
- Provide for appropriate arrangements in the event of adverse impacts that may require compensation associated with remediation.

Monitoring programmes and procedures

Comprehensive monitoring programmes to ensure the above measures are applied effectively need to be outlined. Discussion of mechanisms for handling pollution incidents related to the mine and processing activities, including necessary management arrangements lends credibility to the overall environmental safety of the project. Those responsible for monitoring programmes need to be identified including provisions for making use of outside expertise. There also needs to be a statement of the procedures, which will be put in place for reporting on monitoring programmes, and an indication of how these reports will be distributed.

Baseline data collected as part of the description of the existing environment, and any studies proposed to identify changes as the result of the proposed development needs to be included. The design of these studies should take into account the methodology of previous studies and any difficulties encountered to ensure that the results can be meaningfully compared to the baseline data and predictions of the EIS.

There needs to be a description of any provisions made in project planning for the tightening of initial environmental standards, response mechanisms and further remedial action if monitoring indicates that the project is causing unexpected environmental degradation. Examples of the matters that will be addressed in the proposed monitoring programme are as follows:

- Monitoring the effectiveness of pollution control measures (water, air and solid waste) during construction and operational phases,
- Monitoring of safety and health procedures, including monitoring of employee health,
- Monitoring of noise levels,
- Monitoring of air quality,
- Monitoring of radiation levels,
- Monitoring of water quality and hydrology in the surrounding catchment,
- Monitoring of the surrounding environment that may be impacted upon by the proposal including ecosystems, habitats, flora and fauna,
- Monitoring of potential impacts from the proposal on Gammon Ranges National park,
- Monitoring of natural and cultural values that may be impacted upon by the proposal,
- Monitoring of social impacts upon the local communities,
- Monitoring of the adequacy of emergency procedures developed to deal with accidental release of hazardous substances, fire, radiation exposure, etc., and
- Provision for liaison/consultation with relevant authorities, community and user groups, including residents, traditional owners, researchers, educational institutions etc.

Oversight of environmental protection strategies

A description of arrangements for independent oversight monitoring, safeguards and environmental management strategies will identify linkages and compliance with the requirements of relevant State and Commonwealth regulations. A list of relevant State and Commonwealth legislation as well as ongoing agreements relevant to the environmental management of the site needs to be provided.

Contingency planning

Inclusion of a description and outline of contingency and emergency plans, and resources and procedures to address all potential incidents both during and after the project lends credibility to the completeness of the planning process.

VIII.10. Decommissioning and rehabilitation

As the name implies, this section addresses the decommissioning and rehabilitation objectives and goals for the whole project including both progressive and final rehabilitation processes. It also addresses the constraints that may influence the type and extent of decommissioning and rehabilitation throughout the whole project. The success and problems encountered with rehabilitation at other relevant sites can be used wherever possible.

Facilities to be retained after closure need to be listed with the reason for their retention and any long-term maintenance required. The aspects of decommissioning and rehabilitation are best addressed in table form, identifying the original environment, environment to be rehabilitated (including infrastructure), procedures for decommissioning and rehabilitation, time frame, performance bonds or rehabilitation guarantees, and planned final environment.

The time scale for determination of compliance with, and progressive or final release from requirements of the appropriate authorities is an important part of this section. The section should be written in such a form so as to be able to be audited.

Apart from specific project details listed in table form, general information, which also needs to be addressed includes:

- Integration of the rehabilitation programme with mine design and operation,
- Design of rehabilitated landforms that blend with the surrounding environment,
- Stability and erosion control measures including stability of tailings and other waste disposal storage structures for the duration of risk to the surrounding environment,
- Long term monitoring and management of surface and sub-surface drainage,
- Rehabilitation strategies to minimize radiation emission from the site after completion of the proposal,
- Revegetation programme,
- Strategies for the involvement of Aboriginal people, particularly the traditional owners, in determining the rehabilitation goals and objectives, and
- Final use for the project area, taking into account the social, cultural, environmental and economic regime of the region.

VIII.11. Consultation and studies

Describe research and investigation undertaken in the course of evaluating the need, feasibility and design of the proposal including baseline studies undertaken. Cite any sources of information used in preparing the EIS.

Describe any consultations undertaken with Commonwealth/State Agencies, Local Government, relevant Aboriginal organizations, traditional Aboriginal owners and the community over the proposal and the way in which concerns raised by these groups will be, or have been, addressed. Describe any further studies, investigations and consultations, either proceeding or intended to be made in regard to the design and potential impacts of the proposal.

APPENDIX IX. FACTORS TO CONSIDER IN THE EIA PROCESS

Environmental baseline

Meteorology and air quality

- Temperature
- Precipitation, relative humidity and evaporation
- Wind
- Severe weather (hurricanes, volcanoes, etc)
- Atmospheric stability
- Air quality
- Sound level

Topography

Geology

- Local
- Regional (structure, stratigraphy)

Water

- Surface waters and their quality
- Groundwaters and their quality (ore bearing)
- Groundwater and their quality (non-ore bearing)
- Surface hydrology
- Groundwater hydrology

Demographics

- Population distribution (local, regional)
- Municipal services (Fire Protection, Medical Care, Security)

Land use

- Agricultural activities
- Industrial activities
- Mining activities

Soils

- Type/classification
- Trace metals

Mineral resources/activities

- Uranium
- Oil and gas
- Coal
- Other mining

Ecology

- Flora
- Fauna
- Avifauna

- Aquatic Biota
- Reptiles and Amphibians
- Endangered, threatened or other special status

Background radiological characteristics
- Air
- Soils
- Water

Cultural resources
- Archaeology
- History

In Situ Leach project

Description of facilities
- Roads
- Buildings
- Well fields (surface, sub-surface)
- Utilities
- Liquid disposal systems
- Solid waste disposal systems
- Employee facilities (housing, medical, dining, recreation)

Principle Features and Procedures
- Exploration drilling
- Development testing
- Water Balance
- Process descriptions
  - Well field operations
  - Uranium recovery
  - Yellowcake production
  - Drying and packaging
  - Water treatment
  - Solid waste treatment
  - Sanitary system treatment
  - Water supply and utilities
  - Monitoring and control systems
- Hazardous chemicals
- Fire Hazards
- Topsoil protection
- Radiation protection
- Employee health and safety
- Spill prevention

Restoration, reclamation and decommissioning
- Groundwater restoration
- Surface/soils reclamation
- Contaminated equipment (decontamination, disposal)
- Facilities closure and decommissioning

Effluent control systems

- Air emissions
- Radon emissions
- Liquid wastes
- Solid wastes
- Noise control
- Human wastes

Monitoring Systems

- Production zone monitor wells
- Overlying zone monitor wells
- Underlying zone monitor wells
- Pipelines
- Well casing integrity
- Airborne chemical emission
- Airborne radiometric emission
- Health physics

Transportation

- Chemicals spills
- Yellowcake spills
- Employees (air travel, roads)
- Leaching and production fluids spills
- Highway (offsite) traffic accidents
- Security

Social/Economic Impact

- Effect on local communities
- Effect on regional/national level
- Effect on cultural resources

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GLOSSARY

Acid leaching The leaching of useful components from ores using acidic solutions (usually sulphuric acid). Normally restricted to ore with a low carbonate (<2%) content.

ALARA An acronym for "as low as reasonably achievable", a concept meaning that the design and use of nuclear facilities, and in the practices associated with them, need to be such as to ensure that exposures are kept as low as reasonably practicable, with technical, economic and social factors being taken into account.

Alkaline leaching The leaching of useful components from ores, using carbonate and/or bicarbonate solutions.

Aquifer (1) porous water-bearing formation (bed or stratum) of permeable rock, sand, or gravel capable of yielding usable quantities of water. (2) a permeable (water-bearing) geological formation (rock, bed or a part of it) containing, compared with its surroundings, relatively significant quantities of water.

Assessment (1) An analysis to predict the performance of an overall system and its impact, where the performance measure is radiological impact or some other global measure of impact on safety. (2) The process, and the result, of analysing systematically the hazards associated with sources and practices, and associated protection and safety measures, aimed at quantifying performance measures for comparison with criteria. (3) Activities carried out to determine that requirements are met and that processes are adequate and effective, and to encourage managers to implement improvements, including safety improvements.

Background (1) The constituents or parameters and the concentrations or measurements, which describe the operating environment prior to any operation. Also be termed baseline. (2) As relates to radiological safety, natural background is the doses, dose rates or activity concentrations associated with natural sources or any other sources in the environment, which are not amenable to control.

Baseline study A study collecting all relevant information such as geological, biological data prior to an industrial project.

Best practicable technology (BPT) A technology based process justifiable in terms of existing performance and achievability (in relation to heath and safety) which minimizes, to the extent safe and practicable, disturbances and adverse impacts of the operation on human or animal life, fish, wildlife, plant life and related environmental values.

Borehole; drillhole A cylindrical excavation, made by a rotary drilling device. Boreholes are drilled during exploration for and delineation of uranium deposits.

Confined aquifer An aquifer that is overlain by a confining bed, where the hydrostatic pressure at the top of the aquifer is greater than atmospheric pressure.

Decommissioning Actions taken at the end of the useful life of a nuclear facility other than a disposal facility in retiring it from service with adequate regard for the health and safety of workers and members of the public and protection of the environment. Ultimate goal of decommissioning is unrestricted release or use of the site. The use of the term decommissioning implies that no further use of the facility (or part thereof) for its existing purpose is foreseen.

Deposit Mineral deposit or ore deposit is used to designate a natural occurrence of a useful mineral, or an ore, in sufficient extent and degree of concentration to invite exploitation.

Development To open up an orebody as by sinking shafts and driving drifts or developing wells (for in situ leach mines), as well as installing the requisite equipment.

Disposal The emplacement of waste in an approved, specified facility (e.g. near surface or geological repository) without the intention of retrieval. Disposal may also include the approved direct discharge of effluents (e.g. liquid and gaseous wastes) into the environment with subsequent dispersion.

Drilling fluid (mud) A water- or air-based fluid used in the water-well drilling operation to remove cuttings from the hole, to clean and cool the bit, to reduce friction between the drill string and the sides of the hole, and to seal the borehole.

Effective Porosity A porosity index characterizing the specific total capacity of rock, taking into account the physical-chemical interactions of the solution component under study.

Effluent A waste liquid, solid, or gas, in its natural state or partially or completely treated, that discharges into the environment.

EIA Environmental Impact Assessment.

EIS Environmental Impact Statement.

Endangered species A distinct class of animal or plant in danger of extinction, meaning their survival is in serious doubt.

Environmental impact assessment A process in which environmental factors are integrated into project planning and decision making. A process of evaluating the environmental implications of a development project before irrevocable decisions are made.

Environmental impact The expected effects of the projects upon the environment.

Environmental impact statement A statement of the expected effects of the project upon the environment, the conditions (if any) that need to be observed to void or satisfactorily manage any potentially adverse effects of the project and the economic social and other consequences of carrying the project into effect.

Excursion Spreading of the solutions beyond the perimeter of an ISL site or operation block under the forces of subterranean hydrodynamics. It may be controlled and mitigated by creating a local cone of depression by pumping which causes an influx of the groundwater from the surrounding area.

Groundwater restoration — The condition achieved when the quality of all groundwater affected by the injection of recovery fluids is returned to a quality of use equal to or better than, and consistent with the uses for which the water was suitable prior to the operation by employing the best practicable technology.

Grout (cement) — (1) to fill, or the material filling, the space around the pipe in a well, usually between the pipe and the drilled hole. The material is ordinarily a mixture of Portland cement and water. *syn*. cement. (2) a fluid mixture of cement and water (neat cement) of a consistency that can be forced through a pipe and placed as required. Various additives, such as sand, bentonite, and hydrated lime, may be included in the mixture to meet certain requirements. Bentonite and water are sometimes used for grout.

Hydraulic conductivity — The capacity of a rock to transmit water. It is expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic gradient — The change in static head or hydraulic potential per unit distance in a given direction.

Hydrology — The science dealing with water standing or flowing on or beneath the surface of the earth.

***In situ* leaching** — (1) a chemical method of recovering useful components directly underground, using reagent solutions and pumping the productive solutions to the surface for further treatment and recovery of the useful components. (2) the extraction of uranium from the host sandstone by chemical solutions and the recovery of uranium at the surface. ISL extraction is conducted by injecting a suitable leach solution into the ore zone below the water table; oxidizing, complexing, and mobilizing the uranium; recovering the pregnant solutions through production wells; and, finally, pumping the uranium bearing solution to the surface for further processing.

Injection — Feeding a leaching solution or water into underground strata through cased wells.

Injection well — A well used to deliver liquids (leaching solution or water) into a productive aquifer.

Ion exchange — Reversible exchange of ions contained in a crystal for different ions in solution without destruction of crystal structure or disturbance of electrical neutrality. The process is accomplished by diffusion and occurs typically in crystals possessing one or two dimensional channel ways where ions are relatively weakly bonded. Also occurs in resins consisting of three dimensional hydrocarbon networks to which are attached many ionizable groups. Method used for recovering uranium from leaching solutions.

ISL — *In situ* leaching. The in-place mining of a mineral without removing over-burden or ore, by installing a well and mining directly from the natural deposit thereby exposed to the injection and recovery of a fluid that causes the leaching, dissolution, or extraction of the mineral.

Law — A rule established by authority, society or custom.

Leaching well A well used in the ISL process.

(1) Injection wells feed the leach solution into the formation, and recovery wells deliver the pregnant solution to the surface. (2) A cased and cemented hole with equipment installed to inject or recover fluids.

Legislation (a) The process of making laws. (b) Laws collectively.

License A formal, legally prescribed document issued to an applicant (i.e. operating organization) by the regulatory body to perform specified activities related to the siting, design, construction, commissioning, operation, decommissioning of a nuclear facility, closure of a disposal facility, closeout of a mining and mill tailings site, or institutional control.

Licensee The holder of a license issued by the regulatory body to perform specific activities related to the sitting, design, construction, commissioning, operation, decommissioning of a nuclear facility, closure of a disposal facility, closeout of a mining and mill tailings site, or institutional control. The applicant becomes the licensee after it received a license issued by the regulatory body.

Mechanical Integrity Test (MIT) Injection and recovery wells need to be tested for mechanical integrity. To inspect for casing leaks after a well has been completed and opened to the aquifer, a packer is set above the well screen, and each well casing is filled with water. At the surface, the well is pressurized with either air or water to 25% above the expected operating pressure. A well is satisfactory if a pressure drop of less than 10% occurs over 1 hour.

Mineral A naturally occurring inorganic solid substance with a characteristic chemical composition.

Mineral lease See **mining lease.**

Mineral right The ownership of the minerals under a given surface, with the right to enter thereon, mine, and remove them. It may be separated from the surface ownership, but, if not so separated by distinct conveyance, the latter includes it.

Mining lease A legal contract for the right to work a mine and extract the mineral or other valuable deposits from it under prescribed conditions of time, price, rental or royalties. Also called **mineral lease**.

Mitigation An action aimed at reducing the severity, avoiding, or controlling impacts of a project through design alternatives, scheduling, or other means.

Mitigating measures Actions that decrease the effect of a project on the environment.

Monitoring (1) Maintain regular surveillance over a mining or milling site and its surroundings. (2) The measurement of dose or contamination for reasons related to the assessment or control of exposure to radiation or radioactive substances, and the interpretation of the results. (3) Continuous or periodic measurement of radiological or other parameters or determination of the status of a system.

Monitor (observation) well (1) a well used to measure the hydrostatic level and/or chemical and radiological composition of underground waters. (2) a surveillance (observation) well located usually along the periphery of a well field, either around the periphery of the mine zone or in overlying or underlying aquifers. It is used to indicated contaminant and/or lixiviant migration beyond the well field boundary.

Natural background	(1) The normal abundance (or background) of chemical or radiological species within a specific area. (2) The dose, dose rates or activity concentrations associated with natural sources or any other sources, which are not amenable to control.
Ore	A mineral or combination of minerals found in nature, usually mixed with other substances. By convention, ORE denotes economically recoverable quantities of one or more minerals.
Permeability	(1) The ability of rock or soil to transmit fluid (such as water) under a hydraulic gradient (*comp*. Intrinsic permeability, Hydraulic conductivity). (2) The ability of rocks to pass liquids and gases, expressed in DARCY units. The rocks permeability for water (solutions) is generally expressed by FILTRATION COEFFICIENT, accounting for the permeability of rock per se and the physical properties of filtration liquid (density and viscosity).
Piezometric surface	Real surface (open aquifer) or false (confined aquifer) where water pressure equals the atmospheric pressure.
Porosity	The voids or openings in a rock. Porosity may be expressed quantitatively as the ratio of the volume of openings in a rock to the total volume of the rock.
Producing aquifer	An aquifer containing ores, that can be worked by ISL.
Public hearings	The action by which the public has an opportunity to state its view regarding a project.
Radiation protection	Measures associated with limitation of the harmful effects of ionizing radiation on people, such as limitation of external exposure to such radiation, limitation of incorporation of radionuclides as well as the prophylactic limitation of injury resulting from either of these. Also called as **radiological protection**.
Radioactivity	Property of certain atoms to undergo spontaneous random disintegration in which energy is liberated, generally resulting in the formation of new nuclides. The process is accompanied by the emission of one or more types of radiation, such as alpha particles, beta particles and gamma rays.
Radionuclide	A nucleus (on an atom) that possesses properties of spontaneous disintegration (radioactivity). Nuclei are distinguished by their mass and atomic number.
Radon	Chemically inert radioactive gaseous element formed from the decay of radium or thorium (which is then called thoron). A potential health hazard.
Records	A set of documents, including instrument charts, certificates, log books, computer printouts and magnetic tapes kept at each nuclear facility and organized in such a way that they provide a complete and objective past and present representation of facility operations and activities including all phases from design through closure and decommissioning (if the

facility has been decommissioned). Records are an essential part of quality assurance.

Recovery Pumping groundwaters or production solutions to the surface to obtain valuable mineral components in commercial quantities.

Recovery solution The solution pumped to the surface through recover or production wells. It is formed underground as the result of physical-chemical inter-actions between the leaching solution and the rock mass being leached, and contains useful (minable) components in commercial concentrations.

Recovery well A well used to lift subsurface fluids to the surface.

Reclamation Process of restoring surface environment to acceptable pre-existing conditions. Includes surface contouring, equipment removal, well plugging, revegetation, etc.

Regulatory body An authority or a system of authorities designated or otherwise recognized by the government of a country or state as having legal authority for conducting the licensing process, for issuing licenses and thereby for regulating the siting, design, construction, commissioning, operation, safety closure, closeout, decommissioning and, if required, subsequent institutional control of the nuclear facilities (e.g. near surface repository) or specific aspects thereof. This authority could be a body (existing or to be established) in the field of nuclear related health and safety, mining safety, mining safety or environmental protection vested and empowered with such legal authority.

Remediation (cleanup) Action taken to reduce a radiation dose that might otherwise be received in an intervention situation involving chronic exposure, when a specified action level is exceeded. Examples are: (a) Actions that include decontamination, waste removal and environmental restoration of site during decommissioning and/or closeout efforts. (b) Actions taken beyond stabilization of tailings impoundments to allow for other uses of the area or to restore the area to near pristine condition. Actions can be applied to contamination itself or to the exposure pathways to humans.

Reversal of flow Changing the direction of leach solution flow between wells by making injection wells recovery wells, and vice versa, to improve recovery.

Restoration (groundwater) (1) The returning of all affected groundwater to its pre-mining quality for its pre-mining use. (2) (Russian usage) restoring natural waters following decommissioning.

Risk (a) In general, risk is the probability or likelihood of a specified event occurring within a specified period or in specified conditions.
(b) In the safety assessment of radioactive materials, risk may be used as a measure of safety. In this context it is defined as the product of the probability that an individual is exposed to a particular radiation dose and the probability of a health effect arising from that dose.
(c) The mathematical mean (expectation value) of an appropriate measure of a specified (usually unwelcome) consequence.
(d) The probability of a specified health effect occurring in a person or group as a result of exposure to radiation.

Site characterization	Detailed surface and subsurface investigations and activities to candidate nuclear facility sites to obtain information to determine the suitability of and to evaluate long-term performance of the site.
Solvent extraction	A method of separation in which a generally aqueous solution is mixed with an immiscible solvent to transfer one or more components into the solvent. Method used to recover uranium from leach solutions (Also known as liquid-liquid ion exchange).
Storage coefficient	The volume of water release from storage in a unit prism of an aquifer when the head is lowered a unit distance.
Subsurface water	All water in both saturated and unsaturated zones beneath the land surface (same as groundwater).
Surface water	Water, which flows along the surface of the ground.
Test well	A well installed to observe or measure the effect of the leaching solution on the rock, or to determine the residual concentration of the component being leached.
Transmissivity	Rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient It is expressed as the product of the hydraulic conductivity and the thickness of the saturated portion of the aquifer.
Unconfined aquifer	Upper limit of the aquifer is defined by the water table (level) itself. At the water table (the top of the saturated portion of the geologic formation), the water in the pores of the aquifer is at atmospheric pressure (as if it were in an open tank). Synonyms include: water-table aquifer, unconfined groundwater, and free groundwater.
VEC	Valued Ecosystem Component.
Waste, radioactive	For legal and regulatory purposes, radioactive waste may be defined as material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body, and for which no use is foreseen. This definition is purely for regulatory purposes, and material with activity concentrations equal to or less than clearance levels is radioactive from a physical viewpoint – although the associated radiological hazards are negligible.
Water table	(a) the upper surface of the groundwater. (b) the upper surface of a zone of groundwater saturation.
Well completion (well development)	The concluding stage of well installation, bringing the well up to the designed capacity, prior to the long-term performance under the chosen technological operational mode.
Well completion	The process of casing a well, and perhaps cementing the casing in place. Also includes the drilling out to depth and placing the wells screen or other device for filtering any silt out of the fluid flowing into the well.
Well field unit (block)	A portion of an orebody, functioning as an independent production site with its own system of operational wells, communications, preparation and operational plans, under conditions of regular control over the geotechnological performance (on a monthly, quarterly, or annual basis).

Well head — A device, which seals the well at the surface, but allows the release of gas into the atmosphere.

Well field (pattern) layout — The systematic arrangement of the injection and recovery wells. There are two basic types - those arranged in a linear series (generally alternating rows of injection and recovery wells), and the cell type, where injection wells surround each recovery well in a geometric pattern of a triangle, square or hexagon.

Yellowcake — (a) Sludge of solid uranium oxide concentrate formed during the final step of the ISL process.
(b) Applied to certain solid uranium concentrates produced by mills. It is the final precipitate formed in the milling and ISL processes. Usually considered to be ammonium diuranate, $(NH_4)_2U_2O_7$, or uranyl peroxide, $UO_3 \cdot H_2O_2$, but the composition is variable, and depends on the precipitating conditions.
(c) A common form of triuranium octoxide, U_3O_8, is yellowcake, which is the powder obtained by evaporating an ammonia solution of the oxide.

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