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Land and Water

## Review of Environmental Impacts of the Acid In-situ Leach Uranium Mining Process

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CSIRO Land and Water Client Report  
August 2004

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**Cover Photograph:**

Description: Well field at the Beverley ISL Uranium Mine operated by Heathgate Resources, South Australia, December 2003.

Photographer: Peter Woods, Parsons Brinckerhoff

Note: All other photographs within the document, unless stated otherwise were taken by Peter Woods during the inspections of mines, December 2003.

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Members of the Steering Committee for providing reference material and advice throughout the review.

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## EXECUTIVE SUMMARY

In response to claims that acid in-situ leaching (ISL) mining of uranium in South Australia and disposal of wastes will contaminate groundwaters, the State Government requested the EPA to conduct an independent review of the environmental impacts of the mining process. CSIRO Land and Water was commissioned to conduct the Review.

The Review consisted of visits to the operations at Beverley and Honeymoon, a study of company and government documents, literature review, preparation of a Background Document, consultation with the community including a public meeting and receipt of written submissions, and liaison with the Steering Committee. This Report explains the process, details the findings and recommends further action. Some submissions addressed issues beyond the scope of the Review and were not considered.

During the period of the Review, only the Beverley mine was operational, with Honeymoon on a care and maintenance basis. Many of the observations and conclusions are therefore applicable to Beverley only.

Overall, the process of ISL mining of uranium has considerably less environmental impact than other conventional mining techniques. Both sites, which are remote from urban areas and occur in semi-arid pastoral country, have relatively small surface footprints, are environmentally conscious and have initiated some world's best practice techniques. Both sites are considered to be compliant with the many Acts, Codes of Practice and Regulations.

The use of acid rather than alkaline leaching and disposal of liquid wastes by re-injection into the aquifer is contentious. Available data indicate that both the leach solution and liquid waste have greater concentrations of soluble ions than does the pre-mining groundwater. However as this groundwater has no apparent beneficial use other than by the mining industry, this method of disposal is preferable to surface disposal. Although not yet proven, it is widely believed and accepted that natural attenuation will result in the contaminated water chemistry returning to pre-mining conditions within a timeframe of over several years to decades.

As a result of this Review, it is recommended that acid ISL mining of uranium and re-injection of liquid wastes into the aquifer be allowed to continue subject to monitoring showing that there are no excursions of leach solution or waste liquids into other aquifers. A comparison of aerated and non-aerated sampling data is warranted to validate existing monitoring data and assess trends towards natural attenuation. Other minor recommendations are made, none of which precludes continued acid ISL mining of uranium in South Australia.

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# 1 INTRODUCTION

## 1.1 Background and Scope of Review

Uranium mining is a contentious issue that draws much attention from the community. With previous Commonwealth and State Government decisions to permit uranium mining, it is important to ensure that the environmental risks associated with it are clearly understood and managed appropriately. It is equally important to work with the community to ensure they understand both the risks and the management processes that are in place to avoid these risks.

In Australia, although both current and abandoned open-cut and underground uranium mines occur in South Australia, Queensland and the Northern Territory, in-situ leaching (ISL) of uranium is presently conducted only in South Australia.

In response to claims that ISL and disposal of wastes will contaminate groundwaters, the Rann Labor Government announced that the South Australian Environment Protection Authority (EPA) would conduct an independent review of the environmental impact of the acid ISL uranium mining process. In November 2003, after going through a tendering process, the EPA on behalf of the Minister for Environment and Conservation commissioned CSIRO Land and Water to conduct the review.

As indicated in the tender specification provided by the EPA, the specific objective was to conduct a review of the acid ISL mining process with regard to:

- Its environmental impact, with particular regard to:
  - Hydrogeology, groundwater management and impacts on aquifers.
  - The management of process liquids, spill response and clean up.
  - Surface disturbance, including vegetation clearance.
  - Waste management, recovery and disposal (both liquid and solid).
  - Issues relating to rehabilitation on cessation of operations (including aquifer and surface rehabilitation).
- International experience with its practical application.
- Its current application in South Australia, including whether there are more appropriate leaching techniques for extraction of uranium from the ore.
- How existing proposals and operations in SA may be improved to reduce any risk to the environment.

## 1.2 Review Methodology and Team

The review comprised the following steps:

- Investigation; including site visits, access to company and government documents, literature review and input from specialists.
- Consultation; including preparation of a Background Document (February 2004), followed by a public meeting (4 March 2004) and receipt and assessment of written submissions.
- Preparation of a draft report for review by the Steering Committee, and finalisation and submission of the report.



The EPA established a Steering Committee to select the consultant, act as a reference group throughout the review, and to provide comment on the final report. Their terms of reference is provided in the Appendices.

The review team comprised the following key personnel and their expertise relevant to the review:

<i>Team Member</i>	<i>Affiliation</i>	<i>Expertise</i>
Robert Molloy	CSIRO Land and Water	Project Management
Graham Taylor*	CSIRO Land and Water	Mining environmental management and rehabilitation
Vic Farrington*	Parsons Brinckerhoff	Environmental management - mining and minerals processing
Peter Woods*	Parsons Brinckerhoff	Hydrogeology of mining and minerals processing projects
Robert Ring*	Australian Nuclear Science and Technology Organisation (ANSTO)	Chemical engineer - minerals processing and ISL technology
Kath Moore	Kath Moore and Associates	Community consultation
Barbara Radcliffe	Parsons Brinckerhoff	Environmental auditing
Greg Davis	CSIRO Land and Water	Groundwater remediation
Grant Douglas*	CSIRO Land and Water	Geology/geochemistry
Peter Franzmann	CSIRO Land and Water	Biogeotechnology
Martin Houchin*	CSIRO Minerals	Hydrometallurgy - minerals processing

\* Each of these team members has previous experience with uranium mining and/or associated research funded by companies involved in uranium mining.

### 1.3 Matters Beyond Scope of the Review

Members of the public and organisations have expressed a number of issues and concerns in regard to mining and uranium mining in particular, the nuclear power cycle, nuclear waste disposal and possible diversion of nuclear materials for weapons purposes. However, this review is specifically directed at the environmental impacts of acid ISL in South Australia, and there are a number of matters that are beyond the scope. These include:

- The use of uranium in power generation and associated issues including waste disposal.
- Native Title issues.
- Extent of availability of company information to the public.
- Legislative matters – e.g. the issue of exemptions for uranium wastes in the *Environmental Protection Act 1993 (SA)*.
- Comment on national / international standards and codes.
- Uranium mining in Australia including at Olympic Dam.

Some of the submissions received, addressed one or more of these issues. Although acknowledging their importance, these issues are not discussed in this report.

## 1.4 Consultation

The EPA assumed responsibility for public announcements related to this review, including:

- Announcing the Review (10 October 2003)
- Notice for Public Meeting and call for submissions (Adelaide Advertiser, 25 February and 3 March 2004)
- Extending Submissions to April 8 (Adelaide Advertiser, 20 March 2004)

A public meeting was held on Thursday 4 March 2004, in the auditorium of the South Australian Research and Development Institute, Urrbrae. There were 46 attendees, the majority of whom were members of the industry, government agencies, peak bodies and consultants. The purpose of the meeting was to:

- Provide background information about the review and also the consultation process
- Provide a summary of the project tasks that have been undertaken as part of the review
- Present some specialist views on the ISL uranium mining process including its different environmental impacts
- Provide an opportunity to answer questions through a panel of specialists put together for this purpose
- Seek comments on any issues about the acid ISL uranium mining process which attendees at the meeting thought needed to be addressed as part of the review
- Provide some information on “where to” from here i.e. next steps in the review process

Meeting participants were advised that comments, issues and questions about the acid ISL process that were raised on the night would be documented and provided to the project team for further consideration, as part of the review process.

There were a total of 28 written submissions to the EPA, which were passed to the Review Team. Of these 20 were received prior to the release of the Background Document (February 2004), and the other 8 were forwarded after the close of submissions (up to 20 April 2004).

## 1.5 Structure of the Report

The remainder of this first part of the report addresses the ISL process, how it is applied in South Australia, approvals and previous assessments, acid versus alkali leach and alternative mining techniques.

In the second part of report, the application of ISL uranium mining in South Australia is reviewed. It is assessed in relation to the scope and environmental issues identified: in the brief, in submissions and public comments received, and in the Senate Inquiry (2003). Based on this assessment, recommendations are made to improve the environmental management of ISL uranium mining in South Australia.

## 2 THE IN-SITU LEACH PROCESS

### 2.1 Outline of In-situ Mining

In-situ leach (ISL) mining, also known as solution mining, involves leaving the orebody where it is in the ground (in-situ), and using recycled liquids which are pumped through it to recover the metals from the ore by leaching.

For ISL to be an applicable technology, the orebody needs to be permeable to the liquids used, and should be located so that these liquids do not contaminate groundwater away from the orebody. The general term for a rock or sediment layer saturated with water, and through which water may easily pass, is an aquifer. An orebody may occupy only part of its hosting aquifer.

Uranium deposits suitable for ISL occur in permeable sand or sandstones, preferably confined above and below by impermeable layers (called aquitards), and which are below the water table. There are two established operating regimes for ISL mining of uranium, determined by the geology, groundwater and environmental requirements.

In general, if there is significant carbonate in the orebody (typically as limestone), alkaline (carbonate) leaching is more effective. Otherwise, as with the two South Australian examples, acid leaching is more efficient. Other considerations, particularly environmental aspects, must also be taken into account (details in later sections).

An ISL uranium mine comprises the following:

- A pattern of injection wells that inject leach solution into the aquifer orebody zone, and recovery wells used to pump out the leachate with dissolved uranium together with a suite of metals and metalloids usually associated with uranium mineralization as well as a range of elements derived from leaching of the host rock. The leachate comprises natural groundwater conditioned with acid or alkali, usually an oxidising agent (oxidant), and other reagents if required.
- Slightly more water is extracted than is injected, to keep the leaching solution in the vicinity of the orebody by drawing in a small amount of excess groundwater.
- Pipes to and from the injection and recovery wells equipped with a header system, and main trunk lines to and from the processing plant.
- A processing plant in which the uranium is extracted from the leachate. The resulting barren solution is then conditioned with additional reagents as necessary, ready for re-injection. The leach solution is thus continually recycled.
- A series of monitoring wells around each wellfield.
- Facilities for the handling and disposal of liquid and solid wastes. These will generally include storage/evaporation ponds and disposal wells, where excess solution is re-injected into the same aquifer system away from areas being actively mined, or in some overseas examples into a different aquifer containing water of poor quality.
- Spill confinement infrastructure.

Figure 1 shows a typical ISL wellfield operation, and Figure 2 is a flow sheet of the generalised minerals processing operations associated with an ISL acid operation. The minerals processing plant is usually located within close proximity to the wellfield, although with intermediate processing, the wellfield and minerals processing operation can be some kilometres apart.

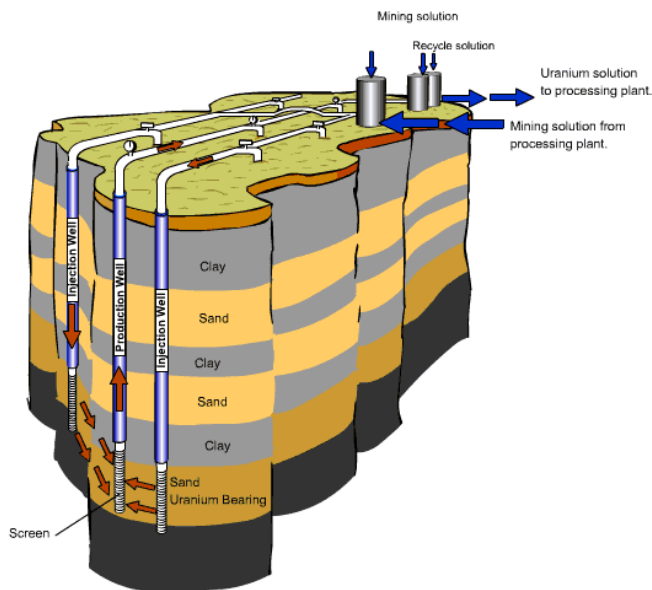


Figure 1 In-Situ Leaching – typical wellfield operation (Source: Uranium SA website)

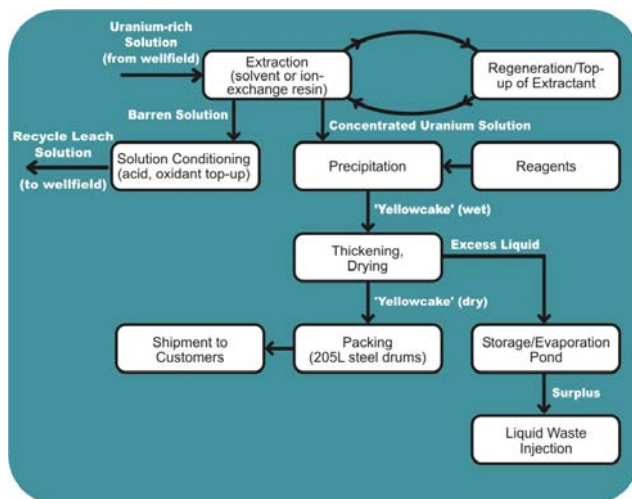


Figure 2 Process chart showing steps in recovery of Uranium

## 2.2 Application of ISL in South Australia

There are two acid ISL uranium mining projects in South Australia. These are:

- The Beverley project, owned by Heathgate Resources Pty. Ltd., which is licensed to produce 1500 tonnes per annum of uranium oxide equivalent (Customs Prohibited Exports Regulations – Permission to Export Natural Uranium). Production commenced November 2000. The 2003 production was 717 tonnes uranium oxide.
- The Honeymoon project, owned by Southern Cross Resources Australia Pty Ltd, for which trials are completed and approvals have been received (other than a production licence from the SA EPA, which is yet to be sought). The demonstration plant used for the trials is on care and maintenance status. The approved production is 1,000 tonnes per annum of uranium oxide equivalent.

The Beverley and Honeymoon uranium deposits are located in the arid Lake Frome region of South Australia, as shown in Figure 3.

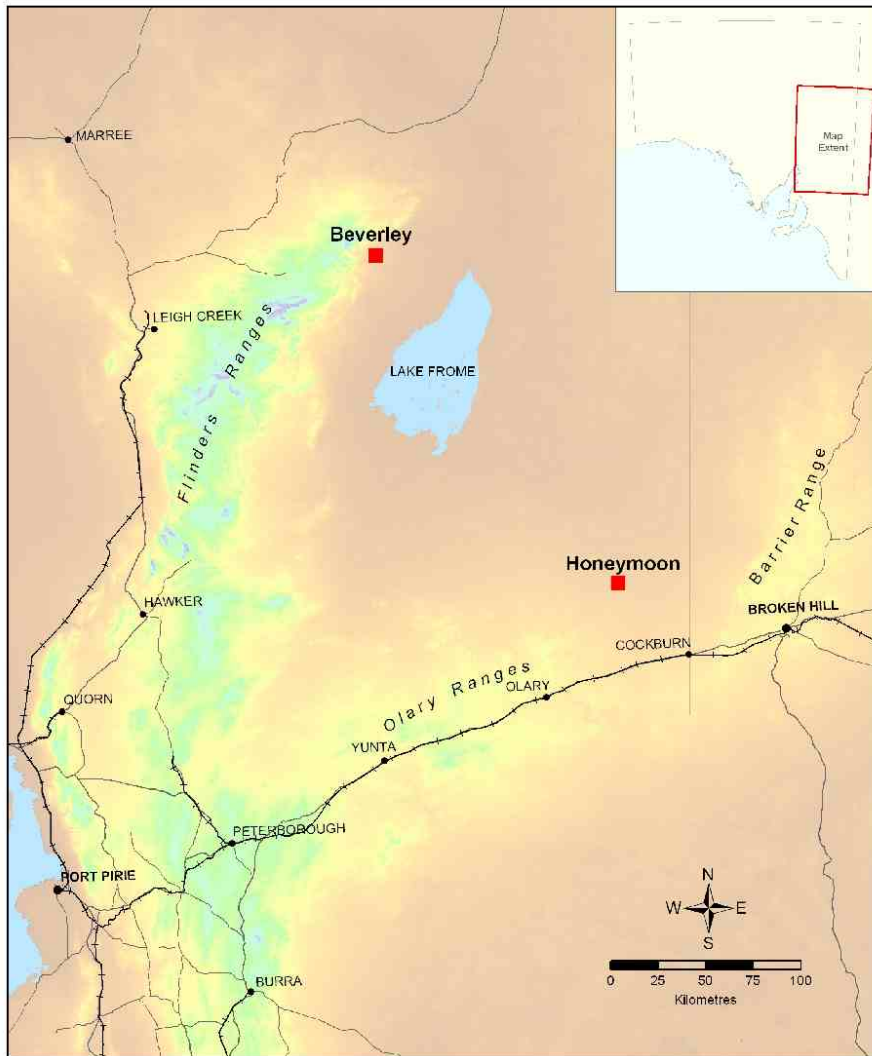


Figure 3 Locations of the Beverley and Honeymoon projects (Source: Parsons Brinckerhoff)

The key features of the Beverley landscape are:

- The location is between the Northern Flinders Ranges and Lake Frome (Figure 3).
- The area comprises flat, partly consolidated Tertiary sediments.
- Groundwater is brackish with a salinity of 3,000-12,000 mg/L.
- Climate is arid.
- No permanent water courses are present.
- Soils are brown cracking clay type with gibber and gilgai patterning, and alluvial soils in watercourse areas.
- Flora is perennial Mitchell grassland with bassias and other low plants, with some shrubland / woodland.
- Introduced flora / fauna species are present on the site and throughout the region.
- The area is remote and sparsely populated.

Figure 4 shows a photograph of the Beverley landscape with the Flinders Ranges in the background, and Figure 5 shows an active extraction wellfield.

The key features of the Honeymoon landscape are:

- The location is between the Olary/Barrier Ranges and Lake Frome (Figure 3).
- The area comprises gently undulating Tertiary sediments.
- The groundwater is of high salinity 10,000-20,000 mg/L.
- The climate is arid.
- No permanent water courses are present.
- Soils are brown calcareous earths with irregular clay pans and alluvial soils in some areas.
- Flora comprises saltbush, bluebush and poverty bush, with some shrubland, woodland and random canegrass swamps.
- Introduced flora / fauna species are present on the site and throughout the region.
- The area is remote and sparsely populated.

Figure 6 shows an aerial view of the Honeymoon site, showing the demonstration plant at the centre of the picture, the office area to the left, the holding / evaporation pond to the right, the wellhead control shed in the foreground and the camp at the rear. Figure 7 shows a photograph of the Honeymoon landscape, taken in December 2003, including wells that formed part of the early extraction trials at the site. Natural rehabilitation of the disturbed areas is evident.



*Figure 4 Beverley landscape with Flinders Ranges in the background*



*Figure 5 Active extraction wellfield at Beverley*



*Figure 6 Aerial view of the Honeymoon operation (courtesy Southern Cross Resources)*



*Figure 7 Honeymoon landscape including wells that formed part of the early extraction trials*

## 2.3 Previous Assessment/Approval Processes/Research

The following assessment, approval and investigation processes have been undertaken into the acid ISL projects in South Australia:

### *Assessments and Approvals*

- Both the Beverley and Honeymoon projects were approved under full State / Commonwealth environmental impact assessment processes, including preparation of a Draft Environmental Impact Statement (EIS), and Supplement Response to comments made on the Draft EIS. A further supporting document on the Beverley Water Quality Databases was also prepared.
- Both operations also sought and obtained approval for Field Leach Trials during the EIS preparation to provide additional operational and environmental data on which to plan the project.
- Honeymoon – further studies following the EIS included characterisation of the Yarramba Palaeochannel (July 2001). A copy is provided in the EIS Assessment Report (Planning SA, November 2001).

### *Reviews (one-off and selected routine audits)*

- An independent review of incident reporting procedures for the SA uranium mining industry was conducted in 2002 – (Hedley Bachmann, August 2002).
- A Senate Committee Inquiry into the Regulation of the Ranger, Jabiluka, Beverley and Honeymoon uranium mines reported in October 2003.
- Beverley – Jan-Feb 2002 - EPA Review into the cause of and action as a result of a spill on January 11, 2002.
- SA Government Task Group report into activities and operations at the Beverley Mine May 2002; independent audit of the EMMP in January 2002; and PIRSA audit in January 2003.
- Following a 60,000L spill, Heathgate conducted a HazOp (hazard and operability) Study in 2002. As a result, 73 action items were implemented within 12 months.

## 2.4 Acid versus Alkali Leach

Both sulfuric acid and alkaline (carbonate) leaching have been and are used in ISL projects internationally. For both acid and alkaline processes, uranium is recovered from the leach solution by an ion exchange and precipitation route.

The main criteria for choosing between acid or alkaline leaching reagent are:

- Composition of the host rock and the ore.
- Reagent cost and consumption.
- Uranium recovery and the leaching intensity (residence time, uranium concentration in recovered solution).
- Environmental considerations (eg aquifer quality).

Usually, the most important factor is the concentration of calcium carbonate in the ore zone. For economic leaching using sulfuric acid, the carbonate content should be less than 1.5 – 2%. Ores containing higher carbonate concentrations would normally require alkaline leaching.

The relative features of the acid and alkaline technologies are compared in Table 1. From a process perspective, acid leaching has the advantage of achieving a higher extraction of uranium in a shorter period, and this is why acid leaching is, in fact, used almost exclusively to treat uranium ore in conventional mills.

The potential environmental impacts of the two leaching systems will, to a great extent, depend on the local circumstances, e.g. pre-mining groundwater quality and use. Acid leaching results in the dissolution of greater quantities of gangue minerals, but the migration of the dissolved ions is limited by the eventual natural neutralisation of the acid and other natural attenuation processes. Alkaline leaching introduces fewer ions into solution, however dissolved ions can migrate for long distances in the alkaline media, if restoration processes were not applied following completion of mining.

*Table 1 Relative Features of Acid and Alkaline In-situ Leaching*

<i>Acid leaching</i>	<i>Alkaline Leaching</i>
Acid leaching achieves a high uranium extraction, typically 70-90%.	Extraction from alkaline leaching is low(er), typically 60-70%.
Acid leaching yields faster dissolution of uranium, requiring 40 to 70 pore volumes.	Slower kinetics of uranium dissolution. Alkaline leaching requires typically more pore volumes than acid leaching.
Increased concentration of dissolved solids (TDS) in recycled leach solutions (10-25 g/L).	Insignificant increase in groundwater TDS
High acid consumption for carbonate-bearing ores.	Potential to treat ores containing high levels of carbonate.
Mandatory use of corrosion resistant equipment and pipelines.	Common material and equipment can be used.
Addition of oxidant not always required because of presence of iron in recycled solutions.	Addition of oxidant always required.
Possibility of recovering by-products.	Leaching chemistry is very selective for uranium.
Additional processing on surface may be required to produce contaminant "free" product.	Product solution from ion exchange should produce product of required quality.
Risk of deterioration of permeability due to chemical and gaseous plugging.	Formation of carbonate or sulfate precipitates also a concern that can lead to plugging of formation.
Restoration to baseline levels requires an extended treatment period. Such restoration has only been demonstrated at one pilot site <sup>1</sup> .	Restoration of water to pre-mining baseline water quality has been demonstrated for some sites.
Seepage beyond bore field is unlikely due to formation of chemical precipitates that reduce porosity, and given natural attenuation due to reaction of contaminants with adjacent barren rock and unaffected groundwater.	Potential for residual solutions to spread beyond the contours of areas being treated.

<sup>1</sup> Note, for many acid ISL sites, restoration to pre-mining water quality has not been a requirement, because of the poor quality of the pre-mining groundwater.



## 2.5 International ISL Practice

ISL mining technology for uranium was independently developed in the former USSR and the USA in the early 1960s, but they used similar engineering and technical approaches. The acid leach system was almost exclusively adopted in the USSR, while in the USA all commercial operations used a carbonate-based alkaline system (there is a report of one small commercial acid operation, which operated from 1963 -1969 (IAEA 1993)). In the following decades, ISL technology for uranium was applied in Bulgaria, Ukraine, Czechoslovakia, the German Democratic Republic and China, and more recently in Australia.

### 2.5.1 Acid ISL uranium mining

The first USSR field tests of acid ISL were at deposits in the Ukraine and in Uzbekistan in 1962. The results from these tests were sufficiently encouraging that other deposits planned for conventional mining were re-designed for ISL mining and ISL was also applied to newly discovered deposits (IAEA 2001).

Testing and developing of the ISL technique was carried out on a group of large roll-front deposits in Uzbekistan and Kazakhstan. In these first few years of research development and implementation, it was found that successful operation of ISL technology required an attentive and creative approach because of the unique and variable characteristics of each uranium deposit (IAEA 2001).

ISL has been applied to common low-grade ores containing 0.03-0.05% Uranium. Common practice has mainly used sulfuric acid leaching at a concentration of 2-5 g/L. However, an initial concentration of 15 – 25 g/L is generally used to accelerate oxidation and reduce the ore preparation period. Depending on the nature of the deposit, an oxidant is not always required. Oxidants in use include hydrogen peroxide, nitrate ions and sodium chlorate. Acid consumption is typically 5-6 kg/tonne, but up to 10-15 kg/tonne of rock mass. Overall recovery is typically 65-80% of the in-the-ground resource.

The comparative merits of acid and alkaline leaching described in Section 2.4 were identified primarily by a comparison of performance with the extensive experience from the acid operations. Table 2 presents a summary of “recent” acid ISL applications for uranium outside of USA and Australia. This information has been taken from the Red Book (OECD 2002) and does not include some of the earlier Soviet era operations and the many pilot scale or production tests sites. Some of these earlier operations are summarised by Mudd (2001b).

The detailed experience and understanding developed in the former USSR is described in a recent IAEA (2001) publication, which provides many insights related to planning, operation and closure of acid ISL uranium mining facilities. This comprehensive and detailed publication describes six techniques that have been applied to achieve restoration.

1. Cleaning by precipitation with reagents
2. Cleaning via electrical adsorption technology
3. Cleaning solutions by compressed air
4. Washing with formation water
5. Method of natural attenuation
6. Method of accelerating groundwater natural attenuation

Technique 6 involves the passage of solution through rocks untouched by leaching, compared to Technique 5, which takes place within the limits of the allocated mining area. Depending on the area to be cleaned (and properties of the rock), Technique 6 can produce clean water in a few months to 2-3 years. By comparison, Technique 5 was said to require generally tens, sometimes hundreds, of years.

Table 2 Acid ISL Operations for uranium outside of USA and Australia

Country	Name of Operation	Grade (%U)	Start	Finished	Nominal capacity (t U/year)	Total production <sup>2</sup> (t U)
<b>China</b>	Kujeertai/Yili basin		1993	-	200	
<b>Czech Republic</b>	Straz	0.03	1967	1998	250	15,500
<b>Former GDR</b>	Konigstein <sup>1</sup>					5,400
<b>Kazakhstan</b>	Tsentranloe	0.063	1982		1000	
	Stepnoye	0.042	1978		1000	
	No. 6 Mining Co.	0.086	1985		600	30,000 <sup>#</sup>
	Katko	0.064	2001		700	
	Inkay	0.063	2001		700	
<b>Russia</b>	Sanarskoye		1968	1980		440
	Dalmatovskoe		2002 ?		700	
	Khiagda		2005			
<b>Uzbekistan</b>	Eastern Mining Div.		1977	1994		
	Northern Mining Div.		1964		3,000 <sup>#</sup>	42,000 <sup>#</sup>
Southern Mining Div.	Sabyrsaji		1966			
	Ketmenchi					
	Shark					
	Ulus					
Mining Div. No. 5	North Bukinai		1968			
	South Bukinai					
	Beshkak					
	Lyavlyakan					

<sup>1</sup> Underground block leaching

<sup>2</sup> Figures are approximate (to 2001)

<sup>#</sup> For all operations in country

## 2.5.2 Environmental considerations

Acid ISL mining can result in significant groundwater contamination when used in an inappropriate location (OECD/NEA 1999) or when projects are not well planned or correctly operated (IAEA 2001). Groundwater restoration following acid leaching is generally considered to be more difficult to achieve than after alkaline leaching.

In most countries an environmental impact assessment is now a fundamental and essential part of the planning of any new uranium (or any mining) production operation. ISL and conventional mining operations should not be started without giving appropriate consideration for environmental consequences.

While ISL technology has environmental and safety advantages when projects are well planned and operated (Underhill 1998), there are several acid ISL operations that have been developed and operated with little or no consideration for the environment. The conditions at these sites are a direct consequence of the Soviet-era operation of uranium mines without effective management of environmental aspects of production, without restoration of contaminated areas, much less planning and design for reclamation and long-term containment of wastes. Similar operating conditions without effective pollution control and closure concepts were apparent at uranium sites in other centrally planned economies such as East Germany, Czechoslovakia and Hungary prior to 1990.

Mining operations without well-controlled environmental protection or closure plans were also common in the US and other western countries before the wave of environmental awareness and implementation of environmental regulation and standards in the 1970s. This was the case for many conventional uranium mines in North America that were frequently abandoned at the end of mine life without proper decommissioning. Most of these sites have been or are being rehabilitated under the UMTRA program (Chung 1995).

The environmental consequences from acid ISL operations under the Soviet-era are significant and a component of the many environmental problems from this era, the majority of which were from mine water/groundwater/tailings/waste rock arising from underground and open cut mines. It is noted that as many of the environmental problems were related to the governance and institutional arrangements of the era, direct comparison with practices in Australia cannot be made.

### **2.5.3 Legacy Issues from Acid ISL**

It is important to examine the examples of ISL projects that have not met acceptable standards to better understand the fundamental reasons behind these outcomes, the extent of the environmental impact and whether there is any evidence of a basic shortcoming in the acid ISL technique. Two such projects that were developed with little consideration for the environment were at Konigstein, in Germany (strictly a block leaching operation and which is not comparable with either Beverley or Honeymoon operations) and Straz, in the Czech Republic. In each case, acid ISL was used in populated areas where drinking water aquifers were present in the immediate vicinity of the site. These operations required the initiation of groundwater clean-up projects, each with estimated costs of about US\$1 billion (OECD 2002).

At Konigstein, acid solutions have been confined to the mining areas, but there is potential for pollution of the nearby Elbe River if the mining area is flooded. At Konigstein, underground leaching was undertaken by injection of sulfuric acid solution (2 g/L) into discrete mining blocks, which varied in size from 100 x 100 m up to 300 x 500 m, with a height up to 25 m. Each block was leached for 4 - 6 years by percolation of acid from a higher mining level, through the ore, into collecting drifts below. The average grade was 530 ppm, as U<sub>3</sub>O<sub>8</sub>.

At Straz, both conventional deep mining and acid ISL leaching were used. The extensive development of both mining methods in a relatively small area resulted in compounding detrimental impacts. In addition, appropriate measures for minimising environmental impact did not accompany the developments. ISL mining was extensively used for more than 20 years in an area exceeding 600 hectares. As a result, 186 million m<sup>3</sup> of groundwater in an area of 25 km<sup>2</sup> was contaminated. One area of contamination is located outside the limits of the leaching fields (OECD/NEA 1999).

At Straz, the situation was exacerbated by the intensive use of chemicals and inadequate casing of wells, which allowed secondary contamination of an upper aquifer containing potable water (OECD/NEA 1999). The technical problems with these developments were partly recognised at the time, but proposed controls were not implemented in time to contain the groundwater contamination. The course of the developments was shaped by political pressure and collective irresponsibility (Fiedler and Slezak 1993).

### **2.5.4 Environmental impacts/restoration experience from relevant operations**

#### *Kazakhstan*

Uranium was initially produced in open-pit and underground mines and because of the low ore grade, significant quantities of radioactive tailings were produced (Fyodorov 2002). To avoid the problems associated with such wastes, a concerted effort has been made to develop a uranium production industry based on acid ISL of suitable deposits. As the need for some form of aquifer

remediation is seen as important for future development and expansion, extensive monitoring and investigation has been undertaken on a number of existing sites to provide data for licensing of new projects.

Fyodorov (2002), reported on an investigation being carried out in co-operation with the IAEA, aimed at providing data to determine whether it is permissible to leave ISL-treated aquifers to natural restorative processes rather than treating by other methods. Kazakhstan laws require reclamation of the aquifer to pre-leach conditions after ISL treatment, and this is reported to have been achieved at some sites in 2-3 years, at a significant cost. The facts that the waters are unsuitable for use, and data from test sites had indicated a decrease in the acid solution halo over the relatively short time frame of 6 years, led to the investigation.

Yazikov and Zabaznov (2002) reported that based on 12 years of data following completion of leaching at the Irkol site, natural attenuation appeared to have effectively reduced the impact on groundwater at the site, as well as keeping contaminated fluids from moving more than a few hundred metres from the wellfield. Similar trends were observed for the Yuzhny deposit, but rates of natural attenuation were slower. Another source reports that natural attenuation results in chemical conditions in the mine area returned to near pre-mine conditions within 15 to 20 years (IAEA 2001).

The only “negative” aspect of the slow rate of natural attenuation was the tens of years required to return to the baseline chemical condition. This drawback led to testing of a method in which solution was pumped from the initial areas of ISL wellfields to adjacent areas of unoxidised rocks. These tests showed that liquor circulation through unoxidised rock was the most effective method of natural attenuation, ensuring total groundwater restoration within a relatively short period of time, i.e. from a few months to two to three years.

Work in Kazakhstan has also identified the potential role that sulfate-reducing bacteria can play in groundwater remediation. Laboratory and well-field tests have demonstrated that sulfate reducing bacteria decreased the sulfate contents of leach solutions from 10 to 0.5 g/L. At the Karamurun deposit, the content of sulfate was reduced from 5.4 to 2.7 g/L over a few months (Yazikov and Zabaznov 2002). Use of bacteria in restoration has also been reported by Weixing (2002), Fazlullin and Boitsov (2002) and IAEA (2001).

### *Uzbekistan*

The Navoi Mining and Metallurgical Combinat (NMMC) has produced uranium by all mining methods, but since 1994, acid ISL has been the sole method used. Grutsynov (2002) reported that this change produced significant environmental advantages, including a substantial reduction in radiation dose to workers.

NMMC has carried out studies on radioactive contamination at the surface of ISL sites. Even where significant spillage has taken place, contamination levels are equal to the background at a depth of 30-40 cm, because of the high sorption capacity of the upper layers (OECD/NEA 1999).

In regard to groundwater contamination, data from monitoring wells in aquifers adjacent to ISL wellfields have shown that water conditions remain unchanged further than 200 to 300 m from the field limits. As natural pre-leach water is regarded as not suitable for farming or human use, the main method of eliminating aquifer contamination after ISL is based on natural attenuation as residual leach solution migrates with the groundwater stream.

As acid leaching can require the use of expensive restoration techniques after decommissioning of a wellfield, an improved mining method has been developed. This method is now applied to about 50% of the production operations in Uzbekistan. The new process uses a small amount of acid, and water saturated with air to form a leaching solution of pH 4 to 4.5, which selectively dissolves

carbonate in the rock to form bicarbonate. The resulting bicarbonate solution containing oxygen dissolves the uranium as a uranyl-carbonate complex.

It is reported that this “weak acid” leaching method has significant advantages over the normal acid leaching process, as no restoration is required after the in-situ leach process has been completed. The uranium recovery using this technology is claimed to be as high as in acid leaching.

#### *Ukraine*

In Ukraine, two deposits, Devladivske and Bratske, were mined by acid ISL during the 1970s and 1980s. No restoration of the affected aquifer was made after mining. With the passage of time, decreases in U, Th, Ra and sulfate concentrations have been observed, and the pH increased from 3.9 to 6.2.

Natural attenuation of the aquifer was attributed to the significant contents of coal and clay minerals in the leached formation that promote self-neutralization of the affected aquifer (IAEA 2004). However, at both sites migration of the contaminated groundwater has been observed; some 2 km at Devladivske and 4.2 km at Bratske (Mudd 2001b).

### **2.5.5 Alkaline ISL uranium mining in the USA**

Commercial ISL uranium mining commenced in the USA in the mid-1970s. Both acid and alkaline leach systems were evaluated. While there were several pilot tests using acid leach systems, there have been no commercial operations, by current standards, using an acid leach system, essentially because of the difficulty of restoring groundwater after acid leaching (Underhill 1993). Note, however, that in the USA most uranium bearing aquifers are suitable for drinking water or, as a minimum, for livestock use.

While difficulty of restoration is the commonly reported reason for the use of alkaline leaching, first-hand reports of ISL from the early stages of development in the USA are not as definite. The high carbonate content of deposits, coupled with gypsum formation and other operational problems, are also considered factors in the shift to alkaline leaching, which would then appear to have been sustained by the emphasis on restoration and licensing requirements.

The US Bureau of Mines carried out a detailed assessment of a pilot scale, acid leach operation in Wyoming. Pugliese and Larson (1989) reported successful restoration, but noted that extended flushing was required.

ISL production was undertaken predominantly in south Texas, but more recent projects have been in Wyoming and Nebraska. The growth of ISL in the USA in the late 1980s to early 1990s, while conventional mines were closing down, was a reflection of the status of alkaline leach ISL as a mature technology. This growth was based on low production costs and ability to meet the increasingly restrictive US regulatory environment. The technology of the 1990s followed the experimental years of the early 1970s and early 1980s, during which many projects were not as successful as would be expected from performance of current operations (Underhill 1993).

Ammonium or sodium bicarbonate leaching has been used in all commercial operations. Most of the early operations used the ammonium bicarbonate system (at a concentration of about 1 g/L) because the sodium reagent caused swelling of the clay minerals associated with Texas ores (IAEA 1993). Grant *et al.* (1989) and Mays (1993) report that difficulties in restoring groundwater contaminated with ammonia desorbed from clays led to the use of this system being discontinued.

Current US practice is to inject carbon dioxide (CO<sub>2</sub>) and oxygen into the formation groundwater, which may also be fortified with sodium bicarbonate or carbonate, to form a low strength

bicarbonate solution. The pH of the lixiviant is typically 6.5 to 7.6, with the bicarbonate concentration at 0.3 to 1.5 g/L. A number of operational practices are adopted to limit calcite precipitation and clay swelling, including pre-injection of CO<sub>2</sub> before addition of other chemicals. The injection of CO<sub>2</sub>, rather than a sodium salt, also limits the exchange (by minimising concentration) of sodium with calcium in clays and reduces precipitation. CO<sub>2</sub> injection relies on cations, already present in the system, as counter-ions (Catchpole and Kirchner 1993, Schmidt 1989).

The differences in groundwater restoration approaches in the US relate to the background water quality and regulatory requirements, rather than the process used (Montgomery 1989). In most cases, well-field restoration has been routine. In 1989, the Nuclear Regulatory Commission concluded that “based upon the accumulation of operational data and information, it has become apparent that ISL operations pose no significant environmental effects” (Underhill 1998).

Up to early 2001, approximately 43,000 t of uranium had been produced by ISL in the USA (OECD 2002). There are currently three ISL operations producing about 900 t U/year, which accounts for 85% of total USA uranium production. Excluding the current operations, there have been about 25 commercial ISL projects and double this number of pilot projects.

## **2.6 Alternative Mining and Processing Methods**

The two most commonly used alternative uranium mining techniques are conventional underground mining (as at Olympic Dam) and open-pit (as at Ranger). Both techniques produce ore that is crushed and ground in a surface mill and the uranium extracted by leaching. There are variations within these mining techniques and also other potential minerals processing methods. A brief comparison of the issues associated with other conventional mining and mineral processing techniques follows.

### **2.6.1 Underground mining**

The key features associated with underground mining, compared with ISL mining, are:

- Poor ground conditions may give rise to major stability issues (applies to both the Beverley and Honeymoon sites).
- Potential to compromise inter-aquifer separation – sealing of aquifers may be required, if this is considered to be an issue (applies to both the Beverley and Honeymoon sites).
- Groundwater inflows need to be managed.
- Disposal facilities for groundwater are required.
- Crushing / grinding facilities are required.
- A tailings disposal system is necessary.
- Larger evaporation ponds are likely to be necessary.
- Water usage is increased.
- Increased radiation exposure control measures are necessary.
- Energy requirements are increased.
- Much greater surface impact than ISL.
- Tailings storage facility remains as a permanent legacy.
- Surface rehabilitation needs are greater than ISL.

## 2.6.2 Open-pit

The key features associated with open-pit mining, compared with ISL mining, are:

- Management and rehabilitation of overburden dumps is required.
- Aquifers are compromised, if not destroyed.
- Groundwater inflows need to be managed.
- Disposal facilities for groundwater are required.
- Crushing / grinding facilities are required.
- A tailings disposal system is necessary.
- Larger evaporation ponds are likely to be necessary.
- Water usage is increased.
- Increased radiation exposure control measures are necessary.
- Energy requirements are increased.
- Much greater surface impact than ISL, and greater impact than underground mining.
- Tailings storage facility and abandoned pit remain as a permanent legacy.
- Surface rehabilitation needs are greater than ISL.
- Need to consider on-going safety issues and end-use of pit after abandonment.

In particular, for both underground and open pit mining, the size and impact of the mining and processing operations (the ‘footprint’) would be significantly larger than the ISL process. Figures 8 to 10 show a typical open pit mine, waste rock dumps and tailings storage facilities respectively.



*Figure 8 Example of an open pit mine (Provided by Peter Woods)*



Figure 9 Example of waste rock dumps (Provided by Graham Taylor)



Figure 10 Example of tailings storage facilities (Provided by Graham Taylor)

### 2.6.3 Other mineral processing methods

In ISL, underground and open-pit mining, the uranium is extracted from the ore by dissolving in a leach solution (usually sulfuric acid or an alkali) whether in-situ, or in surface plants after crushing and grinding.

#### *Alternative ISL methods*

Acid leaching is used at Beverley, and proposed for Honeymoon, but the alternative alkaline leaching process would be an option. Alkaline leaching would have little impact on the nature and extent of surface operations, but would change the composition of liquor remaining in the wellfield when leaching operations were finished.

As discussed in Section 2.5, acid leaching is generally more effective than alkaline leaching, provided that the ore is low in carbonate, as is the case at Beverley and Honeymoon. In addition to a high carbonate concentration, the requirement/need to restore groundwater to a baseline approaching drinking water quality has been a driver for the use of alkaline leaching in the USA.

The need and approach to “restoring” groundwater after acid leaching is being addressed in several countries where commercial acid ISL is used to produce uranium. Where the quality of the pre-mine water is not suitable for human or stock consumption, the emerging view from long-term operations is that there is no need to treat water to achieve pre-mining conditions.



At several sites, monitoring data are showing that natural attenuation occurs naturally, and that natural attenuation has reduced the impact from acid ISL on groundwater and has limited the movement of leach liquor from the wellfields, with eventual return approaching pre-mining conditions. The time taken to achieve natural attenuation or restoration depends on many factors, mainly local, but is likely to be of the order of 20 years.

The weak acid ISL leaching method under trial in Uzbekistan is claimed to minimise changes to groundwater composition. This technique requires the presence of carbonate in the ore, and is therefore not likely to be applicable to Beverley or Honeymoon. Other factors including the stability of the lixiviant and solubilized species, such as silica, would also need to be considered.

#### *Heap leach process*

An alternative to the normal milling process is the heap leach process as used at some gold and copper mines, in which ore is piled onto a plastic liner and leach solution spray-irrigated onto the ore. Heap leaching of low-grade uranium ore was attempted at the Nabarlek uranium mine in the Northern Territory. Key issues associated with the general practice of heap leaching are:

- Integrity of liner below heaps and outer collector drains — potential for groundwater contamination.
- Integrity of piping systems to / from recovery plant.
- Blocking / overflow of outer collector drains during heavy rainfall.
- Mist from the circulation spray system on the heaps (if sprayers used).
- Long-term rehabilitation of the heaps.
- Extremely slow and incomplete recovery of uranium.
- Large footprint.

#### *Bacterially assisted in-place leaching*

Bacterially assisted in-place leaching of the uranium remaining in worked out underground stopes was used at Elliot Lake in Canada in the 1960s producing about US\$25 million worth of uranium (IAEA, 1993). Acidic mine water supplemented with bacterial nutrients containing *Thiobacillus ferro-oxidans* was pumped into stopes to flood the ore.

There continues to be research interest into bio-leaching, however, we have not found any economic assessments that suggests biological leaching may have a practical or cost advantage over conventional ISL.

#### *Emerging Method*

Although still in the development stage, a new technique for remote underground mining in wet collapsing areas, which may have application in palaeochannel environments, has been developed by SORD Technologies (<http://www.sordtech.com>).

The system utilises a remotely-controlled, wedge-shaped mining head, called SORD (Subterranean Operated Remotely Dredge) that can travel underground in continuously collapsing sandy and gravelly material with ore sucked in through the head of the machine and pumped back to surface as a slurry, using water jets and large pumps. This technique, if proven, would minimise the radiation exposure of workers as the orebody is mined remotely, as with ISL. It would still disrupt the aquitards between aquifers, and surface tailings disposal would be required as for conventional underground mining (see Section 2.6.1).

### **3 ENVIRONMENTAL CONCERNS OF ISL URANIUM MINING IN SOUTH AUSTRALIA**

The list of environmental concerns was developed through several processes. Those noted in the tender specifications were added to by comments and questions raised at the public meeting, and further by written submissions provided by various members of the public. Additionally, for completeness we included issues raised in the Senate Enquiry (2003) into “Regulating the Ranger, Jabiluka, Beverley and Honeymoon Uranium Mines”, which was released after the tender specifications were prepared.

By far the most comprehensive submission was the joint technical submission from the Australian Conservation Foundation, Friends of the Earth Australia and the Conservation Council of South Australia. In it they stated that the primary scientific question the review must demonstrate with vigour is that of the long-term geochemical changes to the groundwater systems at the Beverley and Honeymoon sites and whether “natural attenuation” will evidently allow the re-establishment of pre-mining conditions. If not, then credible proposals should be presented to ensure that the long-term pollution burden is not increased due to acid leach uranium mining activities.

In Section 10 of the report we present conclusions on those issues (within our scope) in relation to the information gathered during the course of this Review and which is discussed in the preceding Sections. Below is a summary list of the concerns and issues raised through the various processes:

#### **Legislation / Government role**

- No more approvals / remove approvals for disposal of waste into groundwater.
- Need independent Environmental Impact Assessment of all uranium related activities.
- Need new public environmental approval processes for Beverley and Honeymoon, particularly in relation to disposal of wastes to groundwater.
- Make acid leach miners deposit sufficient money to restore aquifers to their previous condition before being granted a licence to operate.
- Need a requirement to rehabilitate groundwater to pre-mining standard.
- Remove secrecy surrounding the matter of ISL mining.
- Remove exemptions for uranium mining in SA Environment Protection Act.
- Make uranium wastes subject to the same powers to prevent environmental harm as other industries.
- The SA Government is doing little to control ISL companies, whose transgressions are becoming commonplace.
- Government should promote public understanding of the issues associated with uranium production.
- There should be transparent management and monitoring processes and public reporting.
- That if ISL mining is permitted, the mines utilising this technique should be subject to strict regulation with regular independent monitoring to ensure environmental impacts are minimised, with public release of all data and reports relating to monitoring and incidents (Senate Recommendation 17).

#### **Uranium / nuclear issues**

- Make industries accountable to the public for radiation issues.
- South Australian people being put at risk, as during atomic testing in the 1950s and 1960s.

- Radon emanation poses a significant health risk and should be monitored comprehensively and reported publicly.

### **Groundwater / hydrogeology**

- Concern about pumping radioactive waste into groundwater.
- Disposal of wastes to groundwater is irresponsible.
- Miners have no control over where the acid and later the metallic solutions actually go.
- No mining should be allowed that endangers water supply.
- Discharge of wastewaters (liquid wastes) to the palaeochannel aquifer will permanently contaminate the groundwater with high levels of radionuclides and heavy metals. This will render the groundwater unfit for any use in the future and may lead to contamination of other aquifers. All liquid wastes should be disposed of in surface facilities (as at Olympic Dam).
- The process of natural attenuation within the palaeochannel aquifer is not proven and that any liquid wastes should be neutralised prior to re-injection and that any changes to groundwaters due to re-injection should be rectified.
- Comprehensive groundwater monitoring be undertaken with particular emphasis on Eh (redox potential) and also potassium, and that all data be publicly available.
- ISL mining and re-injection of waste pose a threat to the integrity of the Great Artesian Basin.
- The aquifers at Honeymoon are interconnected which would allow contamination of groundwater and that mining operations at Honeymoon be not allowed until there is conclusive evidence that the relevant aquifer is isolated (Senate Recommendation 25).

### **ISL process**

- ISL is a cheap and dirty technique not used by any other western nation.
- ISL is a cheap and dirty technique not used where there is a knowledge and concern about pollution of groundwater.
- There are risks of serious surface spills and leaks.
- Spills and leakages are too frequent posing risks to the environment, requiring the Commonwealth and South Australian Governments to play a more active and assertive role in assessing and regulating ISL mining at Beverley (Senate Recommendation 18).
- Further, that incidents should be reported in writing as opposed to verbal reports, and that serious leaks and spills be investigated by Environment Australia (Senate Recommendation 21).
- ISL is still in an experimental stage and therefore poses a significant risk to human health and the environment (Senate Recommendation 16).
- The quantity and quality of research is inadequate and that a more comprehensive research effort be made based on better organised and more systematic information collection and greater rigour in analysing data (Senate Recommendation 24).

### **Companies**

- ISL mining in SA is being done by companies with no concern for our values.

## 4 HYDROGEOLOGY – SOUTH AUSTRALIAN ISL URANIUM PROJECTS

As ISL mining takes place in an aquifer, the hydrogeology of the deposit is of critical importance both for mining and environmental protection. Unfavourable hydrogeology can render an otherwise attractive orebody uneconomic due to the difficulty and expense of extraction or environmental protection, whereas favourable hydrogeology can simplify both.

Other matters of importance are the chemistry of the groundwater in which the orebody is found, as this affects other uses that the groundwater is being or might be put to, and the nature of the mineral particles in the aquifer. The interaction of natural groundwater, mining solutions, waste solutions and mineral particles exert a strong influence on what happens to the quality of the groundwater once mining stops.

Both the Honeymoon and Beverley deposits are in Tertiary Age palaeochannel sediments (the beds and floodplains of ancient rivers) of the Eyre Basin in the Lake Frome Region of South Australia. The Eyre Basin sediments are underlain in part by the Great Artesian Basin, including important aquifers such as the Cadna-owie Formation and aquitards such as the Bulldog Shale. The uranium deposits are approximately 100–120 m below the surface and 10–20 m thick.

The information in this section concerning the application of acid ISL uranium mining in South Australia is based upon visits to both the Beverley and Honeymoon operations by members of the Review Team, subsequent discussions with staff of Heathgate Resources and Southern Cross Resources (the respective operators), literature reviews, information on the web-sites of South Australian Chamber of Mines and Energy (SACOME) and the Uranium Information Centre (UIC), submissions to various inquiries and contributions from the various non-government organisations (NGOs).

### 4.1 Beverley Mine Hydrogeology

The Beverley deposit has the following key features:

- The deposits are within palaeochannel sands incised into older Alpha Mudstone, an aquitard (both are part of the Namba Formation).
- The ore-bearing sands (Beverley Aquifer) are completely confined by clays above (Beverley Clay) and below (Alpha Mudstone).
- The western boundary of the Beverley Sand aquifer is effectively the Poontana Fault Zone to the west of the Beverley Mineralised Area. This is an impermeable fault.
- At the northern, southern and eastern boundaries, the sands grade into silts.
- Undisturbed groundwater is essentially ‘semi-stagnant’ (very slow lateral flow).
- The Great Artesian Basin (GAB) sediments below have pressurised groundwater in the GAB aquifer (Cadna-owie Formation).
- Older bedrock of Proterozoic age underlies the GAB sediments and outcrops to the west in the Flinders Ranges.
- Due to pressurisation, any minor leakage is from the GAB to the Beverley Aquifer through the Bulldog Shale and Alpha Mudstone.
- Some groundwater is found in the overlying Willawortina Formation.

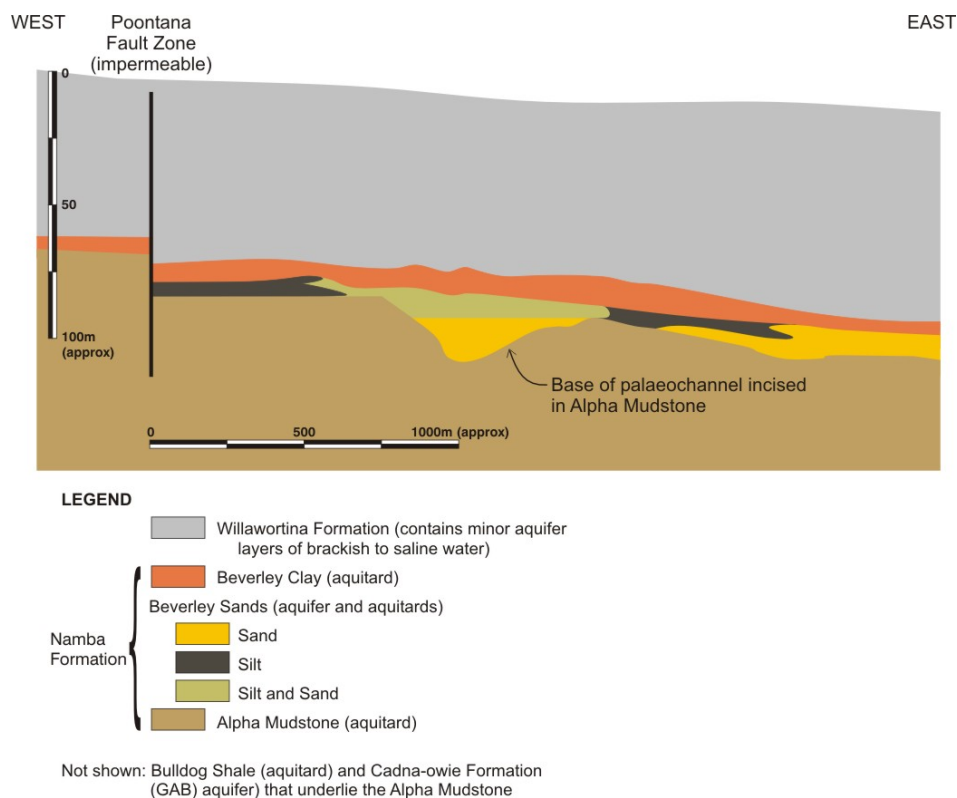


Figure 11 Beverley deposit hydrogeological cross-section (Source: after Habermehl 2000)

## 4.2 Honeymoon Deposit Hydrogeology

The Honeymoon deposit has the following key features:

- The deposits are within sands of the Yarramba palaeochannel of the Eyre Formation incised into older Proterozoic bedrock.
- The ore-bearing sands are the lowest of three main aquifer layers that are largely, but not entirely, hydraulically separated by clays that are not continuous over the full area.
- At the southern and eastern boundaries, the sands grade into silts.
- Other layers also contain uranium, but not of economic grade.
- The aquifer system is confined by clays (Namba Formation) above and bedrock below and laterally.
- The deposit is about 70 km distant from GAB sediments.
- There is gradual groundwater flow along the main axis of the palaeochannel.

Figure 12 shows a cross-section of the Honeymoon deposit hydrogeology (Yarramba palaeochannel). The permeable geological units are sands, and the other units are of low permeability. The Namba Formation clays overlie the upper sand shown in the figure.

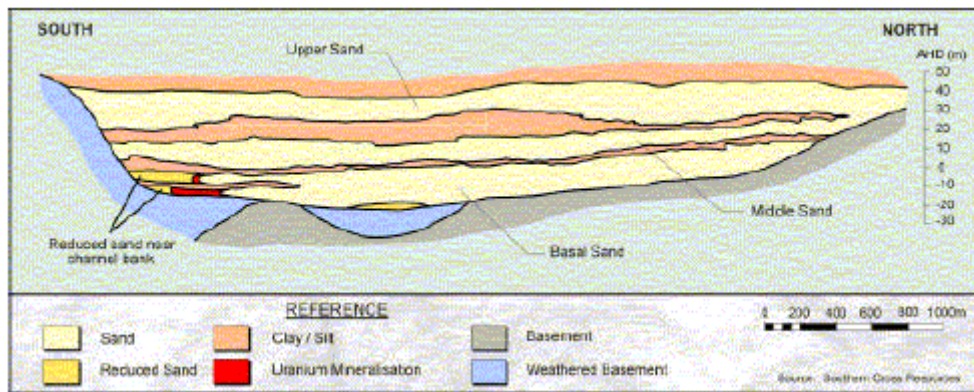


Figure 12 Honeymoon deposit hydrogeological cross-section (Source: Southern Cross Resources)

### 4.3 Inter-Aquifer Isolation or Connection

Environmental management of ISL mines is simplified if there are no connections, limited connections, or remote connections to other aquifers that may contain water with beneficial uses other than mining. In some places overseas, uranium is mined from aquifers containing water that is used for irrigation and potable supply. Historically, poor ISL mining practices have been undertaken, particularly in eastern Europe, that have adversely affected other users (See Section 2.5). In the two South Australian ISL projects, the mined aquifers are well isolated from nearby aquifers in most aspects.

At Beverley, the overlying Willawortina Formation may contain water of stock quality. It is separated from the mined Beverley aquifer by the Beverley clay, which pumping tests have shown forms an effective aquitard. Any interflow from the Beverley Sand to the Willawortina formation is calculated to occur over very long timeframes due to the extremely low hydraulic permeability of the clay (up to millions of years; Armstrong 1998).

Part of the important Great Artesian Basin (GAB) aquifer system underlies the Beverley aquifer, separated by thick aquitards, the Alpha Mudstone and the Bulldog Shale. There is a large hydraulic difference between the GAB aquifer and the Beverley aquifer of tens of metres, with the higher pressure in the GAB. This means that any leakage of water is from the GAB into the Beverley aquifer, but this cannot presently be significant as the salinity of the Beverley aquifer is much higher than the GAB. The potential of mining or use of GAB water to reverse this gradient is not reasonably probable. As such, there is considered to be no potential for mining-affected water from the Beverley project to enter the GAB.

At Honeymoon, the margin of the GAB is about 70 km from the uranium deposit, which is underlain by bedrock. There are three main sub-aquifers in the Yarramba palaeochannel, separated by low-permeability clays. Across the deposit and nearby, the three sub-aquifers are imperfectly separated by these clay layers, which are not completely laterally continuous as illustrated in Figure 12. The palaeochannel aquifer system is sealed from above by clays, but has continuity up and downstream. The salinity is highest in the deepest sub-aquifer where the majority of minable uranium is located.

A single pastoral bore is located about 2 km from the uranium deposit, but because of its marginal suitability for stock due to high salinity is not in continuous use. The mining proponent considers that the likelihood of the project impacting on this well is very small, and the review team concurs. However, this consideration would need to be monitored if the project proceeds, and a contingency

plan provided to replace the water supply if an impact should occur or be predicted to occur by unexpected trends in water quality observed by monitoring.

## 4.4 Hydrogeochemistry

The arid setting of the South Australian ISL uranium projects is reflected in the salinity of local groundwater, which is brackish to saline.

The hydrogeochemical characteristics of the two sites are summarised in Table 3. At Beverley, the groundwater in the Beverley sands containing the uranium deposits exhibits a range of salinity. It is suggested by Armstrong (1998) that at the time the orebodies were being emplaced, the Beverley channel system was in relatively good contact with the fractured rock source to the west (the Flinders Ranges), with flow occurring down a hydraulic gradient which no longer exists.

Faulting along the north-south zones such as the Poontana Fault Zone (Figure 11) appears to have severed the hydraulic connection and left the water in the Beverley Sands as an almost completely isolated, stagnating water body, probably still connected to the evaporative sink (Lake Frome) downstream. The salinity zoning in the channel may be explained by mixing with highly saline waters from the evaporative sink, driven by density difference, in the presence of an extremely small hydraulic gradient towards the sink. Dissolved uranium concentrations are modest compared to Honeymoon, but radium is typically higher.

Groundwater in the orebody aquifers at Honeymoon is more uniformly saline, typically 20,000 mg/L in the lower sands, with some water of lower salinity in the upper sands (approximately 16,000 mg/L).

The detailed hydrogeochemistry of the aquifers, as detailed in the EIS and studies such as Armstrong (1998) for Beverley and Pirlo (2000, 2001) for Honeymoon, are important as, together with the minerals present in the aquifers before and after mining, they affect the interaction of mining solutions including wastewater with the aquifer and the quality of groundwater left at the sites after mining both short and long term.

*Table 3 Comparison of the hydrogeochemistry of the aquifers at Beverley and Honeymoon operations*

<i>Constituent</i>	<i>Typical Beverley Aquifer Concentration</i>	<i>Typical Honeymoon Aquifer Concentration</i>	<i>Comment</i>
Salinity	3,000 to 12,000 mg/L	20,000 mg/L (lower sands that contain deposit)	Varies laterally at Beverley, and vertically at Honeymoon. Aquifers with lower salinity at Beverley are within stock consumption limits, but overall unsuitable due to radionuclide content.
pH	7–8	7–8	Neutral or near-neutral.
Redox (Eh)			See table footnote.
Main ions	Na-Cl-SO <sub>4</sub>	Na-Cl-SO <sub>4</sub>	Similar chemistry, concentrations vary with salinity.
Uranium	1–100 µg/L	1,000 µg/L (average)	Some higher and lower values, unsuitable for irrigation, stock or human consumption.
Radium	50-1,000 Bq/L	169 Bq/L (average)	Some higher and lower values, unsuitable for irrigation, stock or human consumption.

Note: Whilst redox potential (Eh) is an important parameter partially controlling the behaviour of metals in groundwater, measurements to date are not considered particularly reliable and are not included here.

At Beverley, the salinity of groundwater in the Willawortina Formation is in a similar range to the Beverley sands, whilst the underlying GAB water is less saline. Radionuclide concentrations are lower in the Willawortina Formation, and a number of wells in the region (although not at the mine site) are used for pastoral purposes.

## 4.5 Groundwater Microbiology

The nature of microbial populations in the aquifers is presently unknown and will depend on many factors, which are also likely to be site specific. However, it can be assumed to be different in the leached area given the pH drop from about 7 to 2 after the addition of sulfuric acid. Of prime importance is whether the aquifer contains oxygen or not, the reduced or oxidised state of the substrate (i.e. whether sulfide minerals are present in the sand), and the amount of organic carbon available for oxidation.

Natural attenuation is dependent on groundwater quality. If for example, an increase in alkalinity is dependent on the presence of sulfate reducing bacteria, there is a requirement for an electron donor (e.g. hydrogen, ethanol, acetate, lactate or other source of carbon) to drive the reaction. However there are no known sulfate reducing bacteria that act at a pH of 2 – activity commences at a pH of 3.5 and above. Thus, pH will have a considerable effect on the microbiology of the aquifer and the microbial processes.

To gain a better understanding of the microbiology of the mined aquifer it would be necessary to better determine the geochemistry of the water and aquifer solids. Culture-independent methods could then be used to survey the microbial population by genetic (by DNA-PCR-DGGE, and DNA-PCR clone library analysis) and phenotypic (phospholipid analysis) techniques. It is probable that many undescribed new signatures and sequences will be found. To ascertain whether such species will assist in natural attenuation processes would require laboratory testing. This would be an expensive study over many years, which may not provide more timely data than detailed in-situ monitoring of the aquifer.

## 4.6 Natural Attenuation

Natural attenuation is the term given to the process where groundwater, which has been altered through the addition of leach solution or liquid waste, reverts through reaction to its surrounding aquifer matrix and pre-existing groundwater over a period of time to or towards its pre-contaminated state, without additional attenuating treatment.

Data from overseas operations indicates that natural attenuation does occur over time. At Beverley, there is emerging evidence based on available data that natural attenuation has indeed reduced the impact from acid ISL on groundwater and limited the movement of leach liquor from the well-fields, and that eventual return approaching pre-mining conditions is likely.

The EIA for Beverley and Honeymoon suggest that natural attenuation will occur, however, exact timeframes are not given. The issue of predicting attenuation is made more complex by not fully understanding the microbiological or the mineralogy of the surrounding ore bodies, before and after mining, and how these natural conditions will react with the altered water quality introduced by the injection of leachate, and re-injection of wastewaters. Following general practice, geochemical modelling was undertaken with a series of assumptions where data were not available. Although these assumptions are considered reasonable by the review team, some technical experts have a differing opinion. In any case the results must be considered approximate.

The monitoring results from Beverley are limited by the short duration of mining and operation, and there are currently no completely mined-out areas for which the water chemistry can be followed after mining to verify the extent of the expected natural attenuation. However, pH results



for an area that was trial-mined in 1998 and then left until full-scale mining of the same area was due are shown in Figure 13.

Note that whilst other data are available for these wells there are not consistent trends in other analytes. There has been little recovery of groundwater chemistry towards background in the test-production wells other than a favourable change for pH. There are presently no equivalent monitoring data for the northern area, which is presently being mined.

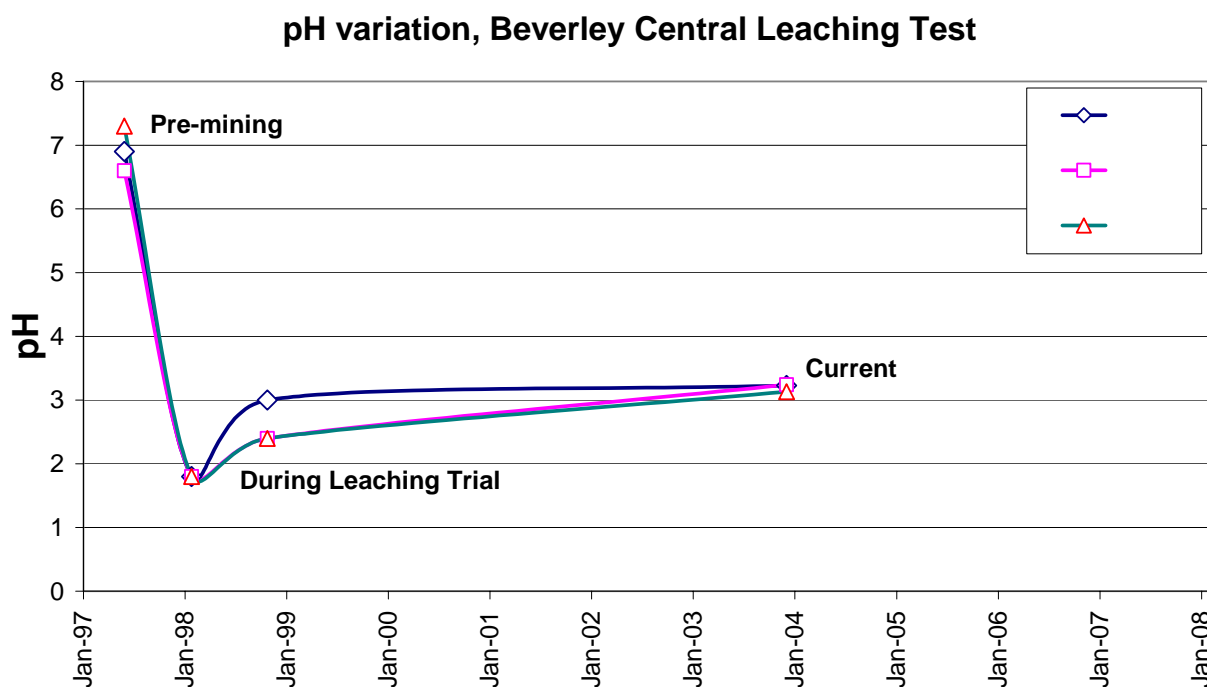


Figure 13 pH variation as measured at Beverley Central Leaching Test site before, during and after trial mining (Source: Heathgate Resources)

For the Beverley operation, groundwater monitoring is required to be conducted for seven years after mining to demonstrate that their expectations in regard to natural attenuation are being borne out.

Research into the use of and ability of chemical amendments to assist with or speed up the processes of natural attenuation processes may be beneficial, especially where the latter may be slow and/or incomplete. This approach may also be of benefit in the case of plant or equipment failure with resultant contamination of soil or shallow aquifers.

Although the climate and mining method are different (i.e. liquid waste is not injected into an aquifer), nearly 10 years of post-rehabilitation monitoring of groundwater is available from the rehabilitated Nabarlek uranium mine in the Northern Territory, where uranium mill tailings were buried and rehabilitated in the former open cut pit. Since decommissioning in 1994 recovery of groundwater quality has been apparent including adjacent to former ore stockpiles and the pit (Waggitt & Hughes 2003).

## 5 MINERAL PROCESSING

The extraction of uranium from ore for both the existing South Australian ISL projects follows the same generic pattern – take the uranium into solution, separate it from impurities by solvent extraction or ion exchange, precipitate it out, and thicken and dry it for shipment as yellowcake.

Both the Beverley and proposed Honeymoon operations use a leach solution comprising natural groundwater, with the pH adjusted to approximately 2 by the addition of sulfuric acid, and with addition of an oxidant. However, at Beverley where the lixiviant is recycled 50 to 80 times, the oxidant is hydrogen peroxide, whereas at Honeymoon, it is proposed to use sodium chlorate.

### *Beverley*

The uranium-rich solution from the wellfields at Beverley flows through columns containing granules of an ion exchange resin, which adsorbs the uranium. When an ion exchange column has become fully loaded with adsorbed uranium, it is taken off line, and the uranium is eluted from the resin using an eluant solution of salt and dilute sulfuric acid.

The uranium in the eluant solution is precipitated as uranium peroxide (yellowcake) by the addition of hydrogen peroxide following neutralization of the sulfuric acid with caustic soda. Finally, the uranium peroxide is dewatered, dried and packed into 205 L drums for export.

Following ion exchange, the leach solution is adjusted to specification with make-up leaching agents and returned to the ore zone via the injection wells to recover more uranium.

The chemistry of the various solutions at each stage through the process used at Beverley is given in Table 4, along with that of the Great Artesian Basin.

### *Honeymoon*

At Honeymoon, the high sodium chloride levels in the aquifer required a slightly different approach, as ion exchange resins do not work effectively in a high chloride environment. Accordingly, the trials at Honeymoon used solvent extraction with a tertiary amine extractant in an organic diluent similar to kerosene. The uranium transfers to the organic solvent and the two immiscible phases (water based leach solution and organic solvent) can then be separated. The recovery of uranium is then similar to the process used at Beverley.

*Table 4 For Beverley, chemistry of uranium-rich solution, barren solution after extraction, liquid waste and that of the Great Artesian Basin (Source: Heathgate Resources Annual Report 2003 and unpublished company data)*

<i>Constituent</i>	<i>Uranium-rich solution</i>	<i>Barren solution</i>	<i>Liquid waste for disposal to aquifer</i>	<i>GAB</i>
Volume	5,790 ML		156.7 ML	51.29 ML
Sulfate (SO <sub>4</sub> )	4-10 g/L	4-10 g/L	5-20 g/L	0.058 g/L
Uranium	75-250 mg/L	Up to 100 mg/L	Up to 200 mg/L	<0.0005 mg/L
Conductivity	10-30 mS/cm	10-30 mS/cm	10-100 mS/cm	3.63 mS/cm
pH	1.7-2.8	1.5-2.5	2.0-4.0	7.9
Redox (Eh)	150-700 mV	150-700 mV	200-700 mV	-
Radium	50-1,000 Bq/L	-	780 Bq/L	-

## 6 EXISTING ENVIRONMENTAL SAFEGUARDS

### 6.1 Relevant Legislation and Codes

The environmental, health and safety approvals and aspects of the operations at Beverley and Honeymoon are covered by some 29 State Acts, 19 Commonwealth Acts, and 17 Codes of Practice.

Of these items of legislation, the key items of legislation in regard to the EIS approval process are:

- The *Development Act 1993* (South Australia).
- The *Environmental Protection and Biodiversity Conservation Act 1999* (Commonwealth) – Note: prior to July 2000, approval was under the *Environmental Protection (Impact of Proposals) Act 1974*.

The key items of legislation in relation to operation of the projects are the following State Acts:

- The *Mining Act 1971* and Regulations and the *Mines and Works Inspection Act 1920* and Regulations, administered by Primary Industries and Resources SA (PIRSA). The *Mining Act 1971* establishes the mining lease and its tenure, which may be subject to conditions such as a Mining and Rehabilitation Plan (MARP), an Environment Management and Monitoring Plan (EMMP), a Native Vegetation Management Plan and also a bond for site rehabilitation.
- The *Occupational Health, Safety and Welfare Act 1986* and consolidated Regulations, the *Controlled Substances Act 1984* and the *Dangerous Substances Act 1979* and Regulations, administered by the Department for Administrative and Information Services (DAIS). This legislation covers the occupational health and safety aspects of the operations.
- The *Environment Protection Act 1993*, Policies and Regulations, and the *Radiation Protection and Control Act 1982* and Regulations, administered by the Environment Protection Authority (EPA). This legislation covers environmental and radiation protection.
- In addition the Department of Water, Land and Biodiversity Conservation (DWLBC) and the relevant Catchment Water Management Board (the Arid Areas Catchment Water Management Board, in the case of both Beverley and Honeymoon) are responsible for input on water management issues, under the *Water Resources Act 1997* and Regulations.

The key codes in relation to acid ISL projects are:

- The *Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores 1987*.
- The *Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores 1982*.
- The *National Standard for Limiting Occupational Exposure to Ionising Radiation 1995*.
- The *Australian Code for the Transport of Dangerous Goods by Road and Rail 1998*.
- The *Code of Practice for Safe Transport of Radioactive Material 2001*.

A comprehensive regime has been established for monitoring the regulation of the sites. This includes:

- Quarterly and Annual reporting and meetings with State Authorities.
- The State / Commonwealth Environment Consultation Committee meets twice a year or as required.

Recent changes to the *Environment Protection Act 1993* have affected existing exclusions under Section 7(4), and as a result these exclusions no longer apply to uranium mining, processing and its wastes. As such, the changes will require ISL uranium mining operations to be licenced under the Environment Protection Act to undertake minerals processing.

As a consequence of these changes, the Beverley operation, which is presently licenced under the Environment Protection Act for its power plant, will now need to apply for the licence to be amended to also include minerals processing. Honeymoon, which is not yet operational, does not have an Environment Protection Act licence.

## **6.2 Wellfields and Pipeline Infrastructure**

High Density Polyethylene (HDPE) pipes are used to transport leach solution from the processing plant to the extraction wellfields and return leachate containing the mined uranium in solution to the processing plant. At the Beverley operational site, these trunk mains are fitted with pressure sensors and alarms to allow rapid response to any major leaks, and are routinely visually inspected for any evidence of minor leaks. In creeklines and wellfields the trunk mains are either buried or banded.

The wellfield areas at Beverley are banded with approximately 50 cm high earth mounds. This both delineates the mining area and acts to retain any potential spills within the mining areas. Drip trays with leak detectors are installed around both the injection and extraction wells (Figure 5, and cover photograph).

The extraction wells in each wellfield are connected to a wellhouse. Sand that may be entrained in the extracted solution is filtered. In the wellhouse individual flows and operational solution quality parameters (pH and Eh) are measured and displayed in the control room at the processing plant, before the flow from individual wells is combined in a manifold and piped to the processing plant using the original water pressure created by the individual down-hole pumps. Each wellhouse has drip trays and a leak detector.

## **6.3 Process Reagent and Fuel Storage Areas**

The process, reagent and fuel storage areas of both the Beverley operations and the Honeymoon demonstration plant are contained by bunding, to collect any process solutions, should any spill or leak arise during plant operations (see Section 6.5). In particular the main process areas of both plants are well provided for, with a fully concreted floor integral containment bund. Reagents and fuel storage areas outside the main process plant are also equipped with appropriate bunding.

The Beverley operation is extensively instrumented, with all main plant operations monitored and controlled from a central control room. The control room has three computer terminals, with the plant able to be controlled and monitored from any single terminal. One terminal is used for training purposes. The computerised system is multilevel, with a desktop block diagram of the entire operation, and menu click down to individual plant areas and ultimately to individual process items.

The Beverley operation has alarm systems expected of a modern plant, including high level alarms on process and reagent storage vessels. The Honeymoon demonstration plant has the more basic instrumentation expected of a pilot operation. It would be expected that the operational plant, if proceeded with, would be of similar standard of centralised control and alarm systems to the Beverley operation.

Four generators fired by natural gas obtained from the Moomba to Adelaide gas pipeline provide power for the Beverley operation (annual power demand is averaging 1.5 MW). Hence there is no major fuel storage on site.

The Honeymoon demonstration plant has diesel-fired generators, but as the plant is in care and maintenance status minimal fuel is stored on site. The camp uses LPG. Many of the reagent tanks in the process plant area are empty, although quantities of some reagents are still held on site within the main plant bunded area. Some minor quantities of solid reagents are also held in a separate bunded and covered holding area used mainly for storage of waste materials.

## 6.4 Transport of Reagents and Products

The locations of both the Beverley and Honeymoon sites require the transport of reagents and product to and from site by truck.

The management of reagent transport and handling is covered through the *Dangerous Substances Act 1979* (South Australia), and practice is covered by the *Australian Code for the Transport of Dangerous Goods by Road and Rail 1992*. The main dangerous goods likely to be involved in any ISL process include fuel such as diesel fuel and LPG, acids including sulfuric and hydrochloric acid, alkalis including caustic soda, oxidants including hydrogen peroxide and sodium chlorate, and other materials such as sodium carbonate and either ion exchange resin or solvent (similar to kerosene), depending on whether the process uses ion exchange or solvent extraction for uranium recovery (refer Section 5).

The management of transport and handling of the ISL mine product, uranium peroxide (yellow cake), is covered through the *Radiation Protection and Control Act 1982* (South Australia), and practice is covered by the *Code of Practice for the Safe Transport of Radioactive Material 2001*. The yellowcake product is packaged in 205 L steel drums, and is transported by truck in standard shipping containers, and shipped from Port Adelaide.

The EIS documentation for both operations included an assessment of the alternative transport routes, a risk assessment of the alternative routes, and the consequences of any incident involving a release.

## 6.5 Spill Response and Clean-up

### *Spill prevention and precautions*

The movement of liquid reagents or fuels, whether to mine sites, industrial complexes, urban water supplies, petrol service stations or sewerage systems, are all subject to the risk of accidental spills. At mine sites, particular precautions are taken to minimise the environmental impacts of spills.

There have been several spills at Beverley (PIRSA website, May 2004). As a result of these spills the State Government commissioned an independent review of incident reporting procedures for the SA Uranium Mining Industry (Bachmann, 2002). The SA Government and industry have adopted the recommendations of this review, which are detailed in the Appendices.

### *Spill recording and reporting*

A comprehensive recording and reporting system is required for all operations. Incidents involving the unplanned release of radioactive process materials, liquids, or wastes must be recorded in the operator's log or recorded and reported to the SA Government, depending upon the circumstances and scale of the release.

For major spills, written reports are provided to the SA Government within 24 hours. The categorisation of recorded and reported spills is available from the PIRSA website, and the requirements for reporting may be summarised as follows:

- Excursions of mining fluids underground.
- Any unplanned release of process materials or wastes to the undisturbed environment.
- Release of radioactive process materials or liquids leading to accidental exposure of a worker to radioactive materials through inhalation, ingestion or contact.
- Release of radioactive process materials or wastes that threatens ephemeral watercourses.
- Degradation of pipelines, ponds or structures that might release process materials or wastes to the undisturbed environment.
- Unplanned release of more than 10 m<sup>3</sup> of radioactive liquids in an ISL well field.
- Release of more than 50 m<sup>3</sup> of process materials or wastes outside secondary bunding but contained within plant boundaries.
- Any release of uranium concentrate outside secondary containment, and unplanned release of more than 2 m<sup>3</sup> of uranium concentrate within secondary containment.
- Unplanned release of more than 50 m<sup>3</sup> of process materials or wastes within pipeline bunds or corridors.

#### *Use of bunding*

The key precaution against the consequence of spills at both Beverley and Honeymoon is the use of bunding. Earthen bunding is used around the Beverley wellfields and pipelines (Figure 14). Similar bunds are utilised as secondary safeguards around the Beverley processing plant. The majority of the processing plant, reagent storage areas and fuel dumps are underlain by concrete and surrounded by concrete bunds (Figure 15) so that any spilled liquid is contained within a sealed area and capable of being returned to the process.



*Figure 14 Example of earthen bund, around Beverley wellfield*



*Figure 15 Example of concrete bunding, at Beverley process plant*

### *Additional precautions*

At Beverley, which is an operating mine, the following additional precautions are utilised:

- Leak detection devices are installed at wellfield headworks, wellfield collector stations and under evaporation/holding ponds.
- Pressure monitoring of main pipes to/from the wellfields, which trigger pump shutdown in the event of a pipe break.
- Visual inspections of wellfields and pipelines are conducted on a 24 hour basis.
- Alarm systems are provided on all main process equipment items and monitored from a central control room.
- Use of monitoring wells to detect possible excursions of leaching solutions outside the mined areas of aquifers.

Similar precautions were utilised at Honeymoon during the trial periods.

In the event of a spill, both sites have clean-up equipment suitable for a variety of liquids and solids. The Beverley project, which is an operating mine, has all essential emergency equipment on a trailer for immediate transport to a spill site and utilisation. Clean-up procedures are documented and training is undertaken by Environment Health and Safety personnel.

Where it is not possible to return the liquid to the process, contaminated soil is removed and deposited in the low-level contaminated waste pits (see Section 7.1).

## **6.6 Radiation Issues**

Uranium is naturally radioactive and mining operations may involve a risk of exposure of workers and members of the public to radiation produced by the decay of uranium. The radioactive decay of uranium proceeds through a chain of radionuclides (uranium series decay products) that eventually ends with the formation of a stable (i.e. non-radioactive) isotope of lead. Each radionuclide in the chain decays by emission of radiation (in the form of alpha, beta or gamma radiation) to the next radionuclide in the chain.

Radiation issues associated with ISL projects have been reviewed in the Beverley EIS Assessment Report (Minister for Primary Industries, Natural Resources and Regional Development 1998), and the Honeymoon EIS Assessment Report (Minister for Minerals and Energy 2001).

In the EIS Assessment Report, typical radiation doses arising from uranium mining processes are suggested to be the result of:

- Exposure to sources of gamma radiation from ore bodies and stockpiles, process tanks and stored product.
- Inhalation of dust particles containing alpha-emitting short-lived radon decay products, sometimes known as radon daughters.
- Inhalation of dust particles containing long-lived alpha emitters such as radium and uranium.
- Ingestion of uranium or its decay products can also be a minor source of exposure.

Unlike more conventional mining techniques, ISL does not involve direct exposure to stockpiles of ore. Uranium is brought to the surface in solution, extracted, dried and packaged without the need for extensive ore handling, crushing and grinding, or tailings disposal facilities.

Although the nature of the process significantly reduces the sources of radiation exposure arising from the mining operations, there are nevertheless a number of radiation-related issues. These include estimates of doses to workers and members of the public, releases of radioactive materials from the operating plant to the surrounding environment, transport of final product, waste handling and impacts on groundwater.

A summary of radiation monitoring and dose estimates at Beverley and Honeymoon reported for 2003 is provided in Table 5.

*Table 5 Summary of radiation monitoring and dose estimates at Beverley and Honeymoon reported for 2003 (Source: EPA based on company data)*

<i>Parameter</i>	<i>Beverley</i>	<i>Honeymoon<sup>4</sup></i>
Number of employees	179	11
Average employee dose (mSv) <sup>1</sup>	0.68	0.04
Maximum employee dose (mSv) <sup>1</sup>	3.33	0.13
Average environmental radon (Bq/m <sup>3</sup> ) <sup>2</sup>	36	28
Member of the public dose <sup>3</sup>	Indistinguishable from natural background	Indistinguishable from natural background

- Notes:
1. Average annual limit for radiation workers = 20 mSv (NHMRC)
  2. Worldwide background Radon concentration range = 1 Bq/m<sup>3</sup> - 100 Bq/m<sup>3</sup> (UNSCEAR 2000a)
  3. Worldwide average background radiation dose = 2.4 mSv (UNSCEAR 2000b)
  4. Honeymoon pilot plant non-operational during 2003

### 6.6.1 Radiation Exposures

Monitoring of the various radiation parameters was conducted during the operation of the Beverley Field Leach Trial. The monitoring findings are presented in the EIS (Heathgate Resources 1998 page 14-2) and a supporting document (Sonter, M. – Beverley Field Leach Trial: radiation monitoring and estimates). The Beverley EIS Assessment Report (Minister for Primary Industries, Natural Resources and Regional Development 1998) concluded that:

- Only plant workers would be exposed to enhanced gamma radiation. Gamma radiation dose rates fall off quickly with distance from any single source of radiation and as a consequence, gamma radiation exposures from the mining operations is considered to be very small beyond the plant boundary and in particular, negligible for members of the public at the nearest inhabited site some 20 km from the minesite.
- Exposure to radioactive dust is possible during product packing and where there is re-suspension of any spilt material. Again this limits such exposures to workers in the immediate vicinity of the plant and is not considered significant as a source of exposure to the public.
- The main radioactive emission from the Beverley operation would be radon gas produced from the decay of radium contained in sludge in the holding ponds. Monitoring during the operation of the Beverley Field Leach Trial enabled an upper estimate to be made for total radon emission rate (from all sources) of approximately 100 GBq/day. A model was then used to predict radon dispersion associated with the proposed development at Beverley.
- In summary, the information provided in the EIS supports the proponent’s claim that worker doses would be generally less than 20% of the relevant dose limit, and that doses estimated for members of the public at the nearest permanently inhabited location would be less than 1 % of the relevant dose limit.
- The Supervising Scientist Group of Environment Australia stated in their submission on the EIS, “Overall, annual doses to workers at the Beverley uranium mine may lie between 2 and



5 mSv. The application of a sound radiation safety system, as is implied in the EIS, should limit doses to less than 3 mSv per year. This compares favourably with the limit for a worker, which is 20 mSv per year, averaged over five consecutive years, with a maximum of 50 mSv in any one year.”

The radiation monitoring (Table 5) indicates that the radiation safety systems at Beverley will comply with all relevant standards and guidelines.

Similar conclusions were reached in the Honeymoon EIS Assessment Report (Planning SA 2001).

### **6.6.2 Doses to workers**

The Beverley EIS Assessment Report (ibid.) had the following conclusions in relation to worker doses:

- Unlike conventional mining techniques, the ISL process does not produce large amounts of radioactive dust. With the exception of product drying and packaging, all operations would be conducted using solutions. The main sources would therefore be re-suspension of dried spilt material and product handling.
- Exposure to radon decay products may arise through the release of the parent radon from the process stream and evaporation/holding ponds. Gamma exposures would arise through exposure to accumulated radionuclides in filters, ion exchange columns, pipes, evaporation/holding ponds and stored product. Ingestion of contaminated material is another, although minor possible source of exposure.
- The EIS outlines procedures and equipment designed to limit doses from these exposure pathways. It went on to suggest the maximum worker dose would be approximately 4 mSv per year, or around 20% of the average annual limit for radiation workers.

### **6.6.3 Doses to members of the public**

The Beverley EIS Assessment Report had the following conclusions in relation to doses to members of the public:

- Radon is the main source of radiation exposure to members of the public. The absence of significant sources of radioactive dust or gamma radiation from ISL mining operations means that these sources of exposure are negligible. For the EIS, modelling based on an estimate of average radon emissions from the proposed project showed the increment at the nearest residence (10 km) would be of the order of 0.05 Bq/m<sup>3</sup> above the naturally occurring background, which for the modelling was set at 11 Bq/m<sup>3</sup>. However, the natural average atmospheric background radon concentration is known to fluctuate considerably due to factors such as moisture content in the ground and atmospheric conditions. A value of 0.05 Bq/m<sup>3</sup> is well within the range of these normal variations in the natural atmospheric background radon concentration and represents a radiation dose increment of less than 1% of the annual dose limit for members of the public.
- The exposure pathway analysis, modelling and dose estimates presented in the EIS and Response/ Supplement suggest that doses to workers at the Beverley mine site and for members of the public at the nearest residence, would be well below the appropriate limits. These details and, those of the overall Radiation Management Plan for the Project, were subject to approval under conditions on the licence to mine or mill radioactive ores issued under the *Radiation Protection and Control Act 1982* administered by the South Australian Health Commission.

## 7 MANAGEMENT OF WASTES

The *Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores (1982)* is followed at both the Beverley and Honeymoon sites, as a requirement of site licences under the *Radiation Protection and Control Act 1982*. The key wastes associated with acid ISL mining are categorised as solid wastes and liquid wastes. Solid wastes comprise:

- Low-level radioactive wastes, comprising material such as filtration solids; equipment such as filters, pumps and pipework possibly with some retained internal scale; solids from vehicle washdown; and laboratory wastes. This waste needs to be disposed of in a suitable low-level radioactive waste repository.
- Other wastes such as reagent containers and packaging; service items such as spent lubricating oils, filters, seals and bearings; camp waste such as containers, packaging and organic waste from the kitchen; and office complex waste including paper, packaging and containers. This waste is suitable for disposal by sanitary landfill.

Liquid wastes comprise:

- Bleed solution, i.e. excess extracted groundwater to maintain inflow into mined areas.
- Excess uranium recovery solutions.
- Plant and vehicle wash-down.
- Reject brine from the reverse osmosis water treatment plant that produces drinking standard water from groundwater pumped from the GAB.

The other main type of waste generated in ISL mining operations are drill cuttings, that arise during drilling of the production and injection wastes.

### 7.1 Solid Wastes

#### *Solid Wastes at Beverley*

The Beverley solid waste disposal facilities comprise a repository for low-level radioactive wastes, a sanitary landfill for other solid wastes, and a recycle area.

The low-level radioactive waste repository is consistent with the *Code of Practice for the Near-Surface Disposal of Radioactive Waste in Australia* (NHMRC 1992). The repository comprises disposal facilities about 15 m square and 6 m deep, with a compacted clay base with sand layer over, which slopes to one side, and an access ramp. The sides and base of the facility are lined with HDPE, and an under-floor monitoring pipe is located in one corner (inside the HDPE liner and within the sand layer) leading to the low area of the clay base. One facility has been completed and capped, and a second is in use. At Beverley all HDPE sheeting and pipes have been laid, welded and repaired by professional contractors.

The less bulky wastes are disposed of in 205 L drums, stacked two high around the perimeter of the facility, and an open space in the centre is to be used for more bulky items such as pipework and equipment. Once at capacity the HDPE liner is to be folded over and the repository capped with HDPE cover and suitable clay material. At the time of the visit by members of the Review Team, some drums had been placed in the second facility, ready for ultimate disposal (Figure 16).



*Figure 16 Low level radioactive waste repository at Beverley (the cut in the plastic HDPE liner allows folding)*

The sanitary disposal area is adjacent to the low-level repository, and is similar in shape but is unlined. The recycle area is located between the repository and landfill. Wastes that have a potential for recycle or re-use are placed in the recycle area for sorting and possible re-use.

Apart from the underfloor monitoring pipe within the low-level repository, there are no monitoring bores around the waste disposal area.

Inspection of the Beverley plant indicated that the recommendations of the task group (EPA, 2002) have been implemented. As a result of replacing the ABS pipeline with HDPE, there is a large volume of slightly contaminated ABS pipe and fittings at the waste disposal site, which is to be disposed of.

#### *Solid Wastes at Honeymoon*

The Honeymoon waste disposal facilities, being as part of a demonstration plant, are not as developed as for a full-scale operation such as Beverley. The facilities comprise:

- A small bunded and covered holding area, approximately 12.5m x 7.5m, which is used for some reagents and low-level radioactive waste. The bund drains into an adjacent lined evaporation pond. A concreted vehicle wash area also drains into this pond.
- A small landfill pit for other solid wastes, primarily for wastes arising from the camp.

The Honeymoon EIS details the proposals for the proposed full-scale operation (Southern Cross Resources Australia Pty Ltd, 2000). The proposed facilities are similar to those provided for the Beverley Project.

## **7.2 Liquid Wastes**

### *Liquid Wastes at Beverley*

Beverley has a total of six evaporation/holding ponds, comprising four ponds adjacent to the processing plant, three of which accept process wastewater and one that accepts reverse-osmosis plant reject brine. The other two ponds are the Field Leach Trial pond and the wellfield pond

(Heathgate Resources Pty Ltd Annual Environment Report 2001). The evaporation/holding ponds are lined with HDPE sheeting (Figure 17).

Each of the ponds has a leak detection system to monitor any possible fluid migration. During the reporting period for the 2001 report, fluid was detected at one of the process ponds. The source was found to be rain entering through a broken cap. More recently leakage was found to have occurred in one pond, resulting from a small tear in the HDPE. This was successfully repaired. During the period of the most recent report (1 January to 31 December 2003), no leaks were detected (Heathgate Resources Pty Ltd Annual Environment Report 2003).

As stated in the Beverley Assessment Report, the bleed solutions, waste solutions from uranium recovery, plant washdown waters and bleed streams from the reverse osmosis plants are collected prior to disposal into the Namba aquifer via disposal wells. These liquid wastes are combined and concentrated in holding/evaporation ponds, with excess injected into selected locations within the mined aquifer. The injected liquid is acidic (pH 1.8 to 2.8) and contains heavy metals and radionuclides originating from the orebody. Data from the Heathgate Annual Report (2003) on the volume and quality of water sent to the disposal wells is provided in Table 4.

In the case of Beverley, a further liquid waste is the reject brine that arises from the water treatment plant. The treatment plant takes water from the Great Artesian Basin (GAB), and as such the reject brine has only trace levels of radionuclides. The reject brine is used to assist in the maintenance of a wetland that was initially created from a formerly free-flowing GAB well, which is now capped.

It was accepted during the EIS process that the groundwater in the Namba Formation aquifers is essentially stagnant, with a very low to non-existent rate of recharge and has no connection with other aquifers. It was noted also that Namba aquifer is too saline and / or has levels of uranium or other metals too high for stock watering, and the Namba groundwaters are unlikely to have any beneficial use outside the Beverley project (Minister for Primary Industries, Natural Resources and Regional Development, South Australia, 1998).

#### *Liquid Wastes at Honeymoon*

As mentioned previously, the Honeymoon wastewater facilities include a lined evaporation pond (Figure 18) adjacent to a bunded and covered holding area, approximately 12.5 m x 7.5 m, which is used for some reagents and low-level radioactive waste. The bunded area, as well as a concreted vehicle-washdown area, drain into this pond.

The Honeymoon EIS states that the production well pumping rate would be greater than the injection rate in each pattern, to ensure the maintenance of a positive hydraulic gradient towards the production wells, and thereby prevent excursion of leach solution from the well-field. However, to avoid unnecessary drawdown of groundwater from overlying aquifers and undesirable dilution of the leach solution, the overproduction would be limited to 0.5% to 2% of the injection rate, with an average rate of approximately 1% (Planning SA 2001).

The overproduction would be removed as a 'bleed' stream from the barren solution after removal of uranium in the process plant. The EIS Assessment Report (Planning SA 2001) states that re-injection of liquid waste into the Basal Sands is not viewed as presenting any hydrogeological risk, provided that injection occurs at 'hydrogeologically acceptable' sites, and is the preferred disposal option. It would be expected that, as for the Beverley operation, evaporation/holding ponds would be used as part of the overall water management, to manage the quantity of water requiring re-injection.



Figure 17 Evaporation/holding pond, Beverley



Figure 18 Evaporation/holding pond, Honeymoon

### 7.3 Drilling / Wellfield Wastes

The installation of production and injection wells involves drilling through a small cross section of ore. This allows the minor inflow of water from the Namba Formation. This muddy water along with the cuttings from barren areas is contained within small pits dug adjacent to the well (Figure 19). This type of disposal pit is standard practice for drilling operations. Owing to the presence of Namba water, the cuttings disposed of to the pits will exhibit low levels of radioactivity.

The water is allowed to evaporate prior to the solids being covered with soil. No specific rehabilitation of the covered pits has been undertaken as the area remains disturbed during production. Baseline gamma surveys are conducted prior to the installation of the wells and will be repeated after rehabilitation has been completed.



Figure 19 Drill cuttings pit, Beverley

## 8 SURFACE DISTURBANCE AND REHABILITATION

The principal surface impact of the acid ISL uranium mining operations are the well-field areas including bores and pipelines, the processing plant (Figure 20) and evaporation ponds areas, roadways and the airfield, and accommodation / office areas.

In comparison with other uranium mines (underground and open-pit) the ‘footprint’ of ISL mines is small as there are no waste rock dumps (stockpiles), tailings storage facilities, high and low grade ore dumps, no crushing /grinding mill and no counter-current decantation circuit (the latter is a major fraction of plant footprint). Because of the simplicity of the process, the onsite work force is smaller and energy requirements significantly less. The surface environmental impact is therefore reduced.

At Beverley all well-field pipelines are buried approximately 1 m below the surface, necessitating trenching. The soil is returned to the trenches immediately the pipe has been laid and pressure-tested, thus reducing erosion and impediments to regeneration of flora and re-introduction of fauna.

The planned decommissioning and rehabilitation of surface-disturbed, mined-out areas has not yet commenced at either the Beverley or Honeymoon sites, as the initial areas are still in use. However, there has been natural re-vegetation of wellfields and some vehicle tracks at Honeymoon (Figure 7).

At Beverley, the old construction campsite and concrete batching areas have been rehabilitated. All buildings and utilities were removed and the areas ripped. Despite near-drought conditions, native flora has re-established at both sites (Figure 21). Monitoring of flora and fauna and sediment is detailed in Section 9.

As noted in Section 7.2, reject brine from the reverse osmosis plant at Beverley is piped to wetlands that were established around a previously free-flowing pastoral well drilled into the GAB. This well has now been capped by Heathgate Resources as part of the GAB capping initiative being implemented in South Australia. Piping the reject brine to the wetland area, and maintaining some of the previous wetland, was considered a better environmental option than disposing of it to an evaporation/holding pond.



*Figure 20 Pipeline from wellfield to processing plant, Beverley*



*Figure 21 Rehabilitation of construction camp area, Beverley*

## 9 MONITORING AND REPORTING

Heathgate Resources have an Environmental Management and Monitoring Plan (EMMP) and a Radiation Management Plan in place for their operations at Beverley, the results of which are submitted to the State Government in Quarterly and Annual Reports. Beverley's Annual Environmental Report is available to the public via the PIRSA and Heathgate Resources web sites.

Although there is no consolidated EMMP for the Honeymoon project, the requirements of such a plan are included in a number of other documents, which have been approved by the relevant State authorities. These include plans for radiation management, radioactive waste management and environmental management (physical, biological and human). These requirements would be updated and consolidated into an EMMP prior to commencement of commercial operation.

### *At Beverley*

The monitoring and reporting at Beverley, SA's only operating ISL mine, include:

- Hydrogeochemistry of aquifers including GAB— monitored on a scheduled basis
- Well-heads and pipelines for leaks and spillages
- Processing plant for leaks and spillages
- Evaporation/holding ponds for leaks
- Chemistry of re-injection water
- Leaks from solid waste disposal pits
- Radio-activity – occupational and environmental under Radiation Management Plan
- Flora and fauna
- Landscape and rehabilitation
- Other – meteorology, heritage management, community liaison

In addition to the Quarterly and Annual Reports, written reports of any spills are provided to the SA Government within 24 hours. Spill reporting is discussed in Section 6.5.

### *At Honeymoon*

The monitoring and reporting at Honeymoon, which is presently on care and maintenance, include:

- Hydrology / hydrogeology — monitored on a scheduled basis.
- Other — meteorology, waste management, evaporation/holding pond for leaks, heritage management and community liaison.
- Rehabilitation activities.
- Occupational and environmental radiation, under the Radiation Management Plan.

As for the Beverley project, in addition to the Annual Reports, written reports of any spills are provided to the SA Government within 24 hours.

Because the Beverley project is fully operational, and the Honeymoon project is a pilot scale plant on care and maintenance, the monitoring and reporting at Honeymoon is not as developed as at Beverley. The comments in the sub-sections below thus relate primarily to the Beverley operation. If the Honeymoon project were to become operational, it would be expected that a similar level of monitoring and reporting would be implemented to that in use at Beverley.

## 9.1 Hydrogeochemistry and Water Quality

At the Beverley operation, in order to detect vertical leakages into other aquifers, migration away from the well-field, chemical reactions and water balance, water levels and chemical data are collected from monitoring wells. The parameters include pH, electrical conductivity (EC), and total dissolved solids (TDS).

The chemistry and volume of the groundwater drawn from the mined aquifers is tested as per the EMMP. Likewise the water drawn from the GAB is tested, as is the liquid waste that is sent to the disposal well.

The interaction of the injected liquid waste with the water in the aquifer is monitored to ensure that chemical reaction with the groundwater does not lead to secondary mineral precipitation that could interrupt the process.

Chemical analysis of waters is undertaken on-site with duplicate monitor well water samples being sent to an external NATA-accredited laboratory on a quarterly basis.

## 9.2 Processing Plant, Wellfield and Other Infrastructure

Because of the potential for leaks at the wellheads, each one in use at the Beverley operation has a drip tray (Figure 22) fitted with a leak detector that is monitored constantly. The wellfield collection station is also fitted with instrumented drip trays. The pipeline from the wellfields to the processing plant is pressure monitored to detect any leakages. If a leak or spillage is detected, that part of the production infrastructure is shut down immediately and the cause investigated.

The processing plant is monitored at a number of locations for release of reagents and fuels. All tanks, ponds piping are inspected on a daily basis and the results recorded by the control operator on a daily inspection sheet.

At Beverley there are six evaporation/holding ponds, and one at Honeymoon. These are lined with HDPE. Each of these ponds has a leak detection system beneath the deepest portion of the pond (Figure 23). Any leak results in the liquid being transferred to another pond, and the source of the leak repaired.

As mentioned previously, there are three types of solid wastes to be disposed of – drill cuttings, non-radio-active solids and low-level radioactive waste – all of which are placed in pits. The small pits for drill cuttings are covered with soil and gamma surveys conducted prior to the well installation. The plan is for these to be repeated once rehabilitations have been completed.

Solid non-radioactive wastes are either recycled or placed in pits, which are checked weekly for water in a monitoring bore, installed nearby. The placement of such bores is crucial.

Low level radioactive waste is stock-piled and smaller items stored in 205 L drums. In the Beverley operation these drums are placed three high around the periphery of a pit with larger



items placed in the middle of each HDPE-lined pit (detail is provided in Section 7.1). Again, a leak detector has been installed.

As mentioned in Section 6.6, Heathgate Resources has prepared a Radiation Management Plan, which has been approved under the *Radiation Protection and Control Act 1982*. Environmental radiation monitoring includes, radon concentration, radon decay products and long-lives alpha activity at four sites. Results are reported to the EPA.



Figure 22 Wellhead with drip tray and online detector, Beverley



Figure 23 Evaporation pond with leak monitoring, Beverley

### 9.3 Ecological Monitoring

The flora and fauna of the Beverley lease are monitored on a quarterly basis by consultants. The purpose of this monitoring is to ensure the maintenance of native species, minimal establishment of alien species and maximum protection of vulnerable or rare species. Flora monitoring is undertaken at thirty-three photopoints, eighteen of which have an associated 10 m x 2 m quadrat. The quadrats provide information on the plant species present and their cover. Fauna monitoring uses a number of techniques to determine the various fauna present.

Because both mines occur in desert environments that are subject to flash flooding, both wind and water erosion are prevalent. Sediment sampling in the local creek systems is undertaken to determine whether sediments from disturbed areas are being transported by surface run-off. Dust is monitored and is analysed for contaminants. Most erosion occurs around well-field development and associated activities and is monitored at the photopoints.

As yet minimal rehabilitation of the landscape has been undertaken at either site, as most areas are or will be part of further mining operations. Hence there has been no effort to date to quantify the effectiveness of rehabilitation. As mentioned above, landscape monitoring at Beverley utilises both photopoint and quadrat techniques to determine the floral diversity and cover, and sediment sampling in local creek systems to determine water erosion. Each of these techniques is valid and provides useful information.

However, these floral techniques provide very little information about landscape function and are largely measuring climatic influence. Similarly, sediment sampling provides useful information concerning the amount of erosion, but nothing on its relation to the causes and implications.

Rangelands monitoring has been based on plant cover and biomass, which are time-consuming and subject to high variation between observers. The noisy data have made interpretation difficult and prediction almost impossible (Tongway and Hindley, 1999). The location of monitoring sites often ignores biophysical landscape function. CSIRO has been sponsored by the mining industry to develop a monitoring technique that not only provides a quantitative analysis of a number of indicators to assess the functional status of landscapes but also provides vectors to indicate rehabilitation success. The indices measured are:

- Landscape integrity reflecting overall resource “economy”
- Soil surface considerations, comprising
  - Stability (resistance to erosion)
  - Infiltration (capacity to absorb rain and run-off water)
- Nutrient cycling (organic matter decomposition and cycling)
- Vegetation dynamics
- Habitat complexity (a measure of development of mammalian habitat niches).

Thus, this system of Ecosystem Function Analysis (EFA) not only provides a quantitative analysis of the landscape but also provides vectors that indicate whether the landscape is moving to sustainability (Tongway and Hindley, 2003). It is recommended that this system of monitoring be utilised for rehabilitation of disturbed areas.

## 9.4 Other Monitoring

The EMMP includes other monitoring, which provides both background information and a means to assess the results measured and any associated factors. For example, meteorological data are collected continuously at the Beverley site weather tower. Wind speed, wind direction and temperature are collected at 3 m, 20 m and 28 m and recorded every 30 minutes using a continuous data logging system. Rainfall data are collected every hour. Pan evaporation is recorded on a weekly basis.

Both mines also record meetings with the local community, Aboriginal groups and Government regulators as well as visitors to the sites.

## 10 CONCLUSIONS

Any project, whether it is mining, industrial, infrastructure, residential etc, results in environmental impact. The environmental impact assessment (EIA) process is used to assess the environmental impacts of the project, and to address the potential amelioration of these impacts.

In the case of ISL mining, the primary issue in relation to the EIA process is whether the potential impacts on the aquifers, including not only the aquifer(s) in which the ore body occurs, but also other overlaying and underlaying aquifers, are acceptable.

Both the Beverley and Honeymoon projects have undergone a full EIA process in accordance with national and state procedures and were approved subject to certain conditions.

Much of the information obtained for the EIA, and the assessments in response to the EIA, along with monitoring and other reports and research of relevance has been examined by the Review Team. This has allowed us to make the following assessment on the key areas of concern.

### 10.1 Beneficial Use

The groundwater at both existing ISL mines is highly saline and also contains relatively high concentrations of radionuclides. In its untreated form it is unsuitable for human consumption, and is generally unsuitable for stock use. The only perceived beneficial use for the groundwater used in the existing ISL mining operation is in mineral processing.

The ISL process changes the nature of the groundwater – this includes pH, Eh and concentrations of dissolved species. Thus any future use, most likely by mining interests only, would need to accommodate the nature of the groundwater, which includes high levels of dissolved radioactive species. It is noted that the groundwater in its natural state at both operations also includes high levels of radionuclides, as would be expected in an aquifer in a uranium ore body. These naturally high levels of radionuclides, as well as salinity, preclude the aquifer from most beneficial uses, without treatment.

We note also that better-quality groundwater is available for stock use from different aquifers at or nearby to both the Beverley and Honeymoon projects. Desalination would be required for other foreseeable beneficial uses in the future.

### 10.2 Hydrogeochemistry

The parameters needed for modelling the hydrogeochemistry of groundwaters are all the major anions and in particular bicarbonate (alkalinity), major cations and trace elements of relevance, together with pH and redox potential (Eh). It is possible that microorganisms may have a role in the rates of natural attenuation in the mined aquifers.

At Beverley and Honeymoon, an air-lift technique is used to obtain groundwater samples for production data generation and monitoring. This technique may affect the Eh and concentrations of metals that are sensitive to changes in redox potential. The alternative extraction method using a submersible pump and which is used for some groundwater monitoring, may provide more accurate results for EC, pH, Eh, dissolved oxygen and metal content. Given the potential differences between aerated and non-aerated sample characteristics, a comparison check would determine if in particular the previously determined metal levels are valid or applicable. Similarly, the validity of the hydrogeochemical modelling is dependent on this comparison between aerated

and non-aerated samples. It will also provide a more realistic assessment of the progress of return to original groundwater conditions.

The role of microorganisms (particularly bacteria) in hydrogeochemical processes is poorly understood particularly in mined aquifers. They may have an important role in processes such as the conversion of sulfate to sulfide, with associated effects on pH, Eh, and metal solubility.

Overall the extent of groundwater monitoring around the wellfields at each of the existing ISL mining operations is comprehensive, however, there is a need to re-examine the extent of monitoring bores around the waste re-injection wells and disposal pits.

### 10.3 Natural Attenuation

Overseas operations show that natural attenuation will occur, and that natural attenuation has indeed reduced the impact from acid ISL on groundwaters and limited the seepage of leach solution from the well-fields, with eventual return to pre-mining conditions. The EIA suggests that natural attenuation will occur, however exact timeframes are not given.

The issue of predicting attenuation is made more complex by not fully understanding the microbiology or the mineralogy of the surrounding ore bodies, before and after mining, and how these natural conditions will react with the altered water quality introduced by the injection of leachate, and re-injection of wastewaters.

The monitoring results from Beverley are limited by the short duration of operations. Little recovery has occurred over 3 years, however a favourable trend is apparent (for pH only) in the Central Field Trial area. This area is now part of the production wellfield and recovery monitoring has ceased. Post-mining monitoring of the wellfields and liquid waste disposal injection areas will be required.

Natural attenuation is preferred to adjusting the chemistry of the wastewater prior to re-injection as the latter would result in the need for additional chemicals on-site, generation of contaminated neutralisation sludges which would have to be disposed of, risk of potential clogging of pore spaces in the aquifer and associated higher costs.

Overall, we consider that remediation of groundwaters already impacted by mining and re-injection appears to be unwarranted because of its perceived limited beneficial use and also its expected natural attenuation.

### 10.4 Solid Waste Repository

The solid waste repository seen at Beverley has an underfloor monitoring system, however there is no groundwater monitoring in place. In particular, it is considered that groundwater monitoring of the upper aquifer (the Willawortina) around the repository area should be provided – a minimum of one monitor well upstream and two downstream.

It is noted that the Audit of Radioactive Waste in South Australia (SA EPA, Sept 2003) states that the operation of the solid waste holding area at Beverley is in accordance with current approvals under the Radioactive Waste Management Code. This refers to the *Code of Practice for the Disposal of Radioactive Wastes from the Mining and Milling of Radioactive Wastes* (1982).

The Heathgate Annual Environment Report 2002 states that during the reporting period of the report, a 10 m x 10 m cell was constructed filled and capped as per the Mining and Rehabilitation Plan (MARF) and the requirements of the EPA and PIRSA. It was stated that the cell was lined with HDPE and completely contained with compacted clays. It is difficult to see how the cell

could be completely contained with compacted clays; presumably the discussion may be referring to a compacted clay base and a compacted clay cover. The permeability specification and depth of coverage by the cap, which is the most critical design parameter, is not stated.

## 10.5 Landscape Monitoring

The principal surface impact of the acid ISL uranium mining operations are the wellfield areas including bores and pipelines, the processing plant and evaporation ponds areas, roadways and the airfield, and accommodation / office areas. During construction of facilities and laying of pipes, effort is made to reduce the surface impacts that may lead to erosion or disturbance of flora and fauna.

The planned decommissioning and rehabilitation of surface-disturbed, mined-out areas has not yet commenced at either the Beverley or Honeymoon sites, as the initial areas are still in use. However, there has been natural re-vegetation of a trial wellfield at Honeymoon (Figure 7) and some vehicle tracks.

In comparison with other uranium mines (open-pit and underground) the 'footprint' of the ISL operations is small. Because of the simplicity of the process, the surface environmental impact is also minimal in comparison to other mining operations.

At Beverley, the current landscape monitoring is based primarily on photopoint monitoring. However, many mining sites now undertake ecosystem function analysis to demonstrate the success of rehabilitation, and this would be considered beneficial at Beverley and Honeymoon once full rehabilitation programs are in place.

## 10.6 Alternatives to Liquid Waste Re-Injection

Suggestions made during the community consultation process included not re-injecting the liquid wastes into the aquifer, and neutralisation of waste before re-injection.

Not re-injecting the waste into the aquifer would require either sophisticated water treatment and/or the installation of much larger evaporation ponds. Both would generate solid wastes to be disposed of in a solid waste repository. When the wastes dried out they would become a possible dust source, which could increase the potential radiation exposure of workers, in particular in relation to dust inhalation, but also from radon inhalation and gamma exposure. Environmental radiation levels at the surface would also increase. These are presently negligible issues associated with the existing ISL practices.

Neutralisation of the waste liquid prior to re-injection would precipitate out some metal salts, which would need to be filtered before re-injection, and be disposed of in a solid waste repository. Also following re-injection it is likely that the re-injection bores would rapidly clog owing to precipitation around the bores, as the injected water and existing acidic water in the aquifer interact. Clogging of re-injection wellfields and associated problems with pipelines and pumps may increase the risk of spills due to operational problems with equipment and increased maintenance.

A further alternative suggested during the review consultation stage is to use a reverse osmosis plant to concentrate the liquid waste, and re-inject the treated water into the aquifer, and dispose of the remaining brine in evaporation ponds. The advantage of re-injecting concentrated reject brine into the aquifer is not clear.

Another approach to reduce liquid waste re-injection is to assess the sources/volumes of waste liquors and seek to minimise these volumes through recycle and re-use in other areas of the

process. Whilst this is already done, opportunities for further re-use should be considered on an ongoing basis.

## 10.7 Alternatives to ISL Mining

The main alternatives to ISL are underground and open-pit mining. However these two options are not economic for the low-grade deposits as found at Beverley and Honeymoon at present prices. Importantly, they would create significant environmental impact at the surface where the uranium is processed. Open cut mining would have a large surface impact, both in terms of the pit and also for disposal of overburden, and it would also have a significant impact on the groundwater environment.

Underground mining is not considered feasible for either of the existing SA ISL projects owing to the sandy and collapsing nature of the sediments, as well as for economic reasons. As the ISL method requires a uranium ore body in an aquifer, any future potential ISL projects would also be unlikely to be amenable to underground mining. Underground mining also has a significant impact on the groundwater environment.

An experimental technique using an automated, self-propelled remote mining tool may have future applicability, but has many of the disadvantages of conventional underground mining in the circumstances of the SA ISL uranium mines.

Alkaline ISL is an alternative to acid ISL. Alkaline leaching will yield lower extractions of uranium and considerably increase the duration of wellfield operation, as it will take longer to extract similar amounts of uranium from greater volumes water. Alkaline leaching offers some advantages in regard to the quality of groundwater immediately following the cessation of mining for some ISL applications. The reduced impact on groundwater quality is not considered to offer any benefits in the circumstances of the SA ISL uranium mines, as potential uses of post mining water are not affected.

Heap leaching is an alternative to the normal milling process, however, it requires the ore to be brought to the surface where leaching then takes place. This creates significant environmental problems with regard to the management of the heaps, and it is also provides extremely slow recovery of uranium and low yields. For reasons given above, the use of heap leach processing at the existing ISL operations (and possible future ISL operations) would require open pit mining. The footprint of a heap leaching operation would be similar to an open pit operation. The radiation risk to workers would be increased significantly.

Bacterially assisted leaching has been used in underground mines, and it is also the subject of ongoing research. However, without having it shown to have the potential to provide an improvement over conventional ISL, it is unlikely to be considered by mining companies.

## 10.8 Summary

Based on this Review, and taking into account all factors, we are of the opinion that the present acid ISL mining of uranium and associated disposal of wastes in South Australia is more cost effective and environmentally responsible than any suggested alternative techniques. The Beverley operation, as the only existing mine, has initiated and implemented world best practice methods.

## 11 RECOMMENDATIONS

1. The existing acid ISL mining of uranium at Beverley and that proposed for Honeymoon and the associated disposal of wastes should be allowed to continue without major changes.
2. A comparison of monitored hydrogeochemical parameters using aerated and non-aerated sampling techniques should be undertaken to validate existing data and provide guidelines for future groundwater sampling.
3. Measurements of Eh as a critical parameter in the aquifer should be undertaken on a regular basis and reported with other data.
4. Further investigation of the mineralogy of mined-out areas and comparison with pre-mining mineralogy is warranted.
5. Further hydrogeochemical modelling using validated geochemical and mineralogical data should be undertaken to check on the progress (current and expected) to natural groundwater conditions (natural attenuation).
6. The number of monitoring bores around the waste injection bore and waste disposal pits at Beverley should be examined to confirm whether the present number is considered to be adequate, with three additional Willawortina Formation wells around the Beverley waste disposal site recommended.
7. Although not necessary for the continued disposal of liquid wastes, research into the microbiology of the aquifer and its impact on natural attenuation processes could be sponsored by the mining companies.
8. Additional monitoring and consideration of the outcomes from the recommended investigations would provide greater confidence in the prediction of the extent and rate of natural attenuation.
9. The role of chemical amendments should be investigated if after continued monitoring, natural attenuation processes appear to be slow or non-existent.
10. Inspections should be undertaken to confirm that the EPA licence and Mining and Rehabilitation Plan requirements in regard to any conditions relevant to the Beverley low-level radioactive waste repository design are being met, particularly in regard to clay cap specifications and thickness, erosion protection, and monitoring of seepage.
11. The current landscape and faunal monitoring should be updated to incorporate Ecosystem Function Analysis.
12. Surface-based alternatives to re-injection of liquid wastes should not be considered further because of increased environmental impacts and radioactivity hazards.
13. Presently available alternative mining technologies are unlikely to offer environmental improvements over the acid ISL method used at Beverley and proposed for use at Honeymoon, and are therefore not recommended.

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# APPENDICES

## ISL Steering Committee - Terms of Reference

The ISL steering committee will assist the EPA in the conduct of a review into the environmental impacts of the acid in-situ leach uranium mining process by:

1. Setting the criteria for the selection of a suitable consultant to undertake the project;
2. Short listing tenderers and providing a recommendation to Cabinet;
3. Acting as a reference group for the project consultant during the course of the consultancy;  
and
4. Reviewing and commenting on the draft project report.

### Membership

<b>Organisation</b>
Director, Pollution Avoidance Division, EPA
Executive Director, Minerals, Petroleum and Energy
Principal Environmental Officer, Environmental Impact Assessment Unit, Planning SA
Radiation Protection Division, EPA
Director, Resources Development Infrastructure Initiatives, Office of Economic Development
Conservation Council of South Australia Inc.
South Australian Chamber of Mines & Energy
Manager, Resource Planning Resource Assessment, Dept of Water, Land and Biodiversity Conservation
Manager, Aboriginal Heritage Language and the Arts Group, Dept of Aboriginal Affairs & Reconciliation (DAARE)

## Recommendations from the Bachmann Review (2002)

Recommendation from the report were that the government adopt the following measures:

1. A register of incidents should be kept at each mine site. Incident registers should be available to the regulatory agencies as required and made available for perusal at the three-monthly ISL Radiation Review Committee meetings held between mine management and Government regulatory agencies.
2. In order to allow the release of information about incidents which may cause, or threaten to cause, serious or material environmental harm or risks to the public or employees, the Government should revise and appropriately amend the secrecy/confidentiality etc. clauses in the legislation referred to in Appendix B. Information on individual persons should not be disclosed.
3. The incident reporting requirements as set out in Appendix D should be adopted. If legislative change occurs which affect the reporting requirements, they will need to be further reviewed having regard to any legislative change made.
4. The Chief Inspector of Mines should be required to forward a copy of any incident report form received to Environment Australia and the Department of Industry, Tourism and Resources.
5. Current reporting arrangements should be varied to ensure that all agencies are informed at the same time. I recommend that required incidents be reported to the three agencies by facsimile or email.
6. An incident reporting form (see Appendix E) should be adopted by all regulatory agencies involved in the regulation of mining and milling of uranium ore.
7. If the Mining Act and the Radiation Protection & Control Act continue to apply, public notification should be made of those incidents which cause or threaten to cause, serious or material environmental harm through the Minister for Mineral Resource Development or the Office of Minerals and Energy Resources.
8. A protocol should be put in place such that, when a significant incident arises, a lead agency and a lead Minister are identified (as has been done in the area of water contamination involving the Department of Human Services and S.A. Water).

## Glossary

<b>Alpha emitter</b>	A radioisotope that emits an alpha particle during radioactive decay
<b>Alpha particle</b>	Positively charged particle of two protons and two neutrons emitted by some radioisotopes. Least penetrating of three forms of radiation (alpha, beta and gamma).
<b>Aquifer</b>	Permeable underground soil or rock formation capable of storing and allowing flow of water.
<b>Aquitard</b>	An underground soil or rock formation that retards, but may not entirely prevent, the flow of water.
<b>Barren solution</b>	Leaching solution from which uranium has been extracted. After fortification with sulfuric acid (when necessary) and hydrogen peroxide, this is re-injected into the mining aquifer.
<b>Beta particle</b>	Electron or positron emitted by the nucleus of a radionuclide during radioactive decay. Penetrates paper but not metal.
<b>Bq/L</b>	Becquerel per litre, a measure of radioactivity (defined as one radioactive disintegration per second).
<b>Bund</b>	An earth, rock or concrete wall constructed to prevent the inflow or outflow of liquids.
<b>Complexing</b>	Process of converting insoluble minerals to a form that may be transported in solution. Complexing agents are chemicals that achieve this.
<b>Decay product</b>	Product of spontaneous radioactive decay of a nuclide. One of a sequence of radioisotopes through which a nuclide decays..
<b>Dose</b>	Radiation energy absorbed in a mass unit of material
<b>Dose equivalent</b>	Mathematical product of the absorbed dose, quality factor and other specified modifying factors. The quality factor accounts for the effectiveness of energy transfer of the ionising radiation in causing biological damage. Modifying factors change the effect of the energy absorbed.
<b>Eluant</b>	Chemical solution for elution process.
<b>Elution</b>	Removal of uranium captured by ion or solvent exchange.
<b>Gamma radiation</b>	Form of electromagnetic radiation similar to light or X-rays, characterised by high energy and strong penetration of matter. Emitted from a nucleus left in an excited state after emission of alpha or beta particle.
<b>Great Artesian Basin</b>	A groundwater basin covering about one-fifth of Australia that includes an artesian aquifer whose potentiometric surface is above the land surface in topographically lower parts of the area.
<b>Groundwater</b>	Underground water contained within an aquifer.
<b>Hydrogeology</b>	The science dealing with groundwater and with related geological aspects of surface water.
<b>In- situ leach (ISL)</b>	Chemical leaching of ore by circulating leachate through the orebody.
<b>Ion exchange</b>	Transfer of uranium from pregnant lixiviant to resin beads in an ion exchange column.

<b>Ionising radiation</b>	Radiation which when absorbed causes electrons to be added or removed from atoms in absorbing matter, producing electrically charged particles called ions. This process is known as ionisation.
<b>Isotope</b>	Different forms of a chemical element having the same number of protons in their atoms, but a different number of neutrons. All isotopes of a chemical element have the same chemical properties.
<b>Leachate</b>	In this report, groundwater treated with acid or alkali and other chemicals to allow the in situ dissolution of uranium from the orebody.
<b>Lixiviant (Leachate)</b>	Water from an ore zone aquifer, to which complexing agents and oxidants have been added to enable leaching of minerals from ore when the lixiviant is circulated through the ore body.
<b>Mineralisation</b>	Term used almost exclusively for the introduction of ore minerals and gangue (valueless) minerals into pre-existing rocks, whether by veins, replacement or in a dissemination fashion.
<b>Natural attenuation</b>	Process occurring without the addition of amendments which over a period of time results in the composition of a liquid returning to or towards its pre-contaminated state. In this context, the process occurs within the aquifer.
<b>Nuclide</b>	See isotope.
<b>Orebody</b>	Soil or rock containing minerals of economic value.
<b>Oxidant</b>	A substance that promotes oxidation - gives up oxygen easily, removes hydrogen from another compound, or attracts negative electrons.
<b>Palaeochannel</b>	Ancient river or stream channels that have been preserved in sedimentary rocks.
<b>Permeability</b>	The capacity of a porous rock for transmitting a fluid.
<b>pH</b>	Measure of the intensity of acidity/alkalinity. Numbers above 7 are increasingly alkaline, below 7, increasingly acidic. pH 7.0 is the pH of pure water.
<b>Photopoint</b>	A designated point on the ground from which photographic records of progress of vegetation changes are made, usually on a six-monthly or yearly basis.
<b>Pilot plant</b>	A small version of a planned industrial plant, built to gain operational experience and determine performance characteristics.
<b>Pore volume</b>	Total volume of the space in rock or soil that is not occupied by solid mineral matter.
<b>Radioisotope</b>	Isotope that is unstable and undergoes natural radioactive decay.
<b>Radionuclide</b>	Same as radioisotope, see above.
<b>Radon</b>	Heaviest of the inert gases. Predominant isotope is radon-222, a decay product of radium-226. It has a half-life of just under 4 days and decays to polonium-218 by emitting an alpha particle.
<b>Redox potential (Eh)</b>	A measure of the oxidising or reducing tendency of a solution, expressed in millivolts, where more positive values represent oxidising conditions and more negative values represent reducing conditions.
<b>Rehabilitation</b>	The process of restoring land disturbed by mining to either its pre-mining condition or to a state acceptable to the community.



<b>Ripping</b>	Breaking, with a tractor-drawn ripper or a long-angled steel tooth, compacted soils or rock into pieces small enough to be economically excavated or moved by other equipment.
<b>Roll-front deposit</b>	Mineral deposit formed within porous rocks e.g. sandstone when naturally mineralised groundwater is subjected to changes in Eh and pH causing precipitation of the mineral. It most commonly applies to uranium deposits but may include copper.
<b>Sedimentary rocks</b>	Those formed by deposition by wind, water or ice, by chemical precipitation, or by secretion by organisms.
<b>Sievert (Sv)</b>	Unit of measurement of effective dose. One Sievert equals the product of the absorbed dose, quality factor and modifying factors. Allows comparison of relatively greater biological damage caused by particles such as alpha particles and fast neutrons. For most beta and gamma radiation, one Sievert is equal to an absorbed dose of one joule per kilogram of biological matter.
<b>Solvent extraction</b>	Separation process in which a water-based and an organic-based solvent are brought into contact to recover a component, in this case uranium.
<b>Sorption</b>	A surface phenomenon that may be either absorption (penetration of one substance into the body of another) or adsorption (taking up of one substance at the surface of another), or a combination of the two.
<b>Uranium decay series</b>	Series of radionuclides produced in the decay of radioactive uranium to stable lead.
<b>Well casing</b>	In unconsolidated sands wells must be cased using black steel pipes, for structural purposes to ensure that the hole does not cave. It also prevents exchange of liquor from the inside to the outside.
<b>Yellowcake</b>	In this report the term yellowcake refers to uranium peroxide ( $\text{UO}_4 \cdot 2\text{H}_2\text{O}$ ), which is the product from both the Beverley and proposed Honeymoon operations.

## Abbreviations

The abbreviations for measurements and chemical formulae used in the document are listed below, followed by other abbreviations used in individual chapters and appendices.

<b>ANSTO</b>	Australian Nuclear Science and Technology Organisation
<b>ANZECC</b>	Australian and New Zealand Environment and Conservation Council
<b>ARPANSA</b>	Australian Radiation Protection and Nuclear Safety Agency
<b>ARPANSA 2001 Code</b>	<i>Code of Practice for the Safe Transport of Radioactive Material 2001</i>
<b>CSIRO</b>	Commonwealth Scientific and Industrial Research Organisation
<b>DAIS</b>	Department for Administrative and Information Services
<b>DWLBC</b>	Department of Water, Land and Biodiversity Conservation
<b>EIS</b>	Environmental Impact Statement
<b>EMMP</b>	Environment Management and Monitoring Plan
<b>EPA</b>	Environment Protection Authority, South Australia
<b>EPBC Act</b>	<i>Environment Protection and Biodiversity Conservation Act 1999</i> (Comm)
<b>GAB</b>	Great Artesian Basin
<b>HDPE</b>	High density polyethylene
<b>IAEA</b>	International Atomic Energy Agency
<b>ICRP</b>	International Commission on Radiation Protection
<b>ISL</b>	In-situ leaching
<b>MARP</b>	Mining and Rehabilitation Plan
<b>NHMRC</b>	National Health and Medical Research Council
<b>NHMRC 1992 Code</b>	<i>Code of Practice for the Near-Surface Disposal of Radioactive Waste in Australia 1992</i>
<b>PIRSA</b>	Primary Industries and Resources SA
<b>TDS</b>	total dissolved solids

## Measurements

Technical units of measurement in this report are based on the International System of Units (SI) wherever possible. These technical units may be broadly grouped as prefixes and measurements. A prefix applies to the unit of measurement that immediately follows it, for example, milligram is abbreviated as mg.

Superscripts <sup>2</sup> and <sup>3</sup> following a linear unit indicate area and volume respectively, for example, m<sup>2</sup> (square metres) and m<sup>3</sup> (cubic metres). A solidus (/) is used to indicate 'per'. For example, kilometres per hour is abbreviated as km/h, and megalitres per day per square kilometre is ML/d/km<sup>2</sup>.

## Prefixes

G	giga	1 000 000 000
M	mega	1 000 000
k	kilo	1 000
m	milli	0.001
μ	micro	0.000 001
n	nano	0.000 000 001

## Units of Measurement

Bq	Becquerel (radioactivity)
°C	degrees Celsius
d	day
Eh	redox potential
g	gram
ha	hectare
L	litre
m	metre
m <sup>2</sup>	square metre(s)
m <sup>3</sup>	cubic metre(s)
pH	degree of alkalinity/acidity
ppt	parts per thousand
ppm	parts per million
s	second
Sv	Sievert (radiation dose)
t	tonne
yr	year

## Chemical Symbols and Formulae

Ra	radium
Rn	radon
Th	thorium
U	uranium