National In Situ Leach Uranium Mining Best Practice Guide: Groundwaters, Wastes and Radiation Protection

Draft released for Public Comment

Geoscience Australia was engaged by the Department of Resources, Energy and Tourism to develop world best practice guidelines for In Situ Leach (ISL) uranium mining in Australia, in consultation with a steering group made up of officials from environmental and resources agencies in the Australian, South Australian, Western Australian and Northern Territory governments.

1 June 2009

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Executive Summary

It is Australian Government policy that uranium mines be approved subject to world best practice environmental and safety standards. This guide communicates the Australian Government's expectations for in situ leach (ISL) mining with a view to achieving:

- greater certainty that ISL mining projects meet Australian Government policy;
- consistency in the assessment of ISL mine proposals within multiple government regulatory processes; and
- increased certainty for proponents in preparing ISL proposals.

ISL is a well established technology in use internationally for recovering uranium from mineralisation occurring in sandstone aquifers – it accounts for over a quarter of world uranium production.

The general principles and approaches outlined are also consistent with those for uranium mining by traditional underground and open cut techniques.

General principles and guidelines

There is no universal template for best practice mining – the operational and regulatory practices and procedures need to be best for the characteristics of the particular site.

A full description of the mining operation is required to enable assessment of the potential impacts of the mining proposal, having regard to the interests of relevant stakeholders. The basis for planning and approval of a best practice uranium mining project is a comprehensive characterisation of the geological and environmental setting, involving the proponent, the regulatory authorities and the public, including the local Aboriginal community where relevant.

Approval and licensing depends on the proponent convincing government authorities that it has identified all of the potential environmental, social and economic risks – measured in terms of 'consequences' and 'likelihoods' – and that its plans for mining, environmental management, radiation protection, monitoring, mine closure and rehabilitation are best practice for mitigating these risks.

Best practice for mine regulation in Australia is formally recognised as outcome-based, rather than prescriptive. This ensures increased trust by stakeholders through a clear demonstration that the environmental, social and economic impacts of the mining operation are being managed appropriately. It involves a continuing, integrated process from planning to closure.

Mining companies are responsible for achievement of agreed outcomes, and can be prosecuted for failure to do so. The environmental outcomes are set by the regulators through an iterative process involving the proponent and the public to identify all of the qualities and physical characteristics that are conducive to ecological health, public amenity and safety.

Throughout the life of a mine, operators have to meet minimum performance standards set by government regulators and are expected to pursue continual improvement. Rigorous monitoring programs are required to demonstrate progress towards, and achievement of, outcomes. All decision making and performance assessments are transparent.

Governments should not be left with any liabilities after mining. A rehabilitation security bond has to be lodged, and reviewed regularly to reflect the full costs.

ISL specific principles and guidelines

As the main potential impacts of ISL mining in Australia are on the mineralised aquifers, assessment of these relies on a full understanding of the hydrological/hydrogeological aspects of

the proposed project, and of the current uses and values of groundwaters in the region. These features constrain the nature of the mining solution; the best option for uranium recovery; the optimal well-field technology; the extent and distribution of monitoring wells; the options for disposal of liquid and solid wastes; and the groundwater rehabilitation requirements.

ISL uranium mining is to be planned and conducted so as to protect the use categories of groundwaters down flow from the mine, and in other aquifers in the area. Naturally elevated concentrations of radionuclides occur within geologically young sandstone mineralisation, as occurs in Australia, but the quality of groundwater down flow must not be assumed to be of similarly poor quality as natural attenuation processes in the aquifer can modify its composition.

The nature of the host sediments and ores constrains whether acid or alkaline solutions are used for leaching of uranium ores. The wellfield technology and design is determined by the leaching solution used and the need to keep the leaching solution within the mineralised zone.

The impact assessment process will decide on the best options for disposal of liquid wastes and radiation management. In general, liquid wastes should not be disposed of into aquifers for which the use category may be compromised, or where there are insufficient data to characterise the groundwater quality.

A mine closure, decommissioning and rehabilitation plan should come into effect as soon as practicable after the completion of mining in each area of the lease. The process of development and updating this plan will be iterative between the company and regulatory authorities. The underlying methodology is a ‘risk-based closure planning process’. The completion plan should summarise the progressive rehabilitation process and what measures will be taken for final rehabilitation. Best practice requires remediation of residual mining solutions to accelerate natural attenuation processes where the groundwater down flow from the orebody has potential uses, or the flow rates are high enough to allow residual mining solutions to migrate beyond the mining lease boundary.

Monitor wells should be installed around the perimeter of the wellfield and located so as to provide effective early warning of any excursions of mining solutions within the mining aquifer. Groundwater pressures and chemical monitoring should be conducted for all aquifers in the area to verify the integrity of confining strata above and below the mineralised aquifer.

For the regulator to relieve the company of its responsibilities for environmental management of the site after completion of mining, the groundwater should be returned to its pre-mining use category, or the proponent must establish that natural attenuation is progressing at a satisfactory rate.

Comprehensive guidance is provided on linking the principles and guidelines outlined to best practice planning and regulation of ISL mines.

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Comments on this DRAFT *National In Situ Leach Uranium Mining Best Practice Guide* may be submitted until 30 June 2009, by email to:
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National In Situ Leach Uranium Mining Best Practice Guide: Groundwaters, Wastes and Radiation Protection

1. Introduction

1.1 Australian Government Policy on Uranium Mining

While most mines are approved and regulated predominantly by State and Northern Territory authorities, approval of uranium mining proposals involves integrated consideration under both the federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and State/Territory legislation. The Australian Government also has interests in uranium arising from its international responsibilities, including in relation to export controls and nuclear safeguards. In general, the appropriate level of impact assessment of a proposed uranium project is agreed by the jurisdictions, based on preliminary information presented by the proponent to government authorities.

The Australian Government's policy is that new uranium projects will be approved subject to world best practice environmental and safety standards. However, 'world best practice' has not been defined in this context.

1.2 This guide

This draft guide for public comment was prepared by Geoscience Australia (GA)[1], with inputs from a Steering Group including officials from Australian, South Australian, West Australian and Northern Territory Government agencies[2], and with funding from the Australian Government Department of Resources, Energy and Tourism. It will be revised in July 2009 to take account of comments received from interested parties in Australia and international peer reviewers, before being submitted to Ministers.

The guide communicates the Australian Government's expectations for 'world best practice' in situ leach (ISL) mining (also known as in situ recovery, or ISR) for the benefit of regulators, proponents and other interested parties. It does this by setting out the principles for science-based, objective evaluations for new ISL mine proposals, with a view to:

- Greater certainty for governments, proponents and the community that ISL mining is meeting Australian Government policy on 'world best practice';
- Consistency in the assessment of ISL mine proposals within multiple government regulatory processes, through setting out the underpinning principles and approaches; and
- Increased certainty for proponents in preparing proposals for new ISL mines.

The general principles and approaches outlined are also consistent with those for uranium mining by traditional underground and open cut techniques.

In evaluating 'world best practice' for ISL mining, GA has drawn on first-hand knowledge of ISL uranium operations in Australia, the United States (US), Kazakhstan, China and the Czech Republic, and information from publications by the United Nations International Atomic Energy Agency (IAEA). In contrast with ISL operations elsewhere, Australia's existing and planned ISL

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[1] GA is delegated by the Minister under the *Atomic Energy Act* 1953 to obtain information from persons who have discovered uranium, including in relation to work carried out in connection with its production or use.

[2] The Steering Group comprised representatives of the Commonwealth Departments of Resources, Energy and Tourism (RET) and Environment, Water Resources, Heritage and the Arts (DEWHWA), the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), plus representatives of the government mining and environment regulatory agencies in South Australia – Primary Industries and Resources (PIRSA) and Environment Protection Agency (EPA), Western Australia – Department of Mines and Petroleum (DMP) and Department of Environment and Conservation (DEC) and the Northern Territory – Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR) and Department of Natural Resources, Environment, Arts and Sport (NRETAS).

projects occur in deeply weathered arid regions with relatively low relief, saline groundwaters and very low population densities.

This guide is designed to inform high level consideration of new ISL mining proposals and major changes to existing ISL operations[3] by providing information on best practice regulation principles and best practice approaches to planning, operation and mine closure.

The guide focuses on hydrogeology, waste disposal and radiation protection, which are the key issues for ISL mines, for proponents preparing a mining lease application and mining and rehabilitation program. The guidelines and approaches presented are consistent with the processes and expectations in the three jurisdictions where uranium mining is currently permitted – South Australia, Western Australia and the Northern Territory. They underpin more detailed regulatory documents, which have been or may be prepared by these jurisdictions to ensure applicability to ISL mining in their particular situations.

The introductory discussion covers what is meant by world best practice, the general principles for mining in Australia and general features of in situ leach uranium mining. The guide then covers, in order:

- Site characterisation and baseline environmental description;
- Description of the proposed mine operations; and
- Achieving best practice mining and regulation.

Australian regulatory agencies generally do not specify what technologies and approaches are to be used, in keeping with their focus on outcomes to be achieved, but a summary of technologies and practices that have been used internationally is provided in **Attachment 1** for completeness.

1.3 How is best practice defined?

'World best practice' does not amount to a universal template for ISL mining – it is dependent upon site-specific features, particularly the characteristics of groundwater in the mineralised aquifer system. For convenience, the term 'best practice' is used hereafter to encompass the sentiments of 'world best practice'. The widely used definition of this term in the *Best Practice Environmental Management in Mining* series published by Environment Australia in 2002 captures the essence of how it is generally understood in the context of protecting the environment:

> *Best practice can simply be explained as "the best way of doing things". Best practice environmental management in mining demands a continuing, integrated process through all phases of a resource project from the initial exploration to construction, operation and closure. It is based on a comprehensive and integrated approach to recognising, and avoiding or minimising, environmental impacts.*
>
> *……. best practice is not fixed in space or time. A best practice technique at one mine may not be suitable at a similar mine elsewhere……Continual improvement may be driven by changes in legislative requirements, public expectations, corporate thinking, or by development of new and improved technology.*

With regard to radiation protection in mining, States and Territories adopt the regulatory approach outlined in the *Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)* produced by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). This 'Mining Code' (**http://www.arpansa.gov.au/pubs/rps/rps9.pdf**) provides a standard regulatory approach, to be

[3] Where a field leach trial is proposed to evaluate the feasibility of an ISL operation, this will not be subject to the full process outlined here – but the proponent will need to provide enough information to satisfy relevant government authorities that the trial will be conducted without lasting environmental impact or risk of radiation exposure, and that the site should be rehabilitated immediately after the trials if mining does not proceed.

applied through inclusion in licence conditions, or directly through legislation, and it defines best practicable technology as:

> *That technology, from time to time relevant to a specific project, which enables radioactive waste or exposure to radiation to be managed so as to minimise radiological risks and detriment to people and the environment, having regard to:*
> *(a) the achievable levels of effluent control and the extent to which pollution and degradation of the environment is minimised or prevented in comparable mining operations elsewhere;*
> *(b) the cost of the application or adoption of that technology relative to the degree of radiological and environmental protection expected to be achieved by its application or adoption;*
> *(c) evidence of detriment or lack of detriment to the environment after the commencement of mining operations;*
> *(d) the location of the mine;*
> *(e) the age of the equipment and facilities in use for mining purposes and their relative effectiveness in achieving radiological and environmental protection; and*
> *(f) the potential long term hazards from the wastes.*

This reflects the IAEA’s principle that the magnitude of the individual radiation doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received, are all kept As Low As Reasonably Achievable (ALARA principle), taking account of economic and social factors.

1.4 Mining regulation

Regulation of all mines in Australia focuses on the outcomes to be achieved and is largely the responsibility of State/Northern Territory authorities. It is based on underpinning principles, rather than a fixed set of practices or particular technologies. This approach has proven to be effective for minimising long-term impacts. It is consistent with *Principles and Guidelines for National Standard Setting and Regulatory Action by Ministerial Councils and Standard-Setting Bodies* agreed by the Council of Australian Governments (COAG) in 1995, which endorsed a move away from overly prescriptive standards towards performance based standards, the desirability of avoiding duplication in the impact assessment procedures of different jurisdictions when national standards are set, the monitoring of the appropriateness of proposed national standards to ensure that they conform to accepted regulatory principles and the possible adoption of procedures to encourage compliance with national standards.

1.4.1 Broad principles in Australia

Best practice mining involves determining the operational and regulatory practices and procedures on the basis of a comprehensive characterisation of the geological and environmental setting. A social licence to operate requires that this process involve the proponent, the regulatory authorities and the public.

A full description of the mining operation is required to enable assessment of the potential impacts of the mining proposal having regard to the interests of relevant stakeholders. Approval and licensing depends on the proponent convincing government authorities that it has identified all of the potential environmental, social and economic risks and that its plans for mining, environmental management, radiation management, monitoring, mine closure and rehabilitation are best practice for mitigating these. This amounts to meeting the triple bottom line objectives of balancing environmental, social and economic objectives.

Best practice regulation is performance- or objective-based (focus on the outcomes to be achieved), rather than a prescriptive approach (focus on the control measures). This approach allows for more flexibility on the part of the mine operator, and will provide for increased trust by stakeholders through a clear demonstration that the environmental, social and economic impacts of the mining operation are being managed appropriately. It involves a continuing, integrated process from the planning to construction, operation, closure and rehabilitation.

Mining companies are responsible for achievement of agreed outcomes, and can be prosecuted for failure to do so. The environmental outcomes are set by the regulators through an iterative process involving the proponent and the public to identify all of the qualities and physical characteristics that are conducive to ecological health, public amenity and safety. Any impacts on "environmental values" are to be kept below agreed limits. Achieving this involves consideration of all potential risks, measured in terms of 'consequences' and 'likelihoods'.

Mining companies must meet minimum performance standards set by government regulators and are expected to pursue continual improvement throughout the life of a mine. Rigorous monitoring programs are required to demonstrate progress towards, and achievement of, outcomes. All decision making and performance assessments are to be transparent.

Governments should not be left with any liabilities after mining and processing have been completed. A rehabilitation security bond has to be lodged and reviewed regularly to reflect the full cost.
A series of practical booklets on different aspects of mining, based on these broad principles, has been produced under the "Leading Practice Sustainable Development Program for the Mining Industry" program [Leading_practice_booklets].

1.4.2 More prescriptive regulation in some other countries

Mining regulators in the US and some other countries have used more prescriptive approaches, focusing on prescribed control measures. These mean that mining companies focus on meeting the standards or using the specified technology, rather than seeking to achieve progressively better environmental performance.

For example, the US Environment Protection Agency uses a 'top-down' approach which has ranked all available control technologies in order of effectiveness: the most effective technology is considered as 'Best Available Control Technology' (BACT) unless the applicant can demonstrate that it is not achievable on the grounds of technical, energy, environmental or economic considerations, in which case the next most effective technology is considered.

This approach requires greater government resources as it puts more responsibility on government authorities to make the right decisions at the outset and for ongoing monitoring of performance.

1.5 Overview of ISL mining

ISL mining was developed independently in the 1970s in the USSR and the US for extracting uranium from sandstone type uranium deposits that were not suitable for open cut or underground mining. Many sandstone deposits are amenable to uranium extraction by ISL mining, which is now a well established technology that accounted for more than 27% of the world's uranium production in 2007. The basic requirement for ISL mining is that the mineralisation is located in water-saturated permeable sands confined between impermeable clay-rich strata.

Sandstone deposits are one of the most common styles of uranium mineralisation. This is because uranium is soluble in oxidised waters typical of the Earth's surface – weathering of naturally uranium-rich source rocks (particularly granites) can mobilise uranium into aquifers, where it precipitates under reducing conditions (**Figure 1**). In geologically young sandstone deposits, which are common in Australia, the mineralisation can be "dynamic" – migrating slowly down flow as oxidised waters continue to flow in the aquifer. This can involve migration of some daughter products in the aquifer at different rates to uranium – leading to disequilibrium between the uranium and its more radioactive daughter products.

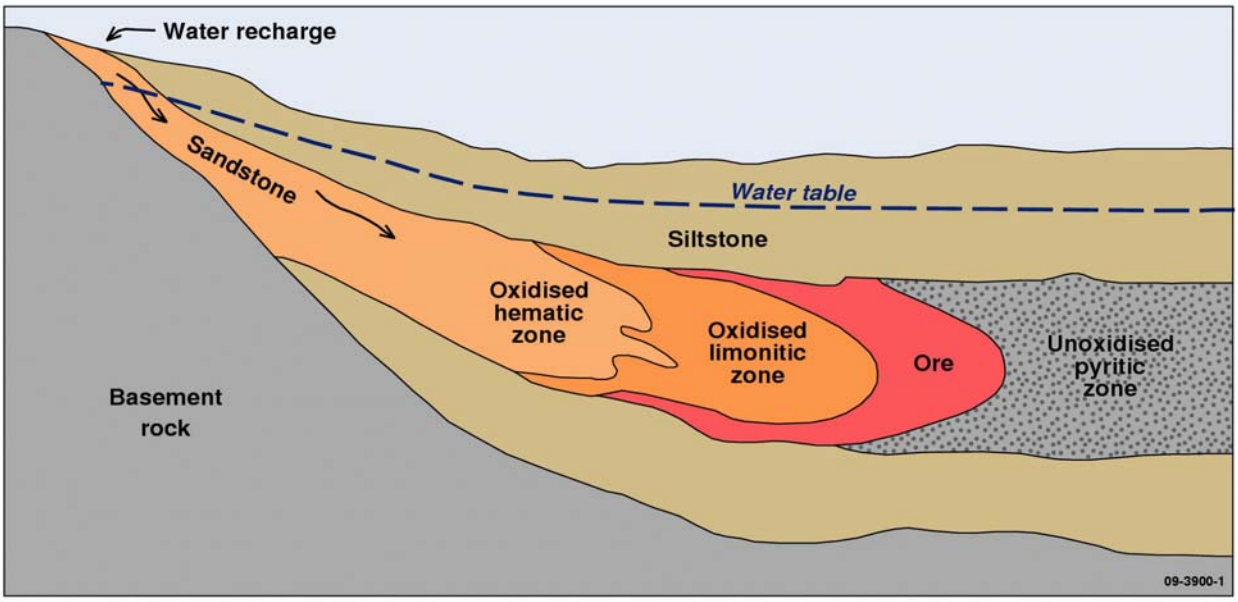


Figure 1. Diagrammatic cross-section of a roll front sandstone uranium deposit in a semi-regional/regional aquifer.

Since the 1970s, this method has been used for mining sandstone deposits in a number of eastern European and central Asian countries. Kazakhstan has had major ISL mines since the early 1990s, and currently dominates world ISL uranium production. In Australia, ISL mining experience is currently limited to Beverley mine, which commenced production in 2001[4].

Sandstone uranium mineralisation is typically low grade – commonly below 0.2% uranium oxide (U_3O_8) – and recoverability of the uranium by ISL is commonly 60-70%. This is comparable with recovery rates for conventional mining of ores with complex uranium mineralogy.

A schematic block diagram of an ISL uranium mine is shown in **Figure 2**. Uranium is extracted by means of a leaching solution (lixiviant) which is pumped down injection wells into the permeable mineralised zone. The uraniferous solution is recovered through nearby extraction wells, the uranium is stripped in a recovery plant and the mining solution is fortified and recycled.

ISL mining results in much less surface disturbance than conventional open cut or underground mining methods: it does not involve tailings, waste rock dumps, or open pits, and the uranium recovery plant is small and easily removed after completion of mining.

The best documented ISL mines have been in the US, mainly in Wyoming, Nebraska and south Texas. Currently several US companies are planning to develop new ISL projects. These US deposits formed in regional to semi-regional aquifers confined by impermeable units which inhibit leakage above and below (Figure 1). There is active flow of groundwaters downstream from the uranium mining areas, where they are used for livestock, crop irrigation and, in some cases, as potable water sources. The groundwaters have to be remediated to their original use category after mining and processing are completed.

The largest currently producing ISL uranium mines are in Kazakhstan, in two regional aquifers which flow from the mountainous uranium-rich source areas in the east towards the Aral Sea in the west. There is an ambitious program underway to increase the number of ISL uranium production centres. There have not been any regulatory requirements in Kazakhstan to

[4] The Honeymoon project in South Australia has been approved and is expected to commence production in 2010. The Four Mile project, near Beverley, is currently being assessed under the EPBC Act. Field leach trials have been approved for the Oban project, South Australia. Extensive alkaline leach trials were carried at the Manyingee deposit in Western Australia in 1986-7.

rehabilitate the aquifers, because natural attenuation is accelerated by minor amounts of carbonate minerals in the aquifer.

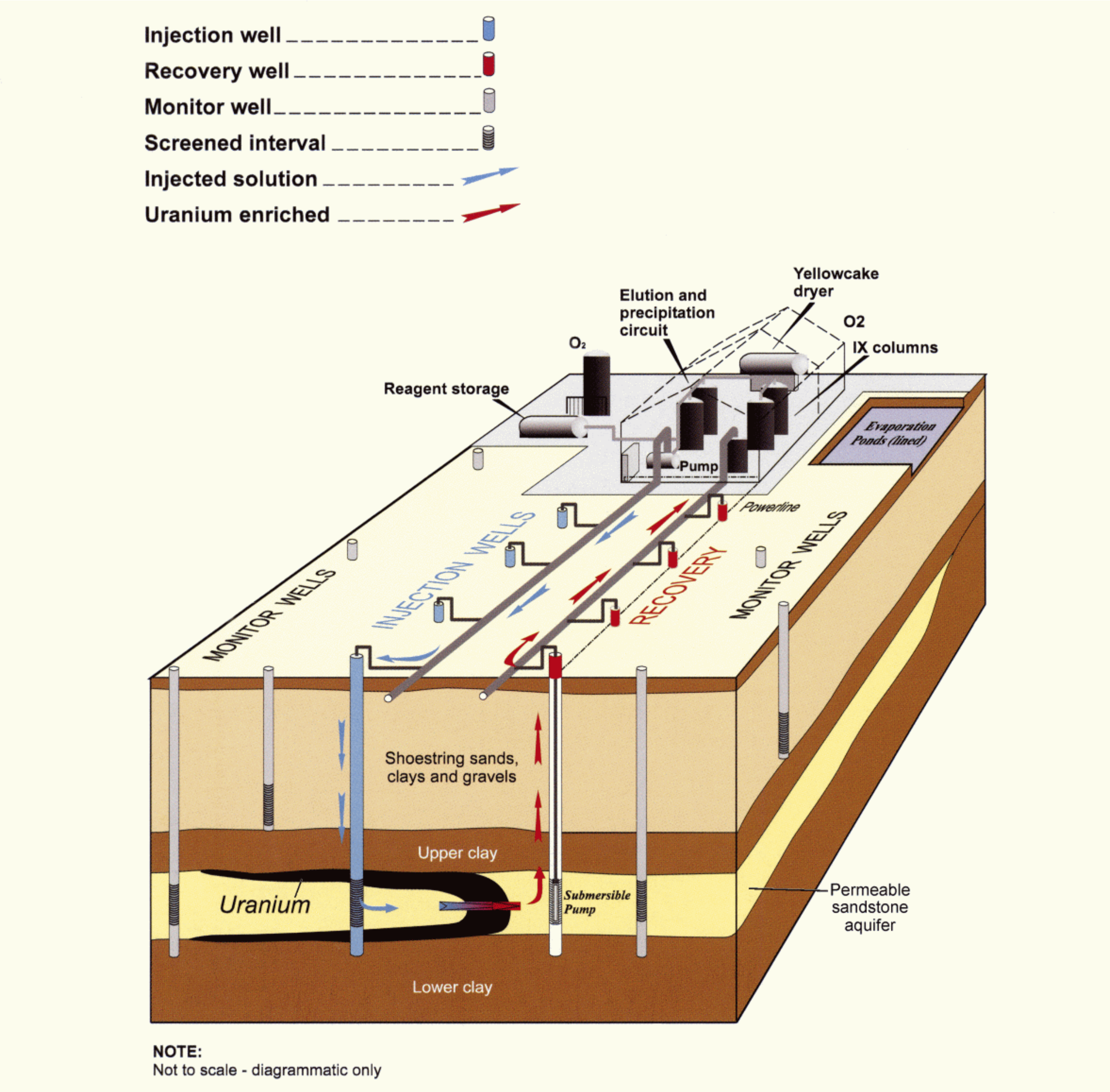


Figure 2. Schematic block diagram of in situ leach uranium mine, based on figure from the Beverley EIS (Heathgate, 1998).

In contrast, the uranium at Beverley (South Australia), occurs in sand lenses which are surrounded by impermeable clay-rich strata and contain naturally poor quality saline, radioactive and stagnant groundwater with no foreseeable use. There is no requirement to rehabilitate the Beverley aquifer.

2. Site characterisation and baseline environmental description

The basis for an informed decision on approval of an ISL project is a comprehensive characterisation of the geological and environmental setting, and the identification of environmental values. This requires collation and consideration of all relevant available data and, typically, gathering and analysing new data to fill gaps. A feasibility and environment assessment process involves the proponent, the regulatory authorities and the public.

2.1 Description of existing environment

The contents of proposals for an ISL mining project need to be aligned with jurisdictional guidelines. The following is an indicative list of topics in an ISL mining proposal required to provide full environmental baseline information:

- Geological and hydrogeological setting;
- Groundwater environmental values (as per national water management quality guidelines: (www.environment.gov.au/water/publications/quality/index.html#nwqmsguidelines) referred to as "use categories" hereafter to avoid confusion with the broader meaning for "environmental values" in this guide);
- Features indicating favourability for ISL mining, including:
    - uranium occurring in readily leachable form in highly permeable strata which are both saturated with groundwater and confined by impermeable strata above and below;
    - mineralogy of the aquifer as a determinant of whether acid or alkaline solutions will be the most effective for leaching the uranium;
- Other baseline features (including local community, land use, proximity to infrastructure, amenity, noise/dust/air quality, topography and landscape, climate, geohazards, groundwaters, vegetation/weeds, fauna, soils/subsoils, heritage, proximity to conservation areas, background geochemistry, pre-existing site disturbance/ contamination).

The baseline data presented – and the analyses and modelling undertaken on these data – must be adequate to enable detailed planning of the proposed mining operation and a decision as to whether the proposed mining, rehabilitation and monitoring plans constitute best practice for the site.

2.2 Hydrogeological aspects

As the main potential impacts of ISL mining in Australia are on aquifers, assessment of these potential impacts relies on a full understanding of hydrological/hydrogeological aspects of the proposed project, and of the current uses and values of the groundwater. These features constrain the nature of the mining solution; best option for uranium recovery; optimal well-field technology; extent and distribution of monitoring wells; options for disposal of liquid and solid wastes; and groundwater rehabilitation requirements.

Sufficient detailed information is required on the hydrological/hydrogeological aspects of the proposed project to enable understanding of the baseline groundwater characteristics and flow dynamics, and the likely response of the groundwater system of the proposed operation at both local (mining operation) and regional scales. This includes:

- Potentiometric surfaces, with sufficient data points showing locations of all wells used and their individual water elevations, and groundwater flow directions;
- Baseline groundwater hydrochemistry;
- Aquifer properties for each aquifer that may be affected by mining operations (for example, proposed mining aquifer, disposal aquifer, water supply aquifer):
    - Hydraulic conductivity, transmissivity, storage coefficient, total porosity, effective porosity, aquifer thickness;

    - Mineralogy of the mining aquifer and the chemical composition range for natural groundwaters in it;
- Hydrogeological characteristics of confining strata (hydraulic conductivity, thickness);
- Connectivity between the mining and disposal aquifers and lateral, overlying or underlying aquifers and surface water;
- Conceptualisation and numerical modelling of groundwater flow dynamics including recharge and discharge areas and processes;
- Identification of aquifer usage category and of values associated with groundwater systems including domestic/stock and irrigation/environmental/surface water recharge uses.

There will generally be naturally elevated concentrations of radionuclides in a mineralised zone, where most observations are made. The quality of groundwater down flow cannot be assumed to be of similarly poor quality, as natural processes may modify its composition as it flows in the aquifer.

3. Description of proposed mine operations

Best practice ISL uranium mining involves matching the operational and regulatory practices and procedures to the characteristics of a particular site.

A full description of the proposed operation is required to enable assessment of the potential impacts of the mining proposal having regard to the interests of relevant stakeholders. The description of the project should include the proposed area to be mined and the estimated ore reserves/mineral resources (under Joint Ore Reserves Committee Code), market and economic significance. Climate and topography have to be taken into account in siting of infrastructure, radioactive waste management planning, management of surface wastes and emissions, and site rehabilitation procedures. A Radiation Management Plan is to be developed consistent with the *Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing*.

A discussion follows of the important elements of the detailed description of proposed mining and uranium recovery operations, waste management and associated infrastructure.

3.1 ISL mining method

Depending on circumstances, leaching of uranium ores can be done with either acid or alkaline solutions. Best practice is a function of the composition of the host sediments and ores. As carbonate minerals neutralise acids, acid solutions are not used where there are significant concentrations of carbonate minerals – as an indication, ores containing more than a few percent calcite or dolomite require alkaline leaching. Acid leaching represents best practice where carbonate contents are low, as it results in lower volumes of reactant, faster rates of leaching, higher uranium recovery rates and minimisation of the amounts of oxidants required in the mining solution.

The uranium-bearing solutions are pumped to the surface where uranium is recovered by hydrometallurgical processing. Ion exchange technology is used to recover uranium from the mining solutions where the levels of soluble chloride salts in the groundwaters are low to moderate. Where the groundwaters in the mining aquifer have Total Dissolved Solid contents in excess of about 8,000 mg/litre, solvent extraction techniques are used because ion exchange resins are inefficient and uneconomic to use for highly saline waters.

The mining operation should protect the environmental values of groundwaters in the mined aquifer downstream of the lease boundary and in other aquifers in the area. All groundwaters must be maintained at their original use category as characterised in the current national water quality management strategy guidelines, unless otherwise agreed with stakeholders and endorsed by regulators.

The well field technology and design is determined by the leaching solution used and the grade and disposition of the mineralisation. The leaching solution must be constrained within the mineralised zone. All injection, recovery and monitoring wells are to be cased and grouted to ensure that mining solutions and groundwater do not move between aquifers. The wells must be constructed from materials that are inert to the leaching solution and strong enough to withstand injection pressures. Hydraulic pressure tests should be used to test for casing integrity and verify that it can withstand the pressures of the ISL pumping operations.

During operations, the volume of the extracted solutions should be slightly higher than the volume injected to ensure a net inflow of surrounding groundwater to minimise the risk of breaching impermeable strata and mining solution excursions. Relative aquifer pressures need to be maintained.

3.2 Liquid wastes

The liquid wastes arising from ISL mining are more acid, or alkaline (depending on the lixiviant), and more saline than the natural groundwaters. Both natural and waste waters contain radionuclides.

The liquid wastes are not to be disposed of in aquifers in which the use category may be compromised, or where there are insufficient data to characterise the groundwater quality. The impact assessment process will confirm the best option for disposal of liquid wastes from the three general disposal options available:

Option 1: Disposal of liquid wastes in deep aquifers where the groundwater is of poor quality (“no foreseeable use”), after evaporation of the wastes to minimise their volumes. This is best practice where suitable aquifers are available in the region; it minimises energy and water use, and production of solid wastes. This approach necessitates extensive characterisation of the disposal aquifers and adjoining hydrostratigraphic units to ensure waste will be contained.

Option 2: Injection of ISL liquid wastes into mined-out areas. This may be accepted as best practice where deep injection is not practicable and the use category of groundwater down flow from the mining activity will not be compromised in the long term, beyond the mining lease or a distance specified by the regulatory authorities. The regulatory authorities will consider the proponent’s predictions of natural attenuation (based on laboratory tests and modelling relevant to the particular site) in considering whether the waste waters should be treated before injection.

To ensure the integrity of the aquifers for the above options, there should be, as appropriate:

- Predictions of sustainable disposal volumes through review of hydrogeological data and modelling of the aquifer;
- Regular determination of the plume extent through groundwater monitoring and chemical analysis;
- Predictions of future disposal plume extent, based on hydrodynamic and hydrochemical modelling; and
- Continued monitoring following wellfield closure to confirm the progression of natural attenuation and the retention of the impacted aquifer water within the mining lease or agreed distance down flow.

Option 3: Surface evaporation of liquid wastes is the only option in cases where there is no deep, poor quality aquifer available, and disposal in the mining aquifer is not permitted by the regulatory authorities. It results in significant quantities of residual radioactive precipitates requiring near surface disposal on site (or at a registered radioactive waste facility off site), and associated radiological handling risks. This method generally will be very dependent on site specific factors and will involve significant regulatory input and strict controls.

All radioactive wastes and emissions including liquid wastes and mining solution excursions are to be managed in accordance with an approved Radioactive Waste Management Plan (RWMP) developed consistent with the *Code of Practice for Radiation Protection and Radioactive Waste*

Management in Mining and Mineral Processing. The RWMP and associated monitoring program should be aligned with the broader Environmental Management Plan for the mine.

3.3 Solid wastes

Solid radioactive wastes generated on an operational ISL mine site are classified as low level radioactive waste (LLRW) and can include used pipes, pumps, filters, contaminated soil and radioactive sludge removed from ponds. These wastes may be disposed of in a purpose built LLRW disposal facility (or disposed off-site if approved by the regulatory authority).

The location and construction of LLWR disposal facilities should be consistent with the general requirements of the *Code of Practice on Near Surface Disposal of Low Level Radioactive Waste* (National Health & Medical Research Council, 1991) and will be approved as part of a RWMP. The disposal facilities must be constructed and lined such that the risk of leachate from the waste is minimised, and located away from areas of possible erosion (as a minimum, above the 100 year flood plain) at a site that will not compromise future land use. Closure reports should be provided for each facility detailing the location and contents, confirmation of construction and monitoring.

3.4 Mine closure and rehabilitation

Mine closure planning should commence as early as possible in the planning stage of an ISL uranium mining project and the mine closure, decommissioning and rehabilitation plan should come into effect as soon as practicable after the completion of mining in each area of the lease. This process of development and updating these plans will be iterative between the company and regulatory authorities. The underlying methodology is a ‘risk-based closure planning process’. As it is expected that rehabilitation will commence soon after mining is completed in an area of the mine, the completion plan should summarise the progressive rehabilitation process and what measures will be taken for final rehabilitation.

It is in the best interests of all parties that the site is remediated as soon as practicable so that the regulator is in a position to relieve the operator of its responsibilities for environmental management of the site. In most cases, this requires that the groundwater either:

- Be returned to its pre-mining use category; or
- In the case of a pre-mining “no use” category, that natural attenuation be established to be progressing at a satisfactory rate.

The nature of the site-specific natural attenuation processes should be described – these result in gradual changes in the pH and chemical compositions of contaminated groundwater towards background values by hydrodynamic dispersion and physical-chemical reactions between the fluids and aquifer minerals. Attenuation should occur within the zone known to be of poor water quality – predictions of the rate and full extent of attenuation should be supported by laboratory tests and modelling.

Active remediation of the residual fluids in the mining aquifer may be required to supplement natural attenuation, where:

- Groundwater down flow from the mine meets the criteria for use as potable, irrigation, ecosystem support or stock water, so as to maintain its use category;
- The quality of the aquifer water downstream is not adequately established; or
- Natural attenuation is not progressing at a pace that will ensure the original use category of the mining aquifer can be restored in an agreed time frame.

There are some cases where natural groundwater in the mineralised aquifer is poor quality and stagnant (as at Beverley), or of extremely poor quality throughout (eg. very high salinity and high levels of dissolved radionuclides). In such cases, the regulatory authorities may decide that groundwater remediation is not required, because it would not provide tangible environmental benefits and would result in higher energy and water use, as well as much higher costs.

3.5 Groundwater monitoring

Predictive numerical modelling should be undertaken based on the calibrated model established as part of the baseline environmental description, to determine the likely movement of mining solution and the appropriate design of monitoring activities.

Monitor wells should be installed around the perimeter of the well field and located so as to provide effective early warning of unexpected excursions of mining solutions within the mining aquifer. Monitoring of groundwater pressures and chemical compositions should be conducted for all aquifers in the area to ensure the integrity of confining strata above and below the mineralised aquifer. The location, spacing and number of monitoring wells should be based on modelling.

Similarly, monitor wells are required to map the movement of any disposal liquids injected into aquifers and detect any unexpected migrations. Where necessary, monitor wells should be installed to detect seepages from surface storages and near surface disposal cells.

3.6 Liquid storage facilities

Reagents and process fluids should have double barrier containment with the ability to monitor and recover any losses from primary containers. The location of the facilities and the incorporated protective measures should be based on consideration of extreme weather events, bushfires, earthquakes and the underlying geology and location of environmental receptors.

3.7 Trunklines

All trunklines should have automatic pressure sensors to detect any leaks. The position of trunklines and bunds should minimise risks posed by creek crossings, roads, etc.

3.8 Reporting of spills and accidental releases

An approved process will be required for reporting to regulatory authorities and dealing with all spills and accidental releases of radioactive (or other) process materials, radioactive liquids or radioactive wastes. The requirements will be incorporated within the approved RWMP and be based on a risk assessment relating to the potential for unplanned radiation or other exposures to workers or members of the public and the potential for impacts on the receiving environment.

4. Achieving best practice mining and regulation

The remainder of this guide provides detailed guidance on what the proponent should take into account in proposing best practice for:

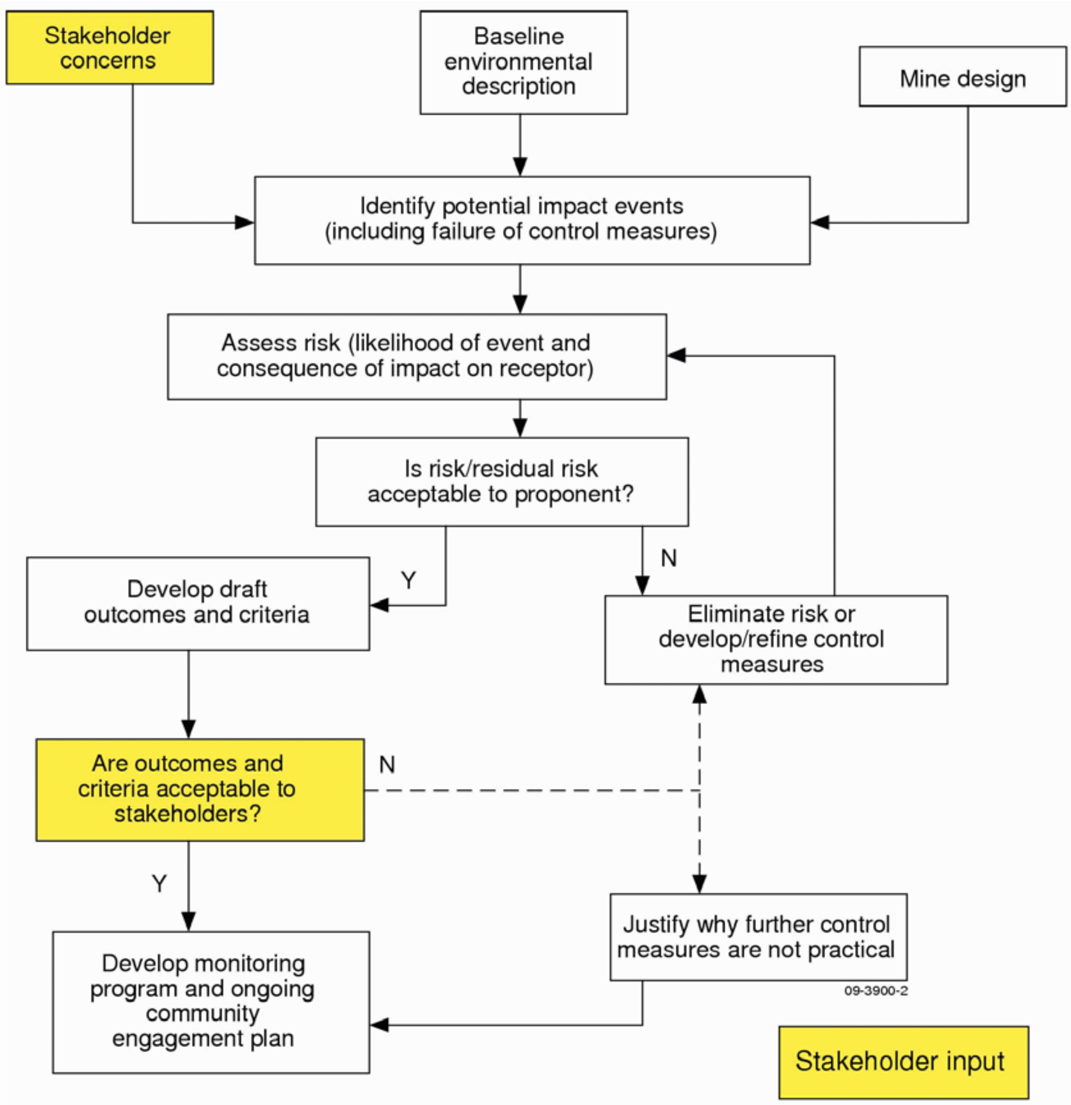
- Environmental impact assessment;
- Justification for mining methods and controls outlined in section 4.1.3 (eg active remediation vs. natural attenuation;
- Mine closure and rehabilitation; and
- Management systems and capability.

It links the principles and general guidelines above to best practice regulation of ISL mines, drawing in particular on Minerals Regulatory Guidelines MG2, prepared by Primary Industries and Resources, South Australia (www.minerals.pir.sa.gov.au).

4.1 Best practice environmental impact assessment

The ISL mining proposal should identify all of the environmental impacts or events that are likely to be created by the ISL mining operation. For each aspect identified, a management program should be developed setting out how each of the identified impacts will be managed.

The process to be followed, which is reflected in the structure of this section, is summarised in the flowchart below, which highlights stakeholder inputs.



The guidelines and process outlined below are considered best practice as they generally follow:

- Key elements of the 'planning' part of ISO 14001 Standard for environmental management systems (section 4.3 of the standard); and
- The process of identifying and assessing the significance of aspects in general follows the Australian and New Zealand standard for risk assessment (AS/NZS 4360:1999). HB203:2000 from Standards Australia also provides a clear guide to environmental risk assessment, and the application of AS/NZS 4360.

4.1.1 Potential impact/events

The proponent needs to identify and describe the actual and/or credible potential impact events associated with proposed mining activities that could pose a threat to the natural environment (including air quality, surface and underground water supplies, flora, fauna). For ISL mining, the key impact will be on potential changes to the use category of the mining and disposal aquifers.

Events associated with construction should be considered as well as events associated with operation of the mine, where these may differ, taking account of the particular complexity posed by environmental and social risk assessment, as opposed to conventional risk analysis, including as a result of:

- Paucity of data, for realistically estimating risk factors, and consequent issues of perceptions of risk by stakeholders;
- The potential long timeframes associated with environmental events;
- The inherent resilience of the natural environment to cope with impacts; and
- Potential for some impacts to be irreversible.

The impact event analysis should identify the source, pathway, barrier, receptor (human, fauna, flora etc.) and consequences (scope, ability to remediate, duration, cumulative effects etc.). The basis for the determination of these issues should be described in some detail.

The effect of impacts on the aquifer may be usefully demonstrated by the use of numerical modelling. If a model is constructed, this may also be used to demonstrate the effect of proposed control measures. The description of the model must clearly state the assumptions used to build the model, and evaluate the effects these assumptions (or alternative valid assumptions) may have on the conclusions reached.

4.1.2 Control and management strategies

A description of any proposed control and management strategies to reduce environmental impacts should be included. The strategies should implement best practice in mining and environmental management, they should be technically and economically achievable, and they should reflect progressive rehabilitation wherever possible.

The risk should be addressed using an accepted hierarchy of controls approach, applied in the following order:

- *Elimination.* Redesign so as to eliminate the risk;
- *Substitution.* Replace the material process with a less hazardous one;
- *Design engineering (physical) controls.* Install barriers to control the risk;
- *Management system (procedure) controls.* Manage the risk through procedures and the way the activity is conducted by personnel.

The description of the control strategies should clearly state if it is a design (physical) based measure or if it is a management system (procedure) based measure and how it avoids or reduces the likelihood of the event occurring or the consequences of an event, should it happen.

As noted in 4.2, the effect of control strategies may often be usefully demonstrated through numerical modelling, showing the effect of the impact after the control strategy has been implemented.

In order to determine the level of risk associated with various impact events, both the likelihood and severity of the consequences of impact events have to be separately considered. Risk should be evaluated and documented both before and after proposed control strategies have been taken into consideration, as follows:

- **Qualitative measure of likelihood.** The likelihood of each event occurring should be determined based on information such as past experience, known environmental data, and modelling data. The likelihood can be classified using a system such as follows, or another recognised risk assessment methodology.
- **Qualitative measure of consequences.** The consequences of each event occurring should be determined based on information such as the potential scale of the event, the range of stakeholders who may be affected, the duration of the event, and the difficulty in remediating the impact.

There should be an evaluation of the uncertainty of the final risk determination due to factors such as:

- Lack of data/knowledge of the environment, the event or the consequences on the receptor;
- Use of novel or innovative control measures;
- Natural climate variations.

Where appropriate, the potential for the risk to be greater than that stated should be documented.

4.1.3 Justification for acceptance of residual risk

There should be discussion of how the residual risks (i.e. after control measures have been implemented) associated with credible events will be managed to as low as reasonably achievable.

Where the risk has not been eliminated, the proponent will need to provide justification that the risk is such that:

- There are no practical control measures available, and the risk is considered acceptable given the benefits that will arise from the mining operation will outweigh the risk; or
- The cost of implementing further control measures is grossly excessive compared to the benefit obtained. In this case there should be included in this section a description and evaluation of these alternate control measures.

4.1.4 Environmental outcomes

A set of outcomes (with associated measurable assessment criteria) must be developed for each of the identified environmental impacts. These will be based on the residual risk and will indicate the expected impact on the environment caused by the proposed or current mining activities subsequent to control strategies being implemented.

The outcomes should be a commitment on the extent to which the ISL operation will limit impact on the environment. These outcomes should be reasonable and realistically achievable, acceptable to affected parties and meet other applicable legislative requirements, to maintain an amiable co-existence between interested parties.

The regulator will consider the extent to which the outcomes are acceptable to affected parties and balance these with the practicality of the alternative mining options when deciding to approve the outcomes.

Where the risk is such that specific control measures are required to eliminate it, there are strong public perceptions, or there is uncertainty in the risk level, reasonable and realistically achievable outcomes need to be proposed.

An outcome may not be needed if the risk can be demonstrated to be very low probability, or trivial in consequence, without the use of control measures.

Clear and measurable criteria should also be set to demonstrate the achievement of outcomes. The criteria should be described in specific terms that clearly define the achievement of the outcomes. They may be expressed in quantitative or qualitative terms, but the former are preferred (where practical).

The criteria should demonstrate clear and unambiguous achievement of the environmental outcomes by:

- Including the specific parameters to be measured and monitored;
- Specifying the locations where the parameters will be measured, or how these locations will be determined;
- Clearly stating the acceptable values for demonstrating achievement of the outcome, with consideration of any inherent errors of measurement;
- Specifying the frequency of monitoring; and
- Identifying what background or control data are to be used, or specifying how these will be acquired if necessary.

For example, a water quality criterion might mention the contaminants to be measured, and state the acceptable levels. If the outcome is to be measured against background levels, these must be already acquired, or if in relation to control points, provide a clear process about how this data will be acquired during operations.

Where appropriate, recognised industry standards, codes of practice or legislative provisions from other Acts can be used as criteria. The measurement criteria should drive development of the monitoring plan. All point-related criteria, such as water bores, sampling points and visual amenity photo points, should be included on a map and in a table of GPS locations of the points.

4.1.5 Leading indicator criteria

Where there is a high consequence event that relies significantly on a control strategy to reduce the risk, leading indicator criteria should be developed. This will include excursion monitoring for ISL mining fluids. These should give early warning if a control measure is failing and the outcome is potentially at risk of not being achieved. These may relate to the proposed control measures (e.g. audits of the management system), near misses, or trends in environmental data. Detection of unexpected results should lead to immediate action being taken.

The leading indicator criteria should be included in the monitoring plan.

4.1.6 Compliance monitoring plan

A company-driven monitoring program to measure the achievement of each outcome and the effectiveness of each strategy should be developed and implemented. This should not be reliant on the regulator’s inspections.

The monitoring program will be built from the outcome measurement criteria and leading indicator criteria identified in the previous sections. The monitoring program should describe in some detail:

- What will be measured, the accuracy of measurements if applicable and who will be responsible for them;
- Where will it be measured (including controls and baseline) and how;
- Frequency of measurement;
- Record keeping; and
- Frequency of reporting to management and external stakeholders.

4.2 Best practice mine closure and site rehabilitation

The elements of the Mine Closure and Rehabilitation Plan can be structured as follows:

4.2.1 Potential environmental, economic and social impacts of mine closure

The focus should be on issues that may remain after mine closure (e.g. contaminated land, contaminated aquifers) and should include a risk assessment.

4.2.2 Outcomes and completion criteria

For closure of an ISL mining site, the key issue will be demonstrating that the mining and disposal aquifers will ultimately revert to a stable condition consistent with pre-existing environmental values. The extent and location of monitoring required to demonstrate this will be determined on a case by case basis and dependent on the predictions of groundwater model of the aquifer after mining.

Outcomes and completion criteria for the site post mine closure should be stated. As a guide the following outcomes would normally be expected to be included as a minimum and must be demonstrated that they are likely to be achieved indefinitely after closure:

- The external visual amenity of the site is in accordance with the reasonable expectations of relevant stakeholders, including removal of all mine-related infrastructure (unless otherwise agreed with the landowner);
- The risks to the health and safety of the public and fauna are as low as reasonably practical;
- Ecosystem and landscape function is resilient, self-sustaining and indicating that the pre-mining ecosystem and landscape function will ultimately be achieved;
- The site is physically stable;

- There is no compromise of the quality and quantity of ground- and or surface-water to existing users and water dependent ecosystems;
- All waste materials left on site are chemically and physically stable;
- All other legislative requirements have been met.

Clear and measurable completion criteria should also be set to demonstrate the achievement of outcomes. These must be explicit and, as far as practical, quantifiable. The criteria will form the basis for relinquishment of the lease and the proponent should be careful in developing these so as to be confident of being able to meet the criterion stated. Where appropriate, recognised industry standards, codes of practice or legislative provisions from other Acts can be used as criteria. The measurement criteria should drive development of the completion monitoring plan.

4.2.3 Sustainable closure strategies

The mine closure and rehabilitation plan should:

1. Include a description of the proposed closure strategies to achieve stated closure outcomes, which should implement best practice in mining and environmental management, be technically and economically achievable and sustainable with minimal ongoing maintenance, and reflect progressive rehabilitation wherever possible;
2. Enable all stakeholders to have their interests considered;
3. Ensure that mine closure occurs in an orderly, cost-effective and timely manner;
4. Ensure the cost of rehabilitation is adequately represented in company accounts and that the community is not left with any liability;
5. Ensure there is clear accountability, and adequate resources for rehabilitation;
6. Establish a set of indicators which will demonstrate the successful completion of rehabilitation;
7. Reach a point where the company has met agreed completion criteria to the satisfaction of the regulating authority.

Closure strategies should avoid a reliance on ongoing maintenance or monitoring, and should be focused on stable physical measures. This is due to the difficulty in ensuring ongoing responsibility and adequate resources for the site in the long term once the operator has relinquished the mining lease. The effect of control strategies may often be usefully demonstrated through numerical modelling, showing the effect of the impact after the control strategy has been implemented.

After restoration of the aquifer to a satisfactory state, the surface must be rehabilitated by returning all lands disturbed by the mining project to at least their pre-mining land use.

All pumps and tubing are to be removed from the wells. Each well is to be plugged so as to protect aquifers, normally by filling from its base with an approved abandonment mud or cement slurry and placing a cement plug at the top.

All mine infrastructures must be decommissioned, decontaminated and removed, unless otherwise agreed with regulatory authorities.

The rehabilitated site must not present any significant radiation exposure risks.

4.2.4 Completion risk assessment

This should include consideration the risks of the proposed closure strategy failing. The risk analysis should follow the process outlined above. The risk analysis needs to consider that the timeframes are much longer than for the operating phase. For instance, 1 in 100 year rainfall events may be considered appropriate for assessing risks during the operational phase, but 1 in 1000 year events may be more appropriate for assessing the risk post mine closure.

Closure risks may include:

- Financial;
- Sudden closure due to market changes;

- Poor management of rehabilitation activities;
- Experimental or novel rehabilitation techniques;
- Ongoing maintenance requirements for protective structures;
- Unexpected or unusual climatic conditions;
- Changes in legislative requirements or community expectations (if the mine has a long life);
- Changes to surrounding land use; and
- Inadequate understanding of the existing environment and the impacts of the operations.

This section should also describe how these risks will be controlled (e.g. by contingency provisions in cost estimates, or by additional monitoring) and demonstrate that these risks have been managed to as low as reasonably practical.

In some cases, where there is significant reliance on engineered protective structures to reduce post-closure risks, an independent third party audit of the closure design and modelling may be required to demonstrate that the structure is likely to meet agreed outcomes.

4.2.5 Closure cost estimate

An estimate must be included of maximum third party rehabilitation and decommissioning costs at any time during the mine life in the mining and rehabilitation plan. Note the maximum liability may not be at mine closure, but may be very early in the mine life. A comprehensive spreadsheet type calculation model should be developed and included. The NSW Rehabilitation Cost Calculation tool can be used (www.dpi.nsw.gov.au). The model should include, where applicable:

- The decommissioning domain or component;
- An estimate of the area, volume, machinery type, personnel, material and/or time (as appropriate) as a measure of the rehabilitation effort required, and how these estimates were derived;
- The rehabilitation costs per unit of rehabilitation effort, and how these costs were derived (including a breakdown of all unit costs);
- Any costs for ongoing maintenance and management;
- Survey and design;
- Project management, administration (normally 10–25% of total costs);
- Provision for normal project variation (10–20%);
- Provision for contingency costs; and
- Allowance for inflation.

The cost should be calculated on the basis that a third party contractor would undertake the rehabilitation work. Unprocessed material and salvage costs should not be deducted due to the likelihood that as an unsecured creditor, the government would not be able to access these assets.

In some cases it may be desirable to avoid large up front bonds and in this case a staged bond schedule could be proposed that reflects the increasing liability as mining progresses, and gradually reduces the bond as rehabilitation progresses. If this option is chosen, the staging frequency can be no more than annual, and the stages must reflect the maximum liability at any time during the forward year.

There will always be some financial risk associated with uncertainty in estimating rehabilitation and closure costs, and contingency costs are a critical element of the closure cost estimate. Key risks are:

- Residual risk;
- The potential to underestimate the costs or effort required to rehabilitate;
- Planned rehabilitation may fail (and hence will require further effort or redesign to achieve the agreed outcomes);
- Sudden (unplanned) closure; and
- Temporary closure (care and maintenance).

The closure plan must document closure cost uncertainty. The cost estimates determined may be used to calculate and set an appropriate bond for the operation.

The proponent should also describe in the mining and rehabilitation plan how provision will be made in the company's accounts for the rehabilitation liability, how this liability will be reviewed during the life of the project, and how the liability will be provided for as the mine progresses to ensure that sufficient funds are left at mine close to fully fund rehabilitation.

4.3. Best practice management systems and capability

The mine operator should demonstrate that they have the capability to operate the ISL mine in a manner that ensures public safety and protection of the environment broadly following elements found in quality management systems standards. Some operators may already have quality management systems in place equivalent to these requirements and hence should have no difficulty in providing adequate documentation to demonstrate that they have the appropriate capability.

The regulator will not be approving the management system, but wants confidence that the operator has in place sufficient systems to ensure compliance. The regulator will use this information to assess the risk of non-compliance by the mine operator and to plan surveillance activities.

Ideally, there should be evidence of a good long-term compliance record for similar operations. If not, at least the recent record should show good or improving compliance. As a minimum, experience should be provided for managing this type of operation anywhere in Australia or elsewhere, and in operating in this particular type of environment. If there is no record for the operator or lessee, the use of an experienced contractor or staff with a good record may give confidence that regulatory objectives will be achieved.

4.4 Public disclosure of documents

Best practice regulation also involves full and immediate public disclosure of key documentation associated with regulation of ISL mining. This should include:

- Mining proposal documentation, including all relevant baseline environmental data;
- Company responses to public consultation on proposals;
- Regulator assessment reports including reasons for the decisions, and approval conditions;
- Company, regulator or independent third party reports on compliance, including all raw monitoring data used to support demonstration of compliance;
- Incident reports (eg spills); and
- Compliance actions taken by the regulator.

Attachment 1: Summary of ISL technologies and practices used internationally

This attachment provides general information on the various technologies and practices that have been used at ISL operations around the world. These are supplied for information, without intending to imply that they constitute world best practice where used.

A1.1 Well-field technology

The installation of wells is an important component of the development of an ISL production facility. Wells are cased holes which are required for injecting and recovering leaching solutions, for sampling solutions which contain uranium, for monitoring the leaching solutions in the production zone and for preventing environmental contamination.

Modern ISL operations worldwide use corrosion-resistant PVC casing for all injection and extraction wells. This is important for operations using acid leach technologies (eg, Beverley Australia and Kazakhstan). Cement is poured between the casing and walls of the hole over the entire length of the well. The wells are constructed to completely seal off the overlying sediments and aquifer from the mining activities and liquid wastes. To check their integrity, wells are pressure tested during installation by subjecting them to hydraulic pressures which are much higher than operating pressures. Furthermore the operation of the well-fields at Beverley are controlled and operated by state-of-the-art process management systems which provide best practice operational controls.

At the US and Kazakhstan operations, and Beverley, well-fields are maintained in a low hydraulic pressure by pumping out slightly more than is re-injected to minimise the risk of leach fluids migrating away from the well-field and to ensure maximum recovery of uranium-bearing solution from the well-field. If monitoring shows that there are excursions, then this level of imbalance is increased.

A1.2 Leaching technologies

Depending on circumstances, in situ leaching of uranium ores can be done with either acid (sulphuric, nitric and/or hydrochloric acids) or alkaline (sodium carbonate, sodium bicarbonate, ammonium carbonate and ammonium bicarbonate) solutions. In most ISL operations, the acid and alkaline leaching solutions are used with an oxidising agent, commonly hydrogen peroxide, oxygen gas, ferric ion and/or hypochlorite. The exceptions are operations in Kazakhstan which do not use an oxidising agent because of the chemistry of the sands which host the deposits. Best practice is determined by the composition of the host sediments and ores, reagent consumption, the degree of uranium recovery and the intensity of the leach process. The uranium-bearing solutions are pumped to the surface where uranium is recovered by hydrometallurgical processing (ion exchange or solvent extraction).

The most important factor determining whether acid or alkaline leaches are used is the composition of the mineralised aquifer, and in particular, the proportion of calcium carbonate, which neutralises the acid. Where the carbonate content is low (up to about 2% CO2 , or ~4% calcium carbonate), sulphuric acid leaching has several advantages over alkaline leaching – these advantages include: lower volume of reactant required, faster rates of leaching, higher uranium recovery rates and minimisation of the amounts of oxidants required if sufficient natural ferric ion (Fe^{3+}) is available. Acid leaching requires the use of corrosion-resistant pipelines and pumping equipment which are more costly than normal pipeline equipment. Sulphuric acid leaching results in the formation of sulphate salts in the groundwater – however their migration is limited by the neutralisation of the acid and also by chemical processes related to natural attenuation of groundwaters within sand aquifers.

Ores with higher than 2% CO_2, as is the case for most western US sandstone deposits, generally require alkaline leaching. Alkaline leaching introduces radium salts (radioactive) to the groundwaters and these salts can migrate for considerable distances in weakly alkaline solutions. Acid leaching does not introduce radium salts to the groundwaters.

A1.3 Management of liquid wastes

The ISL mining industry uses various disposal methods for liquid waste streams, including deep-well injection, evaporation ponds, land application (irrigation), and surface discharge. These disposal methods are used in various combinations for waste streams from leach activities and aquifer restoration activities.

Deep-well Injection

Deep-well injection is commonly used by ISL mining companies in the US for disposal of liquid wastes. Abandoned oil wells are used where these are close to the uranium mining operations. For some projects, deep wells were drilled specifically for disposal of wastes into saline aquifers. These wells range from 1000 m to more than 3000 m deep, and are completed in a sandstone sequence containing non-potable ground water. The sandstone units into which the wastes are injected are generally more than 1000 m below any usable aquifer. An acceptable stratigraphic unit for disposal would contain a deep, confined aquifer with poor quality ground water averaging more than 10,000 mg/L total dissolved solids. Brine concentrates produced by reverse osmosis treatment of waste waters are usually injected into these wells.

Mining companies in the US must hold a permit for deep well injection which is granted by the State Department of Environmental Quality or the US Environmental Protection Agency. The injection pressures and flow rates used must not exceed the allowable limits for the well as stated in the permit.

Evaporation Ponds

The most commonly used water disposal technique at ISL operations is evaporation from ponds. This is the most conservative technique because it concentrates and maintains all the salts as brine that is then disposed of at a licensed disposal site. The use of evaporation ponds is the most costly method of disposal. The ponds must be lined, usually with a double liner, and equipped with leak detection systems. In addition, it is costly to handle (harvest) and transport the resulting salts and sludges.

The area of evaporation ponds is determined by the rate of evaporation and consequently by the climatic conditions, and also by the uranium production rate. Evaporation ponds in colder climates are much larger and may be more than 40 hectare in area. Large sprays have been used to enhance the rate of evaporation.

Where the ISL operation uses ground waters with high levels of dissolved solids, significant quantities of salt and sludges accumulate from the evaporation, which must be disposed of.

Land Application

Land application is a disposal technique that uses agricultural irrigation equipment to broadcast waste water over a relatively large area of land. Uranium and radium must be removed from these waters by reverse osmosis or radium co-precipitation before disposing of water onto a licensed land application area. This disposal method is not commonly used because of the strict monitoring requirements and potential for build-up of salts within the soils, and effects on native plant growth.

Surface Discharge

Surface discharge has only been used for disposal of treated water (permeate) from aquifer restoration activities in the US. Surface discharge requires authorisation by the US Environmental Protection Agency (National Pollution Discharge Elimination System permit) or the State regulatory authorities. Generally, radionuclides in waste water for disposal must be below limits set by regulations.

Precipitation of solids

At the ISL operations in Kazakhstan, liquid wastes are derived mainly from the washing of ion exchange resins to remove the uranium from these resins. Waste liquids are pumped to ‘slime pits’ where the dissolved solids and any residual uranium are precipitated. The liquids are then filtered, neutralised and returned to the processing plant for re-use. The precipitates remaining in the pits are dried and this so-called ‘cake’ is buried in surface disposal sites.

A1.4 Waste water treatment methods

Waste waters from leach operations and aquifer restoration activities in the US are treated to remove radium and to concentrate salts and contaminants into a small volume of concentrated waste which is then disposed of by deep-well injection or at a surface waste disposal site. Treatment of waste water is important where mining companies have to acquire the rights to, and pay for the water consumed and discharged by the ISL operations. The project costs will be lowered if the volume of waste water is reduced by treatment. Further, treatment allows the clean water to be released with minimal impact on the environment.

Precipitation of Radium

Radium can be removed using barium chloride treatment. Barium and radium precipitate as an insoluble salt by combining with sulphate already in the processing solution. Additional flocculent may be added to enhance precipitation and settling. Precipitation of radium can be carried out in retention ponds or in holding vessels inside the processing plants. This treatment method lowers radium concentrations in water below the limits set by the regulatory authorities for surface discharge. The water quality is analysed regularly to check the levels of radium and other salts before discharge.

Radium-contaminated sludge resulting from water treatment is disposed of on site or transported to a licensed waste disposal facility.

Reverse Osmosis

Reverse osmosis is a water treatment technique that splits a waste water stream, purifying one portion of the stream, and concentrating contaminants in the other. The process works by pumping waste water under high pressure through low-permeability membranes. Water molecules can pass through the membrane, while most dissolved and suspended chemicals cannot. The water passing through is referred to as ‘permeate’. The chemical constituents become increasingly concentrated in the portion of the water that does not pass through the membranes. The result is a large volume of clean water, and a much smaller volume of concentrated brine. Reverse osmosis typically concentrates contaminants in approximately one-third of a water stream, while purifying the remaining two-thirds. The permeate can be released onto land application areas or evaporated and the solid wastes disposed of on site.

Brine Concentration

Brine resulting from reverse osmosis water treatment can be processed again through a sophisticated water distiller known as a brine concentrator. A brine concentrator heats and evaporates the waste brine, then condenses the water vapour as pure water. The highly concentrated brine would largely consist of precipitated salts.

The brines and sludge are held in a lined retention pond and kept moist enough to prevent salts becoming airborne due to winds. The remaining larger volume of purified water can then be released without adverse environmental impacts. Ultimately, solid wastes are disposed of by shallow burial on site, or transported off-site to a licensed radioactive waste disposal facility.

A1.5 Groundwater remediation

Groundwater remediation practices adopted by ISL uranium operations in most countries are determined by:

- i) requirements imposed by government regulatory agencies,
- ii) geochemistry of the host sands and groundwaters; and
- iii) whether acid or alkaline leach techniques are used.

Legislation in the US and Czech Republic requires that the water quality in the affected aquifer be restored to its pre-mining use category (ie. potable water, irrigation, stock water). In the US, the aquifers in question are either potable or stock water quality and once ISL mining has ceased, regulatory agencies require the operator to commence aquifer restoration (cleaning of the groundwater) to restore the groundwater to its original category of use. It is recognised by regulatory agencies that not all chemical parameters can be returned to baseline values; however the overall water quality of the aquifer after restoration has been completed must be such that the water can be used for the same purposes as before mining. For example if the water was suitable for stock watering before ISL mining, then it must be suitable for stock watering after restoration is complete. As part of the environmental impact statement before approvals are granted, mine operators in the US are required to carry out groundwater studies to determine the pre-mining water quality of the aquifer.

Regulations governing ISL mining in the US require: well-field monitoring and control during operations to prevent fluid excursions, as well as restoration of the mining aquifers to their pre-mining category. This means, for example, that where ground water was originally of stock water quality, the post-mining aquifer has to have a composition that can differ from the original but it must be within the allowable concentration limits for a wide range of elements as specified for stock water quality. The ground water aquifers which host most of the former, current and planned ISL mines contain good quality water with very low levels of dissolved solids (usually less than 500 parts per million (ppm) total dissolved solids). Most of these aquifers are classified as ‘drinking water’ quality by the State regulatory authorities (e.g. Department of Environment Quality in Wyoming and Nebraska). For some ISL operations in South Texas the aquifer is used outside the mining permit area to supply water to small towns and ranches.

State government regulations in the US require that at the end of mining operations, the company must restore the ground water in the aquifer to its pre-mining quality. Restoration requires pumping large volumes of water from the aquifer and purifying the water by reverse osmosis (RO) treatment. The clean water from the RO plant (permeate) is then re-injected into the aquifer. Restoration activity usually extends over a period of several years. Brine concentrates from the RO plant are disposed of separately via deep disposal wells or at licensed waste disposal sites.

For the large ISL operations in Kazakhstan and Uzbekistan, there are no regulatory requirements for groundwater remediation even for cases where the good quality groundwaters downstream from the mining areas are used by local communities for stock watering (cf. discussion in Natural Attenuation section, below).

ISL uranium operations in the US and Czech Republic use a combination of several methods to rehabilitate groundwater including groundwater sweep, clean water injection and natural attenuation.

Groundwater sweep techniques

To comply with stringent environmental regulations, ISL companies in the US have developed groundwater sweep techniques to accelerate the natural attenuation process. Groundwater sweep (or washing with formation waters) involves pumping contaminated groundwater out at selected wells in the centre of the mining area. As a result, natural groundwater (uncontaminated) from outside the mining area is drawn towards the pumping wells, displacing contaminated water ahead of it. Better quality water may be injected into wells around the perimeter of the contaminated area – this clean water displaces the residual mining solutions as they are removed during the groundwater sweep. The clean water may come from:

- a reverse osmosis water treatment plant,
- groundwater from a new mining area being brought into ISL operations – this may be exchanged with contaminated water from the area being rehabilitated.

In some US operations the waste water from groundwater sweep is treated with barium chloride to precipitate radionuclides and the resultant clean water may be approved for use in agricultural purposes. At operations in Wyoming, the water is evaporated and resulting brines are disposed of in deep disposal wells – in some cases into abandoned oil reservoirs. It is important to note that groundwater sweep and reverse osmosis techniques produce large quantities of wastes (concentrated brines or low radioactive salts) which must be disposed of safely on site.

Chemical reductant

If pre-mining water quality cannot be restored by groundwater sweep and reverse osmosis, (e.g. Smith Ranch ISL mine, Wyoming) then a chemical reductant may be injected into the aquifer to create reducing conditions which will immobilise the remaining contaminants. Adding a reductant to the contaminated zone will expedite the return of the zone to natural conditions and will precipitate some of the metals that were solubilised during the leaching operations.

The chemical reductants used include: gaseous hydrogen sulphide (H_2S), dilute solutions of sodium hydrosulphide (NaHS) or sodium sulphide (Na_2S). Dissolved metal compounds that are precipitated by these reductants include uranium, arsenic, molybdenum, selenium, and vanadium. These may be present in concentrations above baseline levels at the completion of mining. The reductant is normally introduced during the latter stages of groundwater restoration. In some cases it increases the level of total dissolved solids in the restored groundwaters. If gaseous hydrogen sulphide is chosen for use, a program for safe handling in the workplace must be prepared and approved by the regulatory authorities.

Demonstration of stability of groundwater chemistry

When routine sampling of the groundwaters indicates that restoration has been achieved, the operator is required to routinely sample and monitor a number of wells for an agreed period of time to show that the groundwater chemistry has stabilised. During this stability demonstration period, the critical chemical components of the groundwater are measured and analysed from these wells. When the sampling data indicate that the contaminated area has been stabilised, a report documenting this is lodged with the regulatory agencies along with a request for certification of restoration.

Natural attenuation

The concept of groundwater rehabilitation by natural attenuation has gained increasing acceptance during the past decade as a technique for groundwater remediation. Natural attenuation is the process whereby groundwater which has been altered by the addition of leach solutions or liquid waste, reverts towards its pre-contaminated state over a period of time by reaction with the surrounding sands and pre-existing groundwater, without the addition of chemical reagents (that accelerate the attenuation processes). During natural attenuation processes, the pH and levels of dissolved solids in a plume of contaminated groundwater (or residual mining fluids) are gradually returned to natural values by hydrodynamic dispersion and physical-chemical reactions between the fluids and host sands. The overall rate and effectiveness of natural attenuation depend on the acid neutralising capability of the host rock, the ion exchange characteristics of clay minerals, and the hydraulic gradient of the aquifer.

The best evidence for natural attenuation comes from recent studies of the groundwaters from old abandoned ISL operations at the Kanzhugan deposit, Kazakhstan. During the early 1980's, acid leaching was used to extract uranium from a flowing aquifer. Away from the areas of ISL operations, groundwater from the aquifer is used by small communities for potable and stock water. Operations ceased in parts of the Kanzhugan deposit more than 15 years ago and groundwater remediation was not undertaken. Extensive monitoring and groundwater analyses have been carried out in recent years by Kazatomprom (state-owned mining corporation) in conjunction with modelling studies. These analyses have shown that groundwater rehabilitation by natural attenuation is progressing in the old mining zones particularly in areas where fresh groundwater flows into these areas. The carbonate contents of the aquifers, while not high, are sufficient to neutralise the acid solutions quite rapidly.