An Environmental Critique of In Situ Leach Mining :

The Case Against
Uranium Solution Mining

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A Research Report for
Friends of the Earth (Fitzroy) with
The Australian Conservation Foundation

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Preface

The mining and export of Australian uranium has been a controversial issue for many years, and will continue to remain an intense political issue for many more years to come. With a depressed world uranium market, the mining industry has been seeking to cut costs in order to make projects more economically viable. One such method of achieving this is a mining process known as In Situ Leaching (ISL) or Solution Mining. It involves pumping chemicals into the ground to dissolve the uranium mineral *"in situ"* and then pumping these uranium-laden solutions back to the surface for extraction and processing of the uranium into yellowcake for export.

It is claimed by the industry to be "a controllable, safe, and environmentally benign method of mining which can operate under strict environmental controls and which often has cost advantages"[1]. This ignores the reality of many former ISL trials and mine sites across Europe and North America, and the history of ISL trial mines in Australia.

The technique of In Situ Leaching is ***not*** always controllable, safe, nor environmentally benign, and the hidden costs are usually borne by the underground environment. The process of ISL can lead to permanent contamination of groundwater, which is often used by local people and industries for drinking water supplies, and can also contaminate land which was otherwise good agriculturally productive land.

Australia is currently assessing two proposed uranium ISL mines in north-eastern South Australia, within the Lake Frome Basin. There are more deposits across Australia that would only be economic by using the ISL technique and are waiting further exploration or commercial commitment. In an attempt to document the truth of this technology and thereby influence the debate on ISL, Friends of the Earth (Fitzroy) (FoE) and the Australian Conservation Foundation (ACF) commissioned this report.

It covers the environmental importance of groundwater in the wider hydrologic cycle and the Australian environment, how the process of In Situ Leach mining works, potential technical, radiological and environmental problems that can arise, an extensive review of sites where ISL has been employed internationally, especially in the United States and Eastern Europe, and the trial experience with ISL in Australia.

The claims of the industry are then disputed and shown to be questionable.

We hope this is a valuable contribution to the "debate".

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[1] *In Situ Leach Mining of Uranium,* Nuclear Issues Briefing Paper 40 - June 1997, Uranium Information Centre, Melbourne.

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Summary - ISL Mines the World Over

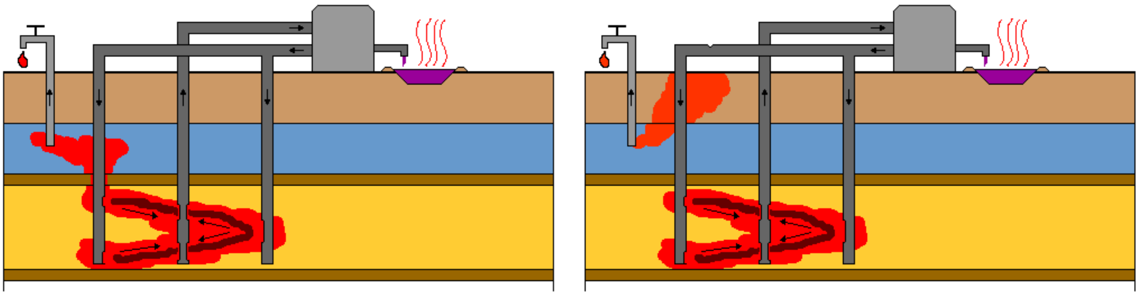
In Situ Leach (ISL) or Solution Mining is a third alternative mining technique, quite different to conventional open cut or underground mining and milling operations. The ISL process can be applied to the extraction of uranium, copper, silver, gold, nickel and many other metals. For an ore deposit to be amenable to ISL it must occur within permeable materials, such as sands or sandstones, be saturated (ie - within an "aquifer" or groundwater system), and be confined above and below by low permeability materials (such as clays or shales). Given these general criteria, chemical leaching solutions are pumped into the ore deposit "In Situ" and dissolves the metal of interest. These metal-laden solutions are then pumped back to the surface and extracted in a processing plant. In this way, instead of the ore being excavated, crushed and chemically treated in a large surface processing plant, the process chemicals are injected underground into the ore directly. As such, the ISL technique generally has lower production costs than conventional mines. The ISL mining method has many advantages as well as inherent problems, and the success of this technique applied to the extraction of uranium is contained within this report and briefly summarised here.

The ISL Technique

The ISL technique, as described above, involves the drilling and operation of an extensive series of groundwater bores, injecting and extracting the chemical solutions continuously. There are two main options for the leaching chemistry - acid or alkaline solutions. In general, acid solutions (such as sulphuric acid) will extract a higher proportion of uranium and at faster rates than alkaline solutions (such as sodium or ammonia bicarbonate). However, acidic solutions will also mobilise high levels of environmentally sensitive and toxic heavy metals (such as cadmium, selenium, vanadium, lead, and others). The level of radionuclides, such as radium, mobilised from the ore into processing solutions tends to be higher in alkaline solutions.

The most critical part of the ISL process is to control the movement of the chemical solutions within the aquifer. Any escape of these solutions outside the ore zone is considered an excursion, and can lead to contamination of surrounding groundwater systems. Some of the most common causes of excursions, identified by international operations in the United States and across Europe, can be through old exploration holes that were not plugged adequately, plugging or blocking of the aquifer causing excess water pressure buildup and breaks in bores, and failures of injection/extraction pumps.

Examples of Failure and Contamination of Groundwater from ISL



After the ore has been depleted and the maximum degree of uranium extraction achieved, it is good policy and (generally) a legal requirement to restore the water quality of the groundwater system that was mined to it's pre-mining level. That is, remove all of the remaining chemicals from the aquifer and return the uranium and heavy metals to their original concentrations. In practice, this is extremely hard to achieve, especially with acidic solutions. Despite nearly 25 years of commercial ISL uranium mines in the United States (all using alkaline leaching solutions), regulators are yet to review or approve a report on the full scale restoration of groundwater at these sites, although they describe the restoration at earlier pilot sites as "satisfactory".

With the current proposals at Beverley and Honeymoon in South Australia, and presumably for the new proposal at Manyingee in Western Australia, the restoration of groundwater is not planned nor is it being required by the regulators.

United States Experience

Texas has been the most prolific state for development of ISL uranium mines, with Wyoming also being popular for ISL sites. The first trial of ISL uranium mining was conducted at the Shirley Basin deposit by then Utah Construction & Mining Company[2] in the early 1960's with operation of an experimental full scale mine in the late 1960's. It was shut down and converted to a traditional open cut mine. The uranium industry, keen to cut costs to compete with developing overseas uranium mines, nevertheless enthusiastically developed new ISL trials and by 1975, the first large scale commercial ISL uranium mine opened in Texas at Clay West. By 1992, there had a total of 62 sites where ISL had been applied, only 24 of which reached commercial production of uranium. Currently, due to the depressed nature of the world uranium market and higher costs at conventional mines, only 5 ISL uranium mines are operating in the USA, despite 12 being licensed.

The early ISL mines, such as Irigary Wyoming and Clay West/Burns in Texas, had many technical problems which led to poor operational and environmental performance. These included mineral precipitation of gypsum ($CaSO_4$) and calcite ($CaCO_3$) plugging the aquifer, restricting groundwater flow and exacerbating excursions; complex reactions of chemicals with clays in the aquifer soils leading to permeability loss; excursions through old exploration boreholes; and excursions outside the mining zone. Problems were also noted with radiation levels, especially at some Texan ISL mines. The restoration of groundwater at many sites was not successful, and companies lobbied regulators to relax cleanup standards, and some sites still had significant problems even meeting these standards. The design of processing plants and infrastructure was also inadequate at some sites.

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[2] - Changed to Utah International, now Pathfinder Mines Corp., owned by Cogema of France.

International Experience

The ISL mining technique has been enthusiastically employed at many uranium deposits across Eastern Europe and the Commonwealth of Independent States (CIS). However, the regulators and environmental policies of many of these countries was not, arguably, of a similar status as their United States counterparts. There is now a legacy of many contaminated sites and polluted groundwater across Bulgaria, the Czech Republic, the CIS and Germany, with some sites considered severe.

The majority of the ISL projects used sulphuric acid and the residual leaching solutions from ISL mines have migrated away from the mining zones. At some sites, notably in Bulgaria and the Czech Republic, these solutions have led to contamination of good quality groundwater systems that are used by nearby towns for their water supply or by local residents as their primary drinking water source. In some cases, the contaminated solutions have been demonstrated to reach these wells and valleys.

The chemical toxicity of these solutions, as well as their radiotoxicity, are a grave concern for modern regulators faced with the intractable cleanup problems now faced by the governments of the countries involved. At the Stráz site in the Czech Republic, the mined aquifer will never be able to be restored to it's pre-mining water quality, and all restoration efforts are merely aimed at minimising contamination of surrounding groundwater. The cleanup of many sites is expected to take some decades, or even centuries.

Australia's Trial of ISL

There has been two previous trials of ISL uranium extraction in Australia at Honeymoon, SA, in 1982 and at Manyingee, WA, in 1985. There are currently two trials operating, prior to Environmental Impact Statements being released or approved for Beverley, SA, and again at Honeymoon, SA, both starting in early 1998. The early trials, however, encountered significant operational and environmental problems which, combined with effective campaigning from the anti-nuclear movement across Australia, led to their refusal for further development.

The Honeymoon ISL trial in 1982 used sulphuric acid and iron sulphate leaching chemistry, and had problems with jarosite[3] precipitating and plugging the flow of leaching solutions through the aquifer. The problems were completely unexpected and led to difficulties with performance of the trial. To date there has been no disclosure of the results and environmental problems of that trial by the companies involved or the SA government.

The ISL trial during 1985 at Manyingee, north-western WA, trialled sodium bicarbonate and hydrogen peroxide leaching solutions. It lasted for a total of 6 months and injected a total of 40.5 million litres into the ore zone aquifer. There was confusion about the trial project, especially with regards to the quantity of uranium produced, where it was stored, and operational and environmental performance of the trial.

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[3] - jarosite is a potassium-iron-sulphate mineral, $KFe_3(SO_4)_3.9H_2O$.

Both the Honeymoon and Manyingee trials were not required to restore groundwater following their respective ISL trials.

With the election of the Howard Coalition government to federal government in March 1996, the old projects of Beverley and Honeymoon were quick to re-apply for development. By late 1997 they had prepared and submitted plans for ISL trial mines, and these were approved by the SA government without hesitation or public scrutiny. These trials began operation in early 1998. Heathgate Resources, subsidiary of US giant nuclear multinational General Atomics and the company behind the current proposal for Beverley, released it’s EIS for an ISL mine on June 29. The new EIS for Honeymoon and extension deposits is expected towards the end of 1998.

Both of the current ISL trials at Beverley and Honeymoon have ignored the numerous potential problems found at ISL mines overseas, and especially at Honeymoon the problems of jarosite precipitation are not given any technical attention as to their cause or control. There can be significant problems expected during the operation of these trials.

The Manyingee deposit was bought by Paladin Resources in June 1998 and they immediately announced plans for an ISL mine within the next two to three years.

The Future of ISL ?

The technique of In Situ Leach uranium mining clearly entails many significant operational and environmental problems. However, as the nature of ISL mining is underground, and essentially *“Out-of-sight and Out-of-mind”*, these problems are ignored by the most toxic industry known to humanity. Successive state and federal Liberal governments appear to be blandly accepting company arguments over jobs at the expense of precious environmental assets and groundwater resources on the driest continent on the planet.

It is recommended that all current plans and operations be closed down until a full public assessment has been conducted and the restoration of groundwater proven to be successful.

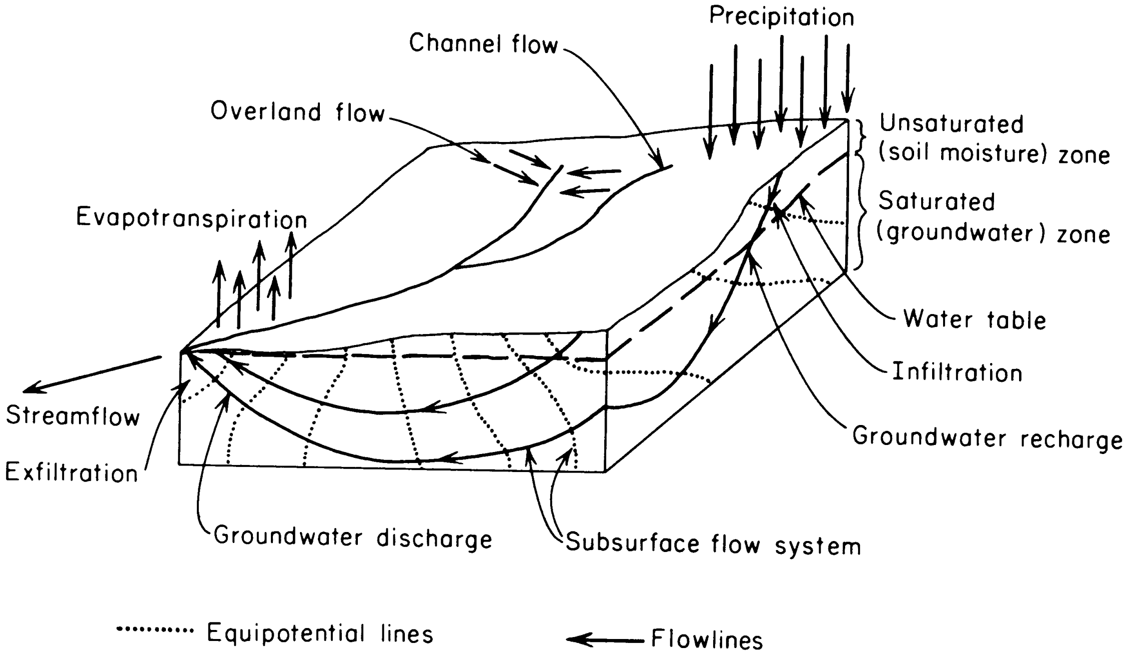
The technique of In Situ Leaching is :

- **not controllable,**
- **inherently unsafe,**
- **unlikely to be able to meet “strict environmental controls”,**
- **not an environmentally benign method of mining.**

1 - Groundwater In The Environment

The hydrologic cycle is the term used to describe the perpetual movement of water between the oceans, the atmosphere and the land. Water is cycled between rainfall, rivers and lakes, soil moisture for use by vegetation and the ecosystem, the atmosphere, and storage deeper in subsurface materials. It is the storage of water in subsurface soils and rocks, known as aquifers or groundwater basins, and their slow release to surface water systems, that maintains baseflow in rivers between rainfall events (Dillon, 1995).

Figure 1 - Schematic Representation of the Hydrologic Cycle (Freeze & Cherry, 1979)



If one was to determine the total volumes of water involved in each part of the environment, it would be found that second to the oceans and seas of the world, groundwater is the second most abundant source of water with approximately 4% of the world's water being found underground (Freeze & Cherry, 1979). Groundwater can therefore be considered an important, perhaps critical, part of the hydrologic cycle. It is simply that part of the underground or geologic environment where water can be found, typically in porous rocks that allow for the storage and flow of fluids such as sandstones.

Despite the volumetric superiority of groundwater to surface waters, the residence times are substantially different. The residence time for water in a river channel is of the order of weeks, whereas for some groundwater systems it can be of the order of 10's or 1,000's of years. The Great Artesian Basin (GAB), one of the world's largest and oldest groundwater systems covering 1.7x10^6 km^2 of Queensland, New South Wales and parts of South Australia and the Northern Territory, has residence times estimated to be greater than 1,000,000 years (Habermehl, 1980; Bentley *et al.*; 1986, Torgersen *et al.*, 1991).

Table 1 - Estimates of the World Water Balance (Freeze & Cherry, 1979)

	Surface Area 10^6 km^2	Volume 10^6 km^3	Volume %	Equivalent Depth m*	Residence Time
Oceans and Seas	361	1370	94	2500	~ 4,000 years
Lakes and Reservoirs	1.55	0.13	<0.01	0.25	~ 10 years
Swamps	<0.1	<0.01	<0.01	0.007	1 - 10 years
River Channels	<0.1	<0.01	<0.01	0.003	~ 2 weeks
Soil Moisture	130	0.07	<0.01	0.13	2 weeks - 1 year
Groundwater	130	60	4	120	2 weeks - >10,000 years
Icecaps and Glaciers	17.8	30	2	60	10 - 1,000 years
Atmospheric Water	504	0.01	<0.01	0.025	~ 10 days
Biospheric Water	<0.1	<0.01	<0.01	0.001	~ 1 week

* Assuming uniform distribution across the entire surface of the earth.

This stark difference in residence times leads to the necessary conclusion that if the ecological integrity of a groundwater system is not maintained, it may take a considerable amount of time to re-establish.

Initial studies of groundwater earlier in this century focused on the potential water yield of a system, and more recent years has seen increasing concern over contamination and groundwater quality (Fetter, 1993). However, it is only in the past decade that the myriad of complex environmental functions that groundwater performs have been recognised.

Groundwater provides a source of drinking water for many parts of the world, with groundwater in the United States providing over 40% of public water supplies (Fetter, 1993). In addition to providing a source of water, groundwater performs many important ecological functions. These include discharge to streams and rivers to maintain baseflows, discharge to springs and interaction with other surface water systems. If the groundwater becomes contaminated, this could persist for the residence time of the groundwater system, creating a significant risk to the functioning of ecological systems, a problem widely recognised in Melbourne’s western suburbs (CSIRO, 1996).

1.1 Groundwater Geology - Where is Groundwater Found ?

The nature and location of groundwater is controlled by the formation and structure of the geology of a region. This can be related to sedimentary materials such as sands and gravels, or various rock types such as sandstones or fractured limestones and granites. As such, groundwater can be found almost wherever one cares to look - it is merely a question of how deep one must drill. However, the flow of groundwater from that system may not be sufficient to yield useful quantities of water.

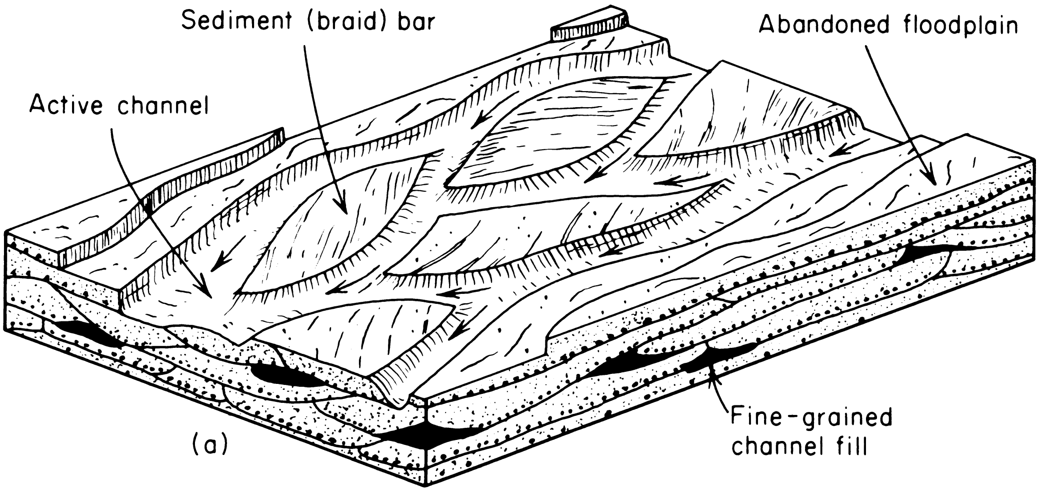
In many cases the pressure of water within a groundwater basin will allow it to flow above the ground surface if a bore or well is drilled into the aquifer. This is known as artesian pressure, and is related to a layer of clay or lower permeability[1] material (known as an aquitard) confining the water to that aquifer and thereby leading to a higher water pressure.

Sedimentary Groundwater Systems

Groundwater is commonly found in the materials laid down by river channels and floodplains. This includes gravel, sand, silt or clays. A layer of sand might be deposited under a particular environment, and over time water accumulates forming an aquifer or groundwater reservoir. They are known as alluvial deposits or aquifers, and due to the inherent complexity of shifting river channels and ever-changing flow velocities, the exact layering and connection of sands or clays can be difficult to determine, even with an extensive number of boreholes. Two distinct types of alluvial deposits are recognised - braided river and floodplain alluvial deposits (Freeze & Cherry, 1979).

Braided river environments generally occur in settings where the sediment available for transport has considerable coarse-grained sand or gravel and where river velocities are large due to steep regional topography. Sequences of sands and gravels can develop, with only minor zones of silty or clayey sediments. The flow of groundwater through an old braided river bed can often thus be unpredictable due to complex channels and bars (braids) that are formed during deposition.

Figure 2 - Braided River Environment (Freeze & Cherry, 1979)



Floodplain river environments also contain coarse-grained deposits of sands and gravels, but are typically dominated by fine-grained silty or clayey deposits. They are characterised by lower slopes and smaller flow velocities. The complex channels that are formed are also highly variable and very difficult to characterise with borehole data.

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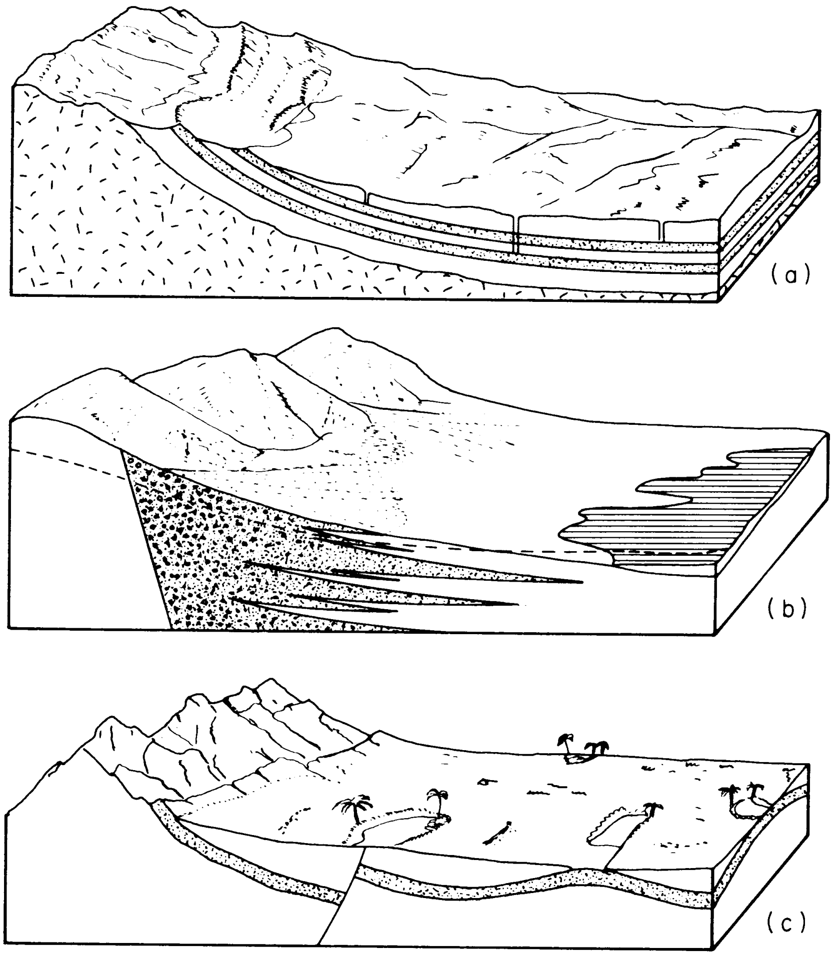
[1] permeability - the rate at which groundwater can flow through a particular material (typically expressed in metres/day or metres/second).

Other types of sedimentary type groundwater systems are formed by the action of winds (aeolian deposits) or glaciers. They are also highly variable, and are characterised by fractures and variable properties. Fractures, or lines where the sediments are discontinuous, often provide avenues for groundwater flow to escape.

Rock-Based Groundwater Systems

Groundwater can also be found in many types of porous or fractured rocks, such as sandstone, limestone or even granite and basalt. The rocks are often part of large regional geological systems. The flow of groundwater is therefore controlled almost entirely by regional geological and structural features. Fractured rock aquifers generally contain much lower quantities of groundwater, and are highly variable in their flow properties and quality.

Figure 3 - Examples of Groundwater Systems (Freeze & Cherry, 1979)



(a) gently dipping sandstone aquifers with outcrop (recharge) area along mountain foot; (b) interfingering sand and gravel aquifers extending from uplands in intermountain region; & (c) faulted and folded aquifer in a desert region. Surface water bodies reflect structural features,

1.2 Groundwater Quality - Is The Water Suitable ?

The chemical and biological components or quality of groundwater determine it’s suitability for particular uses, such as potable drinking water, agriculture or environmental effects. As water moves through soils and rocks it can dissolve some minerals. The exact concentration of different components in groundwater will depend on the type of soils and rocks the water has passed through and sometimes the microbiological action. In the same way that water can dissolve minerals, minerals can also be precipitated again as a solid. Understanding the chemical controls on groundwater can thus be a very important step in locating ore deposits, or the movement of a plume of contamination through an aquifer.

There are a number of terms used to describe and quantify the quality of water :

> *Total Dissolved Solids* (TDS) - the total mass of dissolved elements per litre of a water sample, often referred to as salinity.
>
> *Concentration* - the mass of an element dissolved in water, units are usually mg/l (milligrams per litre, 10^{-3}g/l) or µg/l (micro grams per litre, 10^{-6}g/l).
>
> *pH* - a measure of the acidic (H^+) or alkaline (OH^-) tendency of a water sample. At 25° C, a pH of 7 is neutral, less than 7 acidic and more than 7 alkaline.
>
> *Mineral* - a compound of different elements. Examples include calcite ($CaCO_3$), jarosite ($KFe_3(SO_4)_3.9H_2O$), pyrite (FeS_2) or halite (NaCl).
>
> *Redox Potential* - or oxidation/reduction potential (Eh), is a measure of the chemical energy in a water sample, relative to a known standard, measured in mV (millivolts, 10^{-3}V). A positive redox value, known as oxidising, is typical of the presence of oxygen, and a negative value, known as reducing, usually means the absence of oxygen.
>
> *Solubility* - the amount of a mineral to dissolve in a given amount of water.
>
> *Saturation* - the maximum concentration of a mineral for a given water chemistry and temperature.

The dissolved components of water can be single elements such as calcium (Ca) or chloride (Cl), or compounds such as carbonate (CO_3) or sulphate (SO_4). The levels of these different elements and compounds will determine it’s quality and potential use. Due to different abundances of elements in soils and rocks, the water chemistry will be dominated by the group of common elements - sodium, calcium, potassium, magnesium, chloride, sulphate, carbonate. Minor amounts of aluminium and iron may also be present. Trace quantities of other elements such as selenium, arsenic, barium, or molybdenum can be also be found, but generally in significantly lower concentrations.

Different minerals also vary in the degree to which they will dissolve in water, known as solubility. At some point, no more of a particular mineral will dissolve as the water is saturated with respect to that mineral, in much the same way a cup of water will only dissolve a certain quantity of sugar. It is also possible that if a water becomes over-saturated with a mineral, then the excess amount of that mineral will precipitate out of solution as a solid until the water chemistry reaches a new equilibrium.

The solubility of a particular mineral will also depend on the pH and redox state of the water. For highly acidic conditions (pH less than 7), many trace and heavy metals are highly soluble, whereas under highly alkaline conditions (pH greater than 7) many trace and heavy metals are immobile and stay in a solid form. The solubility also depends on the redox state of the water. In the same way as different minerals are soluble under different pH conditions, many minerals are insoluble under negative (or reducing) redox conditions and highly soluble under positive (or oxidising) redox conditions.

A sample of good fresh water will have quite low concentrations of dissolved components, while seawater has quite high concentrations and is referred to as highly saline. There are established national and international levels for different components, including radioactive elements, for different uses of water, with some typical guideline values shown below in Tables 2 to 4 (although some parameters do vary significantly). The values for drinking water are based on either a health or environmental toxicity risk approach or simply taste and odour.

Table 2 - Water Quality : Major Elements (ANZECC, 1992)

	TDS mg/l	pH -	Na mg/l	Fe mg/l	Cl mg/l	SO$_4$ mg/l	NO$_3$ mg/l	F mg/l	Cu mg/l	Zn mg/l
Drinking Water	500 - 1,000	6.5 - 8.5	300	0.3	400	400	10	-	1	5
Irrigation		4.5 - 9.0	-	1	30 - 700	-	-	1	0.2	2
Livestock [1]	2,000 - 13,000	-	-	-	-	1,000	30	2	0.5	20

[1] - Depending on livestock type, such as sheep, beef or dairy cattle.

Table 3 - Water Quality : Trace Elements (ANZECC, 1992)

	Al mg/l	As µg/l	Ba mg/l	B mg/l	Cd µg/l	Cr µg/l	Pb µg/l	Hg µg/l	Mn mg/l	Mo µg/l	Se µg/l	V µg/l
Drinking Water	0.2	50	1	1	5	50	50	1	0.1	-	10	-
Irrigation	5	100	-	0.5 - 6	10	1,000	200	2	2	10	20	100
Livestock	5	500	-	5	10	1,000	100	2	-	10	20	100

Table 4 - Water Quality : Radioactive Elements (Fetter, 1993)

	Ra-226 (pCi/l)	Ra-228 (pCi/l)	Rn-222 (pCi/l)	U (µg/l)	Gross-α (pCi/l)	Gross-β mrem ede[1]/yr
Drinking Water	20	20	300	20	15 [2]	4
Irrigation [3]	-	-	-	-	0.1 (Bq/l)	0.1 (Bq/l)
Livestock [3]	-	-	-	200	-	-

[1] - ede is effective dose equivalent.

[2] - excluding radium-226, radon-222 and uranium.

[3] - ANZECC, 1992.

Thus the quality of water, either found naturally in the environment or treated for human use, is highly variable.

1.3 Groundwater Recharge, Flow and Discharge

Groundwater will flow through rocks due to differences in water pressure. This is often related to the height of the geology the groundwater is found within, but it does lead to the questions of where water enters a groundwater system and how (the *recharge area*), the time it might take to flow from one point to another (the flow path), and where does the water eventually discharge from groundwater back to the surface environment (the *discharge area*). The overall quantities of recharge and discharge should be similar if a groundwater system is in equilibrium or balance. Excessive discharge (such as too many bores) over recharge can lead to a significant long term degradation of a groundwater system.

Groundwater Recharge

Recharge to a groundwater system, the process whereby rainfall migrates through surface soils and replenishes the water supply of a groundwater system, is often a technically difficult process to qualify and quantify.

The main ways that recharge can be studied include the use of computer modelling of groundwater systems, detailed field sampling and monitoring of the recharge area over long periods of time (dependent on the size and nature of the groundwater system), the use of groundwater chemistry to elucidate the mixing of different waters (including the use of specific elements, isotopes and radionuclides such as tritium), and studies of the geological properties of the aquifer rocks where they outcrop in the recharge area (refer to Figure 3).

Recharge can often be due to single events in space and time, such as during the last glacial period, leading to the problem of determining long term average recharge processes (Freeze & Cherry, 1979). The proportion of rainfall that might enter or recharge a groundwater system ranges markedly, with some values less than a few percent, or expressed as several millimetres (Mazor, 1997).

Groundwater Flow

The direction groundwater will flow is dependent on the water pressure within the aquifer, which will be closely related to geological structure. The main methods use to determine the dominant direction of groundwater flow is to drill a series of groundwater bores to monitor the overall trends in water pressures, and then using these to analyse overall flow rates and directions.

The overall water pressures within an aquifer are contoured and plotted on a map (known as the piezometric surface), with groundwater flowing perpendicular to the pressure contours. The rate of groundwater flow will depend on the permeability of the aquifer materials, such as sandstone or silty gravels. A variety of tests can be conducted to determine an aquifer’s permeability, either from retrieved drill core samples or via pumping tests of the aquifer itself.

The volumetric flow rate will also depend on the thickness of the aquifer, as some aquifers are only several metres thick but parts of the Great Artesian Basin aquifers are hundreds of metres thick and can thus transmit large quantities of groundwater for the same permeability and pressures.

Groundwater will typically flow from the higher recharge areas to the lower discharge areas. With the advent of fast computers, mathematical models are now widely used to help in quantifying the flow of groundwater systems to aid in good management. However, like many numerical computer models, the quality of results obtained from such a study are entirely dependent on the quality of the input data on basic and fundamental hydrogeologic processes for the particular system being modelled.

Groundwater Discharge

After a certain length of time underground, groundwater will eventually find it’s way to a discharge zone - the area where the water will move into a different part of the hydrologic cycle. Common discharge areas for groundwater include lakes and rivers, surface springs, or into another regional groundwater system (related to geology).

The recharge of near-surface aquifers or the water table is one of the most important groundwater processes in sustaining the baseflow of many rivers in between rainfall events, which is in fact the most common discharge area for water table aquifers.

The rate of discharge will depend on pressure levels and flow characteristics of the aquifer, and can vary from small to much larger volumes of millions of litres per day. Any change in the water pressures of a groundwater system (such as that due to bores) in the vicinity of a discharge area, can therefore have a significant impact on the quantity of groundwater discharge.

Miscellaneous Influences on Groundwater Flow

There are many processes that can complicate the interpretation of a groundwater flow system. These can include the presence of permeable or impermeable faults, highly variable geology, complex chemical interactions, bacterial influences, and subsidence problems (that is, settlement of the ground surface due to lower groundwater pressures) among others. These can lead to modification of the physical properties of an aquifer, causing a reduction in flow rates, a decrease in groundwater quality, or a change in the overall flow regime due to a fault allowing discharge from one groundwater system into a different system. Many of these factors, although recognised, are often very hard to predict the exact behaviour of, due to their complex nature, without extensive field studies and research. However, if the integrity of a groundwater system is to be maintained, these issues are of the utmost importance.

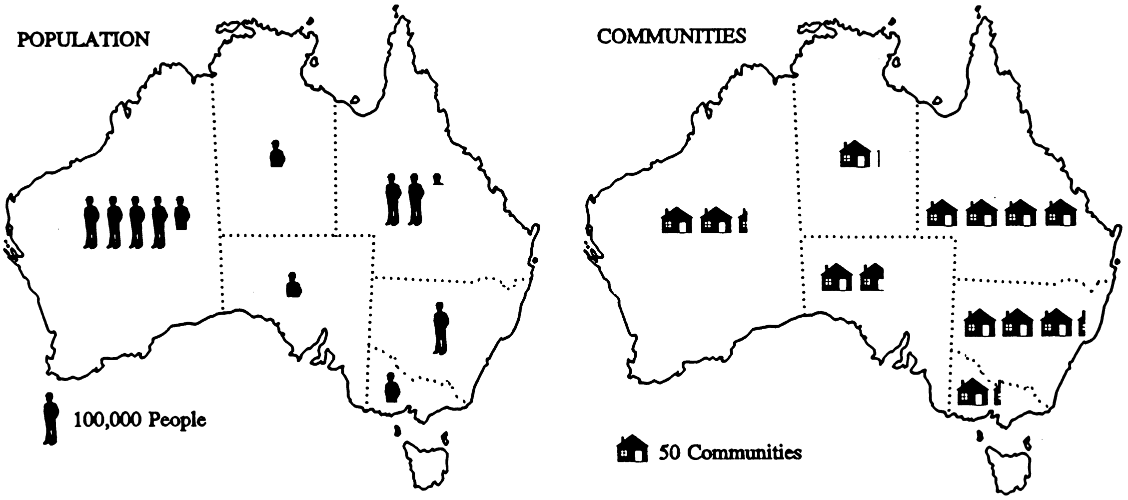
1.4 The Importance of Groundwater Across Australia

The majority of the Australian population lives on the east coast where there is generally good access to high volumes of good quality water from forested catchments. Only select cities actually use an appreciable proportion of groundwater to augment their potable water supplies, such as Geelong, Newcastle and Adelaide (about 30% of 30 billion litres, 20% of 100 billion litres and 5% of 150 billion litres respectively) (AWRC, 1992). Darwin draws about 10% of their potable water supply of 25 billion litres from groundwater (AWRC, 1992). Perth, however, draws upon approximately 65% of it’s potable water supply of 250 billion litres from groundwater (AWRC, 1992). In perspective, groundwater contributes over 90% of the water supply for about half of the area of the Australian continent (Dillon, 1995).

For most parts of the arid interior of Australia, groundwater is often critical. In total, approximately 460,000 people in Western Australia, 45,000 people in South Australia, 50,000 people in the Northern Territory, 100,000 people in New South Wales, 220,000 people in Queensland and 60,000 people in Victoria are served by water supplies derived from groundwater (AWRC, 1992) (refer to Figure 4). This represents about 120 communities in Western Australia, 85 communities in South Australia, 55 communities in the Northern Territory, 165 communities in New South Wales, 200 communities in Queensland and 65 communities in Victoria (AWRC, 1992) (refer to Figure 4).

For much of the groundwater systems within the arid interior, the reserves are fossil water, or groundwater which was recharged in past geological eras that were much wetter than the current era (Jacobson & Lau, 1983). Thus there is significant potential for effectively mining a groundwater system at an unsustainable rate since there is no reasonable process for recharge. Much of the arid interior has only been able to develop important economic industries, such as pastoralism, due to the presence and use of such ancient groundwater systems (Jacobson & Lau, 1983).

Figure 4 - The Importance of Groundwater Across Australia (AWRC, 1992)



2 - The Technique of In Situ Leaching

2.1 Overview

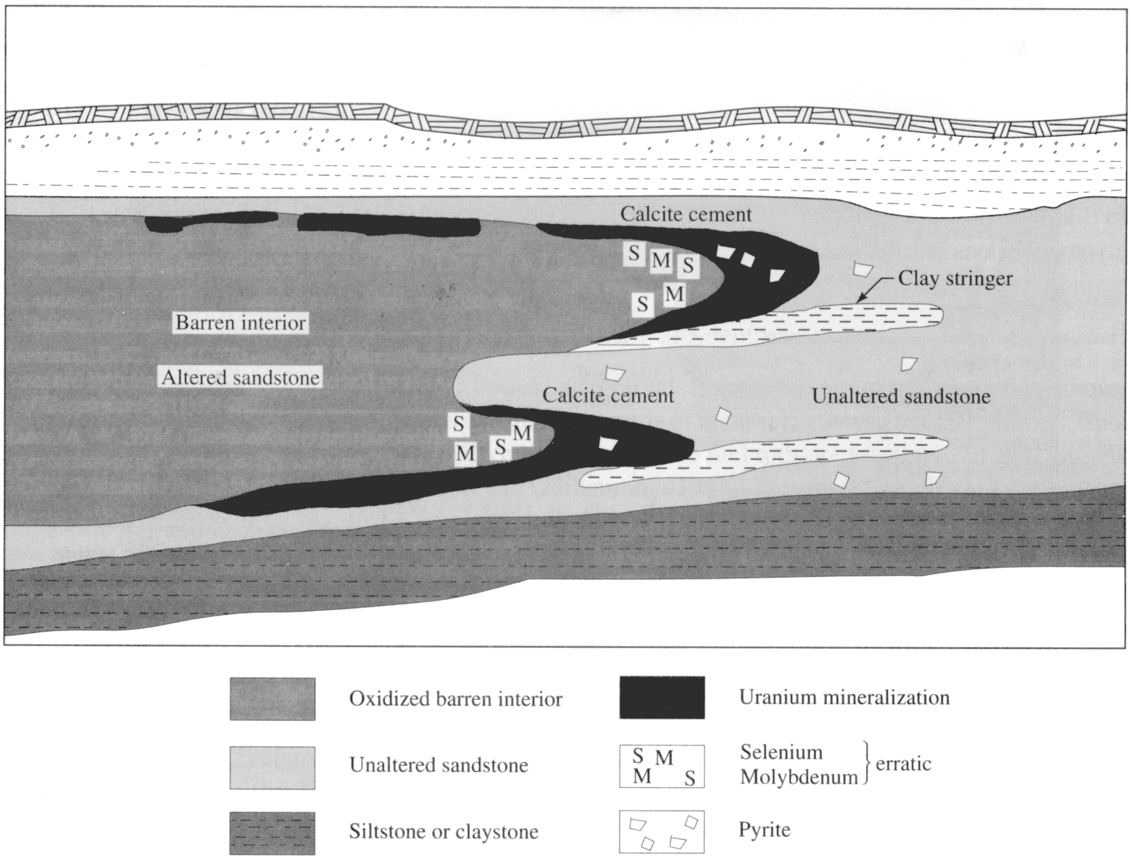
The process of In Situ Leaching (ISL) combines both the mining and beneficiation of a particular mineral or element in one step. It can be used for the recovery of uranium, copper, nickel, gold, iron, phosphate, salt and also potash, although uranium and copper are the principal elements currently mined with ISL. Typical mining involves two main steps of digging or extracting the ore with an underground or open cut mine and then processing the ore with a chemical mill to leach the element of interest from the bulk of the ore. In Situ Leaching involves directly circulating the chemical leaching solutions (typically used in the mill) through the ore zone in the ground and recovering the solutions to extract the uranium, copper or element of interest. In this method, no excavation of ore is required and it reduces the handling of large volumes of ore materials and no traditional tailings dam is therefore required.

However, not all deposits are suitable for application of the ISL technique. In order for ISL to work, the following criteria are generally applied to the ore body (Montgomery, 1987; Underhill, 1992; Brunt, 1998) :

- must occur in porous and permeable rocks (usually a sand or sandstone);
- confined (isolated) above and below by continuous impermeable strata such as clays or shales;
- must be located below the water table and therefore saturated with the naturally occurring groundwater;
- the water pressure must be artesian relative to the clay confining layer above (a minimum of about 15 metres is preferred, 75 m or more is desirable);
- must have uranium mineralisation which is in a form that can be readily leached, eg coffinite or uraninite;
- must meet minimum grade and thickness criteria necessary for economic recovery of the contained uranium;
- effective contact between the leach solution and uranium minerals.

The deposits that typically meet these criteria are usually found in sandstones or in the sands of palaeochannels (old river beds). The uranium is dissolved from an area of primary mineralisation (ie - the original source rocks that contain uranium) and transported through flowing groundwater. In order to dissolve the uranium, the water must be oxidising. When the water reaches a part of the aquifer that is reducing, the uranium precipitates out of solution to form insoluble minerals such as coffinite ($USiO_4$) or uraninite (UO_2). The deposition of uranium occurs on the surface of sand grains as the oxidising groundwater flows through the reducing part of the aquifer, progressively enriching the deposit. Such deposits are known as “roll front” or “geochemical cell” type ores, and are typically long and narrow and tens of metres thick (Langmuir, 1997).

Figure 5 - Typical Roll Front Sedimentary Uranium Deposit (Langmuir, 1997)



Schematic cross-section of an idealised uranium roll-front orebody showing the zonation of elements and primary hydrologic and geochemical features. Oxidised groundwaters flow from left to right. The roll front and associated redox interface moves in the same direction.

There can also be other minerals and elements associated with the uranium mineralisation including pyrite (FeS_2) and carbonaceous matter (either organic or as carbonate, CO_3). The extraneous minerals like pyrite and organic matter are often referred to as gangue minerals (Kasper *et al.*, 1979). Trace elements can include arsenic, vanadium, zinc, selenium, molybdenum, usually present as sulphide minerals (such as zinc sulphide, ZnS). The exact proportions of pyrite, carbonate and other impurities will determine the suitability of different leaching chemistries.

2.2 The In Situ Leaching Process

The ISL process involves the drilling of a series of wells into the aquifer containing the deposits. A concentrated leaching solution, called the lixiviant, is then pumped into the aquifer to oxidise and dissolve the uranium minerals, so they can be pumped back to the surface for extraction at a processing plant. The solution before entering the ore deposit is called barren lixiviant since it contains no dissolved uranium or the mineral or element being extracted. After moving through the ore, it is known as pregnant lixiviant since it is concentrated in the element of interest. The wells are divided into injection and extraction wells, and a number of extra wells are located outside the area where active pumping occurs to monitor any escape of the mining solutions. Due to the inherent complexity and variability of roll front type uranium deposits, there are a variety of leaching solutions that can be used to dissolve the uranium, as well as numerous configurations for pumping and monitoring wells.

Choosing the Leaching Solutions & Chemistry

Uranium is soluble under both acidic and alkaline conditions, but insoluble under reduced conditions. Thus it possible to use either acidic or alkaline leaching chemistry. Typical acids that have been used are sulphuric (H_2SO_4) or nitric (HNO_3) acid; and ammonia bicarbonate (NH_4HCO_3), sodium bicarbonate ($NaHCO_3$) or carbon dioxide (CO_2) for alkaline leaching chemistry (Tweeton & Peterson, 1981). An oxidising agent must also be introduced to ensure the solutions stay in a positive redox state, which could include hydrogen peroxide (H_2O_2), oxygen (O_2) or sodium chlorate ($NaClO_3$) (Tweeton & Peterson, 1981). The process of ISL can extract up to 60-80% of the uranium from a roll front type ore deposit (Brunt, 1998).

The main factors that determine the choice of leaching chemistry are (Kasper *et al.*, 1979; Tweeton & Peterson, 1981) :

- potential or desired rates of dissolution or the rate at which the uranium enters solution;
- effects of leaching solutions on aquifer formation properties (such as aquifer permeability reduction);
- the cost of chemicals;
- the chemical reactions between leaching solutions and gangue minerals;
- the requirement (and ability) to restore groundwater quality to pre-mining levels after the completion of ISL mining.

The latter two of the above are perhaps the most important aspects in the choice of leaching chemistry. Acid leaching was trialled in the USA in the late 60s through to the early 80s, and has been used extensively in Europe and the CIS. New ISL projects in China, Mongolia and Kazakhstan are also using or planning to use sulphuric acid ISL chemistry. Currently in the USA, all ISL uranium production is with alkaline leaching chemistry using carbon dioxide or sodium-carbonate and oxygen (USDoE, 1995). The ability of acid versus alkaline leaching solutions to meet these above criteria is critical in understanding the environmental impacts likely for each method.

Acid Leaching Chemistry

The most common acid used in ISL is sulphuric acid (H_2SO_4), one of the cheapest chemicals available (Tweeton & Peterson, 1981). Other acids are technically possible, such as hydrochloric (HCl) or nitric acid (HNO_3), but sulphuric acid remains the most common as the costs of alternatives are prohibitive (Kasper *et al.*, 1979). The various oxidising agents used include sodium chlorate ($NaClO_3$), oxygen, manganese dioxide(MnO_2), ferric sulphate ($FeSO_4$) and oxygen (Kasper *et al.*, 1979). There have been trials of acid leaching at sites in Texas and Wyoming in the USA, and commercial operation at sites in Bulgaria, Germany, the Czech Republic.

It has been found that pH must be kept below 2 for optimum leaching rates, above 4 the uranium will not dissolve and recovery is therefore not possible (Kasper *et al.*, 1979).

As well as uranium, the solubility of many trace and heavy metals is also greatly increased, and the concentration of arsenic, selenium, lead, vanadium and other elements can be several orders of magnitude higher than pre-mining levels. These can interfere with the extraction process

Alkaline Leaching Chemistry

The various alkaline leaching agents that can be used include carbon dioxide (CO_2), sodium carbonate-sodium bicarbonate (Na_2CO_3-$NaHCO_3$), ammonium carbonate-bicarbonate ($(NH_4)_2CO_3$-NH_4HCO_3). The most common oxidising agents are hydrogen peroxide and oxygen. Many trace and heavy metals are insoluble under alkaline conditions, and the level of impurities in alkaline mining solutions are much lower.

Comparing Acid and Alkaline Lixiviants

Generally, it has been found that alkaline lixiviants give slower leaching rates than acidic lixiviants, and do not leach a very high proportion of the uranium (Kasper *et al.*, 1979). Kasper *et al.* (1979) and Tweeton & Peterson (1981) present the following points of comparison :

Advantages of Alkaline

- significantly lower levels of impurities;
- relatively noncorrosive solutions which have a lower probability for mechanical failure and subsequent spills;
- higher efficiency of regenerating and recycling leaching solutions due to less impurity problems, resulting in smaller waste stream flow rates;
- minimal precipitation of calcium minerals in the extraction process (calcite, $CaCO_3$, gypsum, $CaSO_4$).
- carbon dioxide is very cheap and has little effect on permeability

Advantages of Acid

- leaching rates are more rapid, thereby reducing the mining period;
- uranium recovery rates are higher;
- lower potential for dissolving radium-226;
- no interference problems with clays (compared to sodium or ammonia based solutions).

Controlling the Movement of Leaching Solutions

One of the most critical operational principles of any In Situ Leach mine is to control the movement of leaching solutions within the groundwater area being mined. Not only is it important from an economic standpoint (the solutions contain the product), but it is of the utmost importance for environmental management as the groundwater surrounding the mine site can often be used by local farmers, nearby towns as drinking water or discharge to other sensitive parts of the environment. An escape of leaching solutions is known as an *excursion*.

The main techniques used to achieve this are the careful design of groundwater bores to prevent leakage via the bore, and always pumping out more water than the quantity of solutions injected.

Groundwater Bore Design

Each groundwater bore that is drilled into the deposit is a possible avenue for the escape of solutions if it does not remain sealed and isolated to groundwater of that zone only. A typical bore would be designed and constructed so that the bore is built with a strong casing (such as PVC plastic). The PVC would only be perforated (slots cut into the casing to allow the inflow of water) in the zone of mining, with sand or gravel placed around this part of casing. The remainder of the casing is backfilled with clay, such as bentonite, to act as an impermeable barrier to vertical flow. A typical example is shown in Figure 6.

Adjusting Injection and Extraction Rates

The flow of groundwater is determined by differences in water pressure. Thus, if the injection of solutions were to lead to excessive pressures in the mining zone, this increases the chances of those solutions escaping since the pressure gradients would be away from the injection/extraction well system. To overcome this, ISL mines always extract more water than they inject. This tries to ensure that there is an overall decrease of pressure in the local area of injection and extraction and water will always flow towards the extraction well. The amount of this excess extraction generally ranges between 0.5 to 5% of the water injected. This extra water is known as the bleed solution. This is represented in Figure 7.

Figure 6 - Typical ISL Bore Design and Construction (Brunt, 1998)

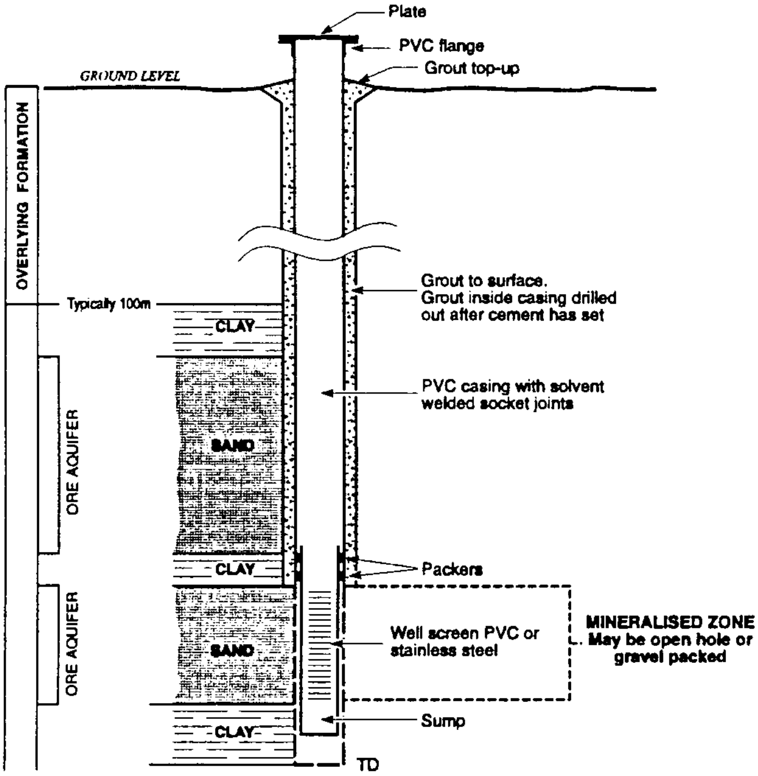
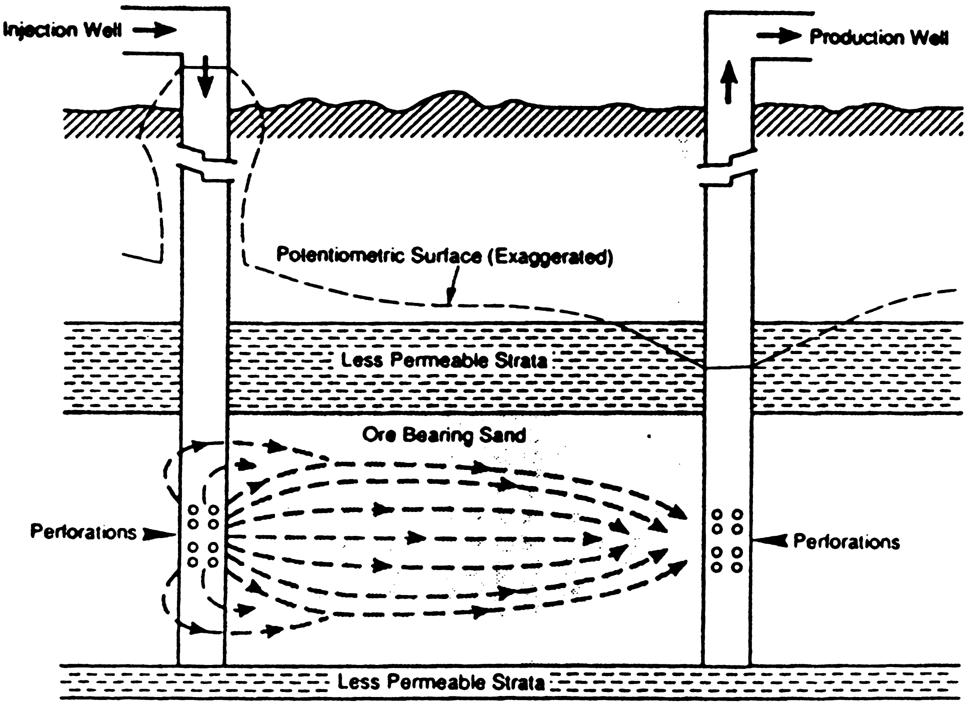


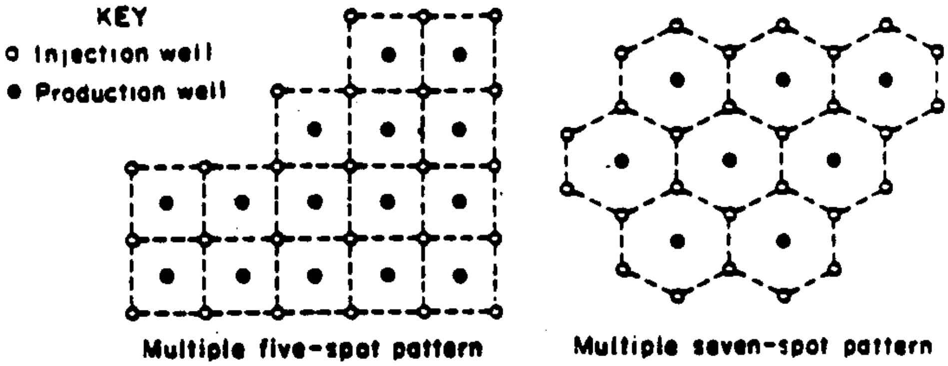
Figure 7 - Overall Pressure Levels for Injection/Extraction in ISL
(adapted from ENDAUM, 1997)



Configuration of Injection/Extraction Wells

The configuration of injection and extraction wells is also quite important for the successful control of the mining solutions. The most common pattern of wells is known as the 5-spot pattern, although 7-spot and even 13-spot patterns have also been used (Kasper *et al.*, 1979). The main principle behind the patterns is that four (or six or twelve) injection wells surround one extraction well. A 5-spot pattern is thus square shaped, while a 7-spot pattern is hexagonal shaped.

Figure 8 - Typical 5-Spot and 7-Spot Injection/Extraction Well Patterns (USEPA, 1995)



The different patterns are normally arranged in sequence to overlap, forming a line of injection and extraction wells, known as drives. This helps to optimise the ratio of injection and extraction wells required to cover an orebody. This leads to a series of wells that cover an area of several hectares at any one time in a commercial scale ISL mine, and hence is known as the wellfield. The spot pattern used not only depends on the physical and chemical characteristics of the aquifer and orebody, but the type of pattern used will determine the density or number of wells covering a certain area, which largely influences the costs of restoration (USDoE, 1995). An example is shown below, which includes the overall flow patterns for groundwater and solutions.

Figure 9 - Typical ISL 5-Spot Groundwater Flow Pattern (Brunt, 1998)

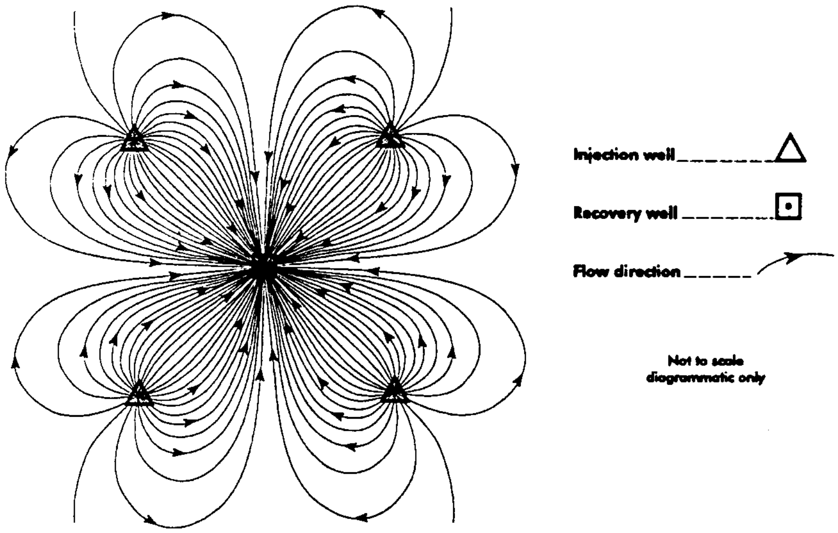
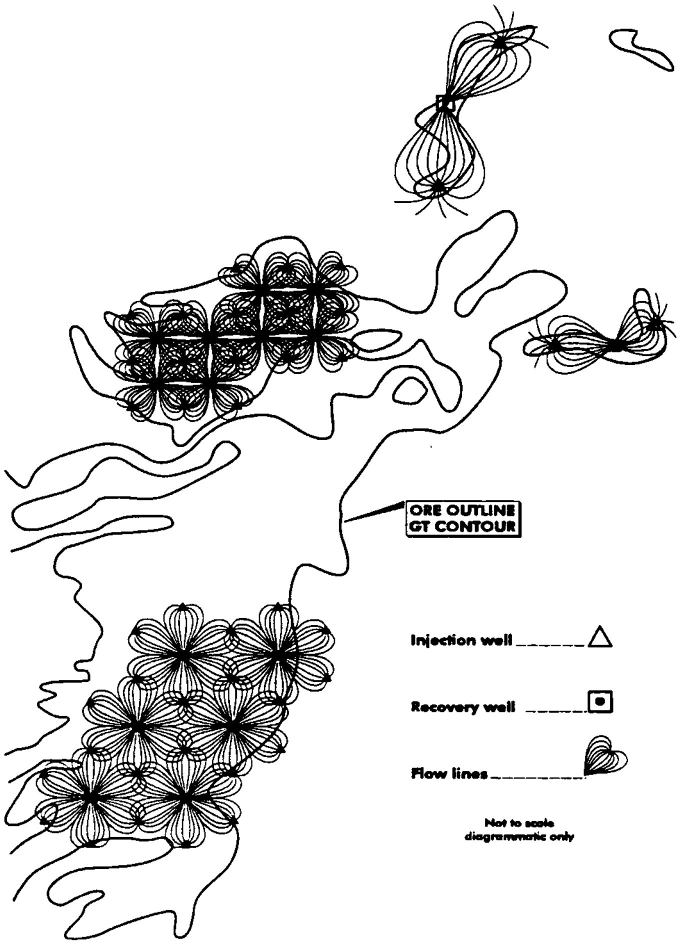


Figure 10 - Full Scale Wellfield Flow Patterns (Brunt, 1998)

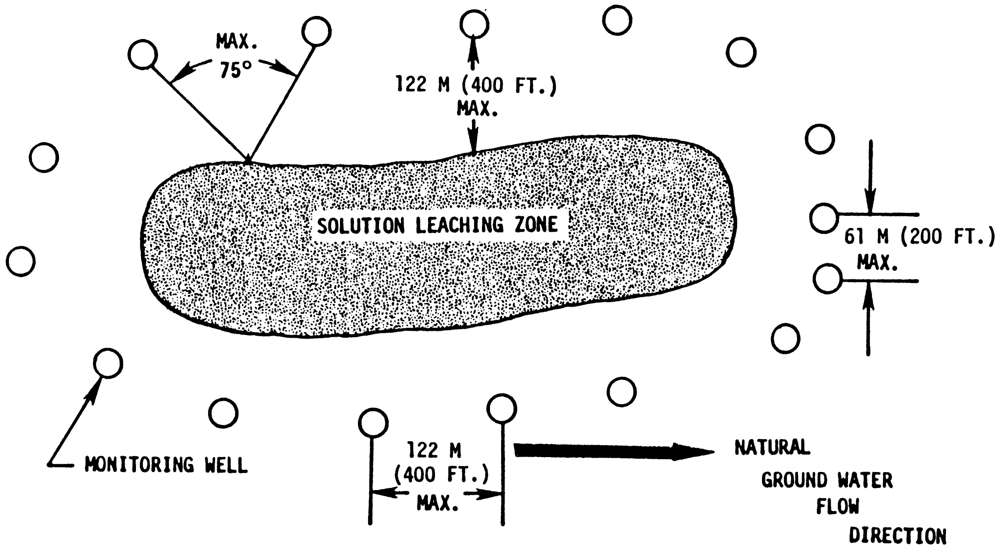


Monitoring Outside the Mining Zone

It is of the utmost importance for any In Situ Leach mining operation to install a well designed groundwater monitoring system that can detect if any escape of solutions occurs (excursion). Groundwater monitoring bores are drilled into the same aquifer outside the mining zone, and also into aquifers above and below the mining zone (if aquifers are present). It is intended that the wells are closely spaced so that any excursion of lixiviant will be intercepted by a monitoring well, detected by routine sampling and remedial action can be planned and undertaken. A typical monitoring well configuration is shown in Figure 10 below, although the exact layout will depend on the hydrogeological nature of the orebody aquifer.

The frequency of monitoring is often at least daily or weekly for indicator parameters, such as sulphate or electrical conductivity (directly related to total salinity), and fortnightly for a complete analysis of groundwater quality parameters. Recent advances in electronic monitoring technology, that can be placed inside a bore permanently and monitor pH, salinity or a specific element of interest, allow for continuous data collection and more rapid detection of any excursions.

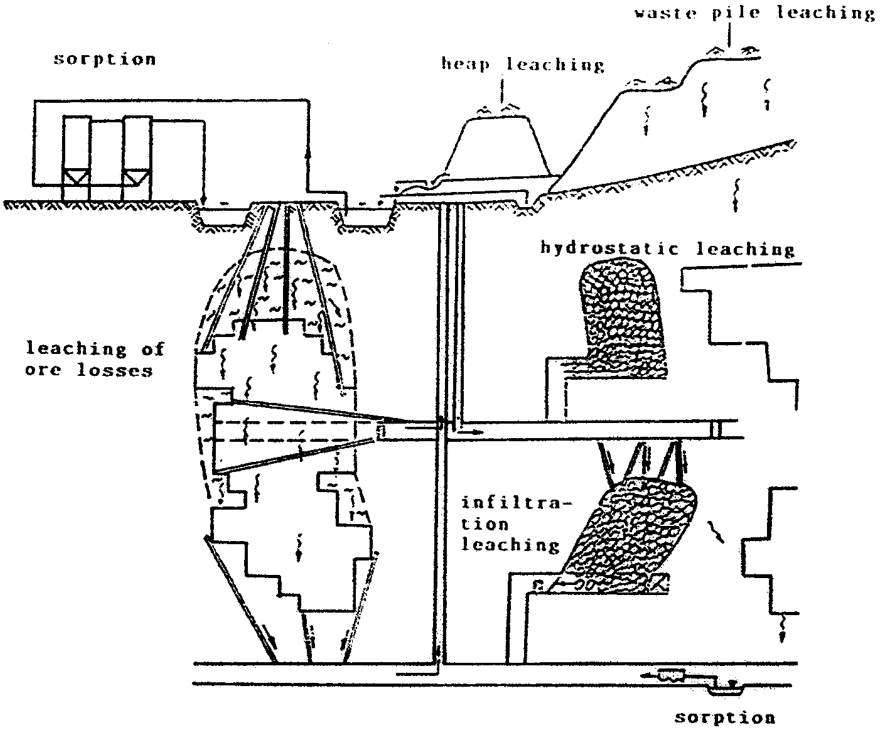
Figure 11 - General Monitoring Well Configuration (Kasper *et al.*, 1979)



2.3 Underground ISL

At many sites across Eastern Europe, the process of In Situ Leaching has been within the confines of an underground mine. This is generally achieved through the use of underground mining stopes being leached with the preferred reagents, with the enriched solutions collected at the bottom of a stope and pumped to the surface for processing. It is often used to extend the life of an underground when only the lower grades of an ore remain, grades which would otherwise be uneconomic to mine otherwise. This technique was quite popular in Eastern Europe, particularly Bulgaria and Germany.

Figure 12 - The Underground ISL Technique (Hähne & Altmann, 1992)



2.4 Uranium Extraction

After the pregnant lixiviant is extracted from the ore zone, it is pumped to the processing plant. Here the uranium is extracted from the solutions using standard metallurgical techniques. There are typically two main choices for this process - solvent extraction or ion exchange. Each of these represents different technical advantages and problems for specific deposits, although only a brief review is required for the context of this report. The solutions are generally cycled through the wellfield, orebody and processing plant numerous times before being replaced by fresh lixiviant (due to the buildup of contaminants which interfere with the extraction process or lead to impurities in the final product).

Solvent Extraction

The principle behind solvent extraction is that uranium is highly soluble in an organic solvent compared to water. By mixing different organic solvents (such as kerosene, alkyl phosphates and amines) with the recovered lixiviants, the uranium is concentrated in the organic fraction, which can then be easily removed to extract the uranium separately as yellowcake.

Ion Exchange

Ion exchange works on the principle that selected elements or compounds can be progressively concentrated on the surface of solid resins, known as ion exchange resins. The pregnant lixiviant is pumped through an ion exchange column, and the uranium concentrated on the resin. After the resin becomes saturated, the process is reversed and the column flushed to extract the uranium for refining to yellowcake.

2.5 Waste Streams and Management

The process of In Situ Leaching leads to the formation of many liquid and solid waste streams. These are produced from the bleed solutions, waste processing solutions, solid residues that build up due to the precipitation of minerals from the highly concentrated solutions involved, solid waste from the processing plant (such as contaminated clothing and equipment), and other normal wastes from industrial facilities.

Due to the nature of In Situ Leach mining, quite large volumes of waste waters are created, which are often highly saline and contain toxic levels of heavy metals, process chemicals and radionuclides. The bleed solution (the excess water pumped out over that injected) is often the most significant component. For ISL mines operated at 25 litres per second (a relatively small scale), the quantity of water pumped each day would be 2,160,000 litres, which for a 2-5% bleed solution would form 43,200 to 108,000 litres per day to dispose of (or 15,768,000 to 39,420,000 litres per year; 15.8 Ml to 39.4 Ml). Some ISL mines operate at flow rates of greater than 100 litres per second, and thus the quantities of water involved are proportionally higher.

Waste solutions are also generated by the processing plant. Fresh lixiviant needs to be introduced regularly to ensure optimal efficiency in the processing plant, and the discarded solutions (now called raffinate) are disposed of.

The different waste water streams are temporarily stored in a retention pond. The final disposal method can be either re-injection into the same aquifer, re-injection into a deeper aquifer that is unused and does not interact with other aquifers that are currently used, or evaporation of the water to leave a solid residue that can be disposed of in an engineered facility designed to minimise leakage of contaminants.

Solid wastes are generally disposed of at an approved radioactive waste management site, or in an engineered facility on site.

Since the orebody itself is not extracted, there is no tailings or residual rock material remaining in a large tailings dam.

2.6 Radiological Aspects

The mining of uranium ores leads to the presence of radiation. This can be in the form of alpha, beta and gamma-emitting radionuclides formed from the uranium decay sequence.

The principle radioactive elements released during In Situ Leach uranium mining are uranium, thorium, radium, radon, and their respective progeny (Tweeton *et al.*, 1982; Kasper *et al.*, 1979). Acidic leaching chemistry tends to mobilise a small proportion of the radium from the orebody, while alkaline leaching mobilises higher quantities since radium hydroxide is more soluble than radium sulphate (Kasper *et al.*, 1979). However, acid leaching does mobilise significant concentrations of thorium (Tweeton *et al.*, 1982)

The decay of radium and thorium leads to the formation of highly radioactive radon gas, which is the main source of workers' radiation exposure for uranium mining operations.

The radium and radon are transported in the mining and processing solutions to the surface. When at the surface and the solutions are pumped to the retention pond, appreciable quantities of radon can thereby be released (Kasper *et al.*, 1979). The radon gas can be transported in the direction of prevailing winds significant distances away from the mine, where radon will decay to a stable solid due to it's very short half-life.

Another source of radiation is uranium dust and residues that buildup around the processing plant (such as salts that precipitate or evaporate and precipitate from the highly concentrated solutions). The venting of air from the processing plant can lead to the release of uranium dust into the wider environment (Kasper *et al.*, 1979).

2.7 Post-ISL Mining Restoration of Groundwater Quality

After the orebody has been mined, it is good policy and practice to restore the groundwater quality to it's pre-mining levels. It is required by all state and federal regulators in the United States. This involves the chemical treatment of the affected area to remove the residual solutions and chemicals from the mined out area and immobilising any elements that have been dissolved into solution by the ISL process, such as arsenic and other trace elements. The restoration of an aquifer following In Situ Leaching is done in four phases (Schmidt, 1987; Catchpole, 1995; USDoE, 1995) :

> *Phase One* - Pumping of contaminated water :
> the injection of the leaching solution is stopped and the remaining contaminated liquid is pumped from the mined area. Subsequently, clean groundwater flows in from outside of the leaching zone;
>
> *Phase Two* - Pumping and pre-treatment :
> pumping with treatment of the pumped liquid (by reverse osmosis) and re-injection into the former leaching zone. This scheme results in circulation of the pre-treated liquid;
>
> *Phase Three* - Chemical remediation :
> with the addition of a reducing chemical (for example hydrogen sulphide H_2S or sodium sulphide Na_2S). This causes the precipitation and thus immobilisation of most contaminants;
>
> *Phase Four* - Final pumping :
> circulation of the liquid by pumping and re-injection, to obtain uniform conditions in the whole former leaching zone.

The most critical part of any restoration attempt is the standards or quality that the groundwater is being restored to. It is extremely important to have an extensive data set of background (pre-mining) groundwater quality before ISL mining, to allow the determination of restoration standards for all quality indicators, such as sulphate, pH, total salinity, uranium, radium, arsenic, molybdenum and selenium among others.

The total volume of water that needs to pumped and the length of any restoration attempt is dependent upon the complex chemistry of the specific ISL deposit and the solution chemistry used for mining. A brief review of these processes is given below.

Geochemical Processes Involved in Restoration

The main geochemical processes that can occur during restoration of an ISL-mined aquifer can be broadly categorised into ion exchange, oxidation-reduction reactions, adsorption, dispersion and mixing, and precipitation-dissolution reactions (Buma, 1979). Each of these processes can act to either immobilise or dissolve different constituents, and are discussed in detail below.

Ion Exchange

Ion Exchange is the process whereby an element in solution replaces an element adsorbed onto the surface of a solid, thereby replacing or exchanging the element in solution. Many natural materials, such as clays, have this capacity. One common example is where calcium is released from the clay surface and sodium is thereby adsorbed onto the clay surface instead. In order for this process to occur, a material that has an ion exchange capacity must be present within the aquifer. This is typically only a viable mechanism for positively charged elements in solution (eg - calcium, ammonium ions and many trace metals), as ion exchange sites are generally negatively charged.

Oxidation-Reduction (Redox) Reactions

In the same way that uranium is mobilised into solution by the ISL process, the same kinds of reactions can occur during post-ISL restoration. However, there needs to be elements or minerals present that control the redox state of the groundwater. These might include pyrite minerals or organic matter, which are arguably the main geochemical reasons why the uranium and associated minerals were concentrated in the roll-front deposit originally (Buma, 1979).

Adsorption

Adsorption is a similar process to ion exchange, except that the direction of contaminant movement is one way only. It involves the sorption onto mineral surfaces of a specific element in solution, typically a positively charged species onto the negatively charged surface of, for example, a clay surface (Fetter, 1993). There will be an equilibrium relationship with the concentration in solution (which can be described by different mathematical relationships), but overall adsorption tends to minimise the concentration of the element in solution.

Precipitation and Dissolution Reactions

In the same way that the solubility of the uranium minerals is altered by the ISL technique, after the completion of mining the remaining chemicals in the groundwater can undergo a complex series of reactions that lead to the precipitation of less soluble minerals from the concentrated solutions, or continuing dissolution of minerals.

Dispersion and Groundwater Mixing

As groundwater flows through an aquifer, it mixes and can thus help to disperse contaminants to a lower concentration. Thus it is possible for oxidised, low pH solutions to migrate through an aquifer and mix with reduced, neutral pH waters. This will lead to intermediate conditions, which will affect the solubility of different minerals. The less soluble minerals will tend to precipitate first, until the water has migrated so far and been mixed thoroughly as to exhaust the oxidising potential of the initial solutions and achieve a near background pH. However, the major element and heavy metal chemistry will not necessarily return to the same background composition.

Summary

The exact geochemical reactions that occur following the completion of ISL uranium mining will depend greatly on the influence of the above types of reactions on overall groundwater chemistry. Often it might be possible to predict the overall trend in pH or salinity, or for particular trace elements, but in general it is simply not possible to control the chemistry for every environmentally significant trace and heavy metal and radionuclide.

2.8 Mine Site Rehabilitation

After an ISL mining project has been completed, the site is rehabilitated and returned to the former land use. All infrastructure is removed, such as buildings, roads, pipes, processing equipment etc. The remaining solid and liquid wastes are disposed of in radioactive waste facilities, and these sites managed according to regulatory requirements.

3 - Potential Problems of In Situ Leach Mining

There is no human endeavour that is without some level of risk. The In Situ Leach mining technique is not immune to problems and difficulties. Broadly, these can be separated into mechanical failure, chemical problems, biological interference, poor engineering design, human error and complex geological and hydrogeological behaviour. Many mechanical failures are related to either chemical or biological interference. It is argued that these different types of failures are indeed significant, and are worthy of detailed investigation as to their potential environmental significance before any ISL type mining should proceed (refer to Sections 4 & 5 for detail on current and past ISL mines where these types of problems have been well documented).

Montgomery (1987) presents the following potential fatal flaws for the suitability of a uranium deposit for In Situ Leach mining :

- presence of humates or organics;
- uranium mineralisation in clays or silts;
- high molybdenum or vanadium concentrations;
- thin, sinuous and deep mineralisation;
- poor vertical solution confinement;
- highly faulted formation.

3.1 Mechanical Failure

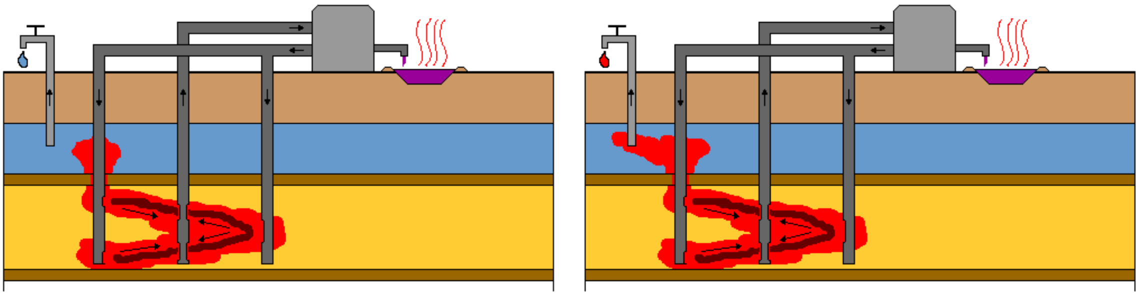
The ISL process requires equipment to operate at peak efficiency at all times, in the same way any other mining or industrial enterprise relies on good operation of machinery. The most common areas where the industrial process in ISL can lead to failure is in the groundwater pumping system (below ground), surface distribution pipes (above ground), leakage of the retention (evaporation) pond, and a failure in the processing plant. Each of these leads to different environmental releases and consequences and will be discussed separately.

Injection/Extraction Pump Failure

It is possible that a pump installed in either an injection or extraction bore could fail, leading to a change in the pressure regime immediately surrounding that pattern. This localised pressure increase, if left unnoticed, can quickly lead to a very significant pressure buildup in the pattern involved, thereby increasing the potential for an excursion of the solutions outside the mining zone. This excursion can occur in the same aquifer outside the influence of injection/extraction patterns, or it can move into an adjacent aquifer above or below the aquifer being mined (USEPA, 1995). Any difference in water pressure will simply force the solutions to move along the line of least resistance.

If surrounding aquifers are used for some purpose, such as agriculture or drinking water, a failure of the pumps in a leaching array poses a very significant threat to the quality of such aquifers. The use of high quality pumps compatible with the strong chemical environments is therefore of the utmost importance, as is good, regular maintenance.

Figure 13 - Injection/Extraction Pump Failure (Diehl, 1998)



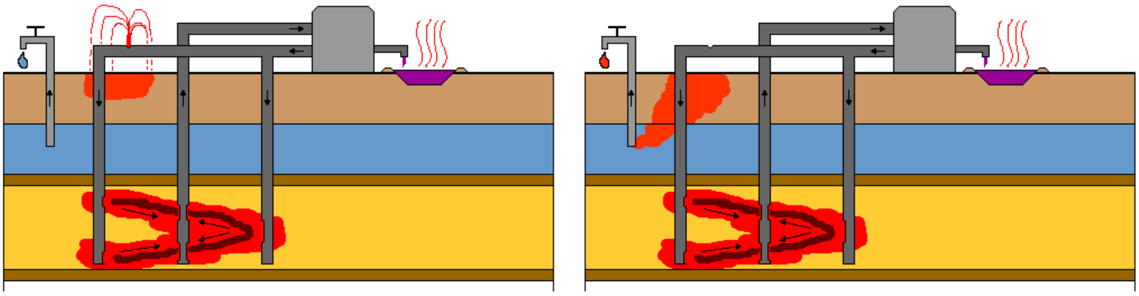
Pipe or Distribution Failure

The piping and distribution system between the wellfield and the processing plant also offers another area where there can be failure and environmental releases. The failure can be caused by poor construction of piping infrastructure, pressure buildup causing failure (due to blocked internal pipes), or external causes.

The nature of most ISL-type orebodies is that they are on flatlying lowlands near older mountain ranges. This leads to the problems of flash floods across an ISL site, and would be a significant problem for the proposed Beverley and Honeymoon mines in South Australia (refer to Sections 6.3 and 6.4). There would need to be some bores inside creek beds to access that part of the ore, with the piping and associated infrastructure needing to meet rigorous engineering in order to minimise potential damage from the ferocious forces of flash floods.

The release of any solutions on the surface will lead to direct contamination of the soil in the area of the accident, potential contamination of the water table or groundwater below, and the potential for off-site contamination and interference in surrounding activities, such as agriculture and tourism.

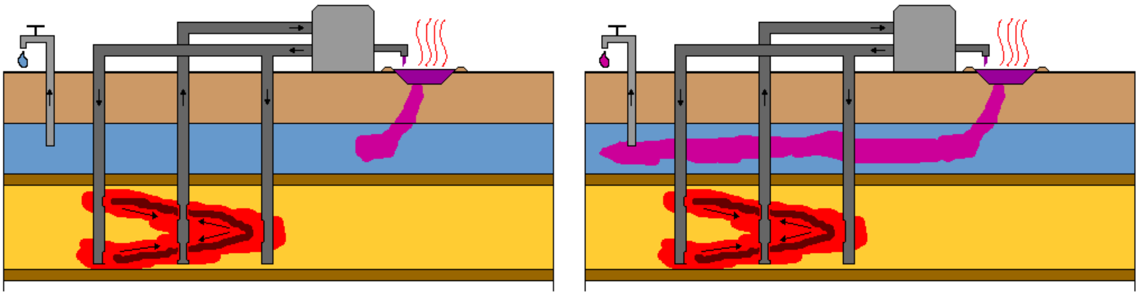
Figure 14 - Pipe or Distribution Pipe Failure (Diehl, 1998)



Evaporation/Retention Pond Failure

Due to the nature of ISL mines, there are high volumes of solutions being handled at any one time. These are stored temporarily in a retention pond, before the solutions are treated or injected into disposal wells or the water evaporated and the remaining solids removed and disposed of. If the pond were to leak and seepage were to escape from the facility, the toxic solutions would contaminate the underlying soil and potentially reach the water table and impact on groundwater resources.

Figure 15 - Evaporation/Retention Pond Failure (Diehl, 1998)



3.2 Chemical Interference Problems

There are many ways in which complex chemical problems can lead to failure and releases from In Situ Leach mining. The most important ways are through precipitation of minerals from a saturated solution and ion exchange with clays. Problems might also arise in the restoration phase of an ISL due to the presence of organic matter within the aquifer materials.

Mineral Precipitation

As highlighted earlier, it is possible for a solution to become too high in the amount of a particular mineral it has dissolved, or super-saturated with respect to that mineral. In this case, the mineral would precipitate out of solution, forming a solid. This is much the same mechanism as when a large amount of salt is dissolved in hot water, and when the water cools, the amount of salt above the saturation point will re-crystallise. A continuing pattern of mineral formation can lead to the pore space of the aquifer itself becoming plugged, the screens of the wells or possibly pumps being clogged, the pipes becoming blocked, or other problems in the processing plant.

Due to the intensive chemical nature of ISL mining, the increase in concentrations of the leaching solutions used tends to exacerbate these problems since it is at higher concentrations that minerals of lower solubility will precipitate out of solution. When the chemical conditions change, it is possible for these minerals to again dissolve into solution, and hence they can become important in long term groundwater quality protection.

These problems have been well documented at the In Situ Leaching trial conducted at the Honeymoon uranium deposit in South Australia in 1982 (Bush, 1998), and at many other sites around the world (for detail, refer to the sections documenting ISL experience in Europe, North America and Australia).

Clay Interference

The unique plate-like mineral structure of clays leads to them to have a strong influence on the chemistry of groundwater (Langmuir, 1997). Clays have a high surface-charge density to mass ratio (usually a negatively charged mineral surface), meaning that positively charged elements in solution tend to adsorb onto the surface of clays in an aquifer (Freeze & Cherry, 1979). This leads clays to have a large capacity to undergo the processes of ion exchange and adsorption, which can significantly affect the overall chemistry observed in groundwater.

Often in groundwater systems, the clays found within the aquifer materials contain a particular positively charged element on their surface, such as calcium. If the chemistry of the groundwater is altered, the clays can undergo ion exchange, whereby the calcium is replaced by sodium or ammonium, for example. Since there is only a positive charge of one on a sodium or ammonium ion in solution and a positive charge of two for calcium, it takes two sodium ions to replace one calcium ion on the clay surface. In order to accommodate the extra ions, the clay will expand or swell (Langmuir, 1997). The ability of a clay to undergo ion exchange with positively charged elements in solution is known as the CEC or Cation Exchange Capacity (Fetter, 1993).

One particular clay mineral that has this property is montmorillonite, a member of the smectite group of highly reactive clay minerals (Langmuir, 1997). The swelling caused by clay minerals undergoing ion exchange can lead to structural instability and a significant reduction in permeability of the aquifer material involved (Langmuir, 1997). This loss of permeability means lower flow rates through the aquifer and higher pumping costs for an ISL mine.

At many early ISL sites in the USA, sodium or ammonium ions (since many early ISL trial mines used sodium or ammonium bicarbonate leaching chemistry) that were undergoing ion exchange with clays caused severe problems with loss of permeability (Kasper *et al.*, 1979; Charbeneau, 1984).

Another important property of clays is that of adsorption. In much the same way that clays can undergo ion exchange, if there is available space on the surface of a clay mineral, they can adsorb elements onto their surface with no release of another element. This can lead to say, ammonium for example, being adsorbed onto the clay surface and not remaining in solution until the chemistry of the groundwater is altered once again. Adsorption is an equilibrium process, meaning that there is always a balance between the amount on the surface of a clay and that in solution. It is also a critical process for many trace elements, as they tend to adsorb very strongly to clays (Fetter, 1993).

The processes of ion exchange and adsorption on clays lead to three important consequences for In Situ Leach mining :

> (i) they can affect the overall leaching chemistry due to removal of, say, sodium, from solution and reduce the effectiveness of the dissolving the element and mineral of interest (such as uranium or copper minerals);
>
> (ii) any element that is adsorbed onto a clay, can later be released upon a change in overall groundwater chemistry, hampering the restoration of groundwater quality;
>
> (iii) the exchange of ions between solution and clays can lead to swelling of the clay, and a subsequent permeability reduction in the aquifer.

Organic Matter

Many trace elements, including radionuclides, attach themselves preferentially (or form soluble chemical complexes) to organic compounds in solution such as humic and fulvic acids formed by the degradation of vegetation (Fetter, 1993). Thus the presence of organic matter within groundwater can lead to conditions where many trace metals and radionuclides, which would not otherwise would be soluble and affect groundwater quality, are soluble and therefore have the potential for migration in the direction of groundwater flow.

Such problems have been the principal reason why there has been migration of radionuclides through groundwater at the Oak Ridge (Tennessee) radioactive waste disposal site (Fetter, 1993; McCarthy *et al.*, 1998). It was thought that before disposal there would be high rates of cation exchange and hence limited migration potential. However, the natural organic content of the aquifer materials led to much higher than expected solubilities of radionuclides such as cobalt-60 (^{60}Co), curium-244 (^{244}Cm) and americium-241 (^{241}Am) (Fetter, 1993; McCarthy *et al.*, 1998). McCarthy and co-workers (1998) concluded that even in formations characterised by minerals known to undergo adsorption or ion exchange, radionuclides can still undergo migration in groundwater with organic matter present.

The presence of organic matter or humates can also lead to the growth of microbial populations, aquifer plugging and reduced permeability (refer to Section 3.3) (Yates *et al.*, 1983; Brierley & Brierley, 1982). Such a condition is potentially a fatal flaw for the application of Solution Mining to a deposit (Montgomery, 1987).

The presence of organic matter in groundwater systems can thus lead to significant difficulties with an In Situ Leach mine, since many trace elements and radionuclides are potentially mobilised from a mineral to soluble state, and hence if complexed by organic matter, can remain soluble after ISL has finished. An excellent state-of-the-art review of the controlling influences of organic matter in groundwater geochemistry is given by Drever (1998).

3.3 Biological Problems

It is possible for bacteria and micro-organisms to thrive in most groundwater systems, and their importance in the controls on groundwater chemistry are becoming more recognised (Fetter, 1993; Langmuir, 1997; Chapelle, 1993). It is widely understood that many mineral reactions in low temperature environments occur at slow thermodynamic rates unless they are catalysed by specialised bacteria. Some examples might include the rapid production of acid mine drainage by bacteria such as species from the *Thiobacillus* and *Ferrobacillus* genus, or sulphate reduction by species from the *Desulfovibrio* or *Desulfotomaculum* genus.

The growth of bacteria in groundwater generally requires nutrients, carbon and an energy source. The carbon can be derived from organic matter or carbonates, while the energy source can be compounds like oxygen, sulphate or pyrite minerals. Often in groundwater systems, one of the above is available only in limited supply and the overall level of bacterial activity is consequently low. However, the introduction of leaching solutions into the aquifer can affect this position, and the bacteria are possibly able to utilise sulphate, for example, to increase their overall level of growth and activity. This increase in bacterial populations can lead to the pore space of an aquifer becoming clogged and problems with permeability. Such problems have been seen in Bulgarian ISL mines (refer to Section 5.1).

At the Honeymoon site, it has been suggested that the bacteria present at the site be utilised to increase the efficiency of the leaching process, due to their influence on the oxidants being proposed to leach the uranium (ferrous sulphate oxidised by bacteria to become ferric sulphate) (refer to Section 6.3).

The presence of an active microbial population in an aquifer is believed to be one of the causes of aquifer plugging and reduction in permeability (Yates *et al.*, 1983; Brierley & Brierley, 1982). Specific studies were undertaken where a mixed culture of organisms were isolated from the ISL mine experiencing the problems, and the culture injected into a uranium core sample. The permeability was decreased as a direct result of the growth of microbes, however, a dose of hydrogen peroxide was found to kill the culture and remove the problem (Pugliese & Larson, 1987).

3.4 Poor Engineering Design

The design of any engineered facility is critical in that facility's ability to meet environmental and operational criteria. The main areas of poor design can include groundwater bore design, bore location and testing, retention or evaporation pond design, flood prediction and mitigation measures and problems of scaling between laboratory studies and field scales.

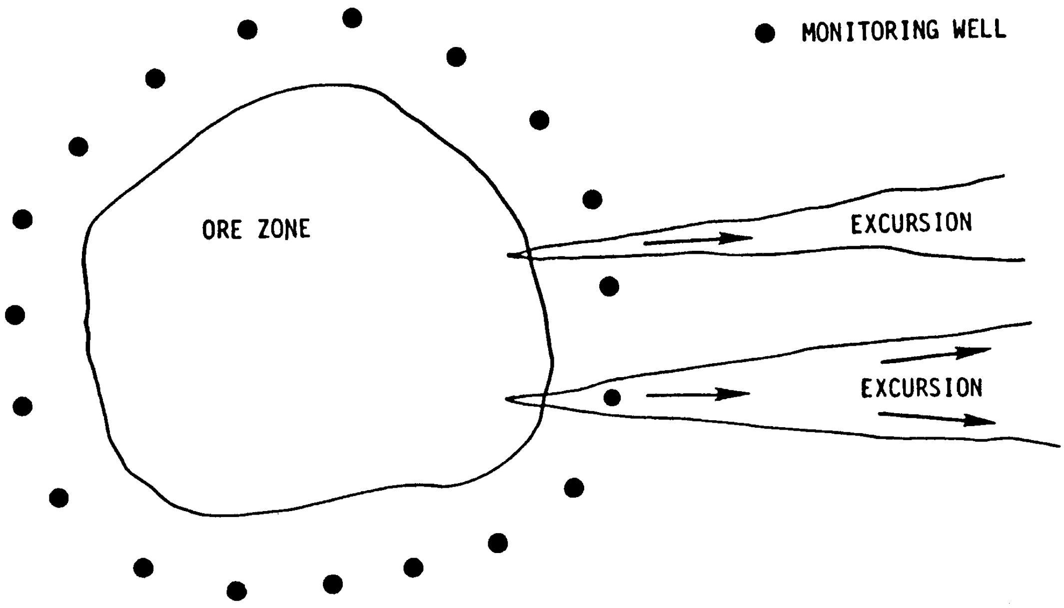
Groundwater Bore Design, Construction and Location

The poor design, construction and location of groundwater bores can lead to increased likelihood of bore failures and the inability to detect excursions or escapes of leaching solutions. The design of a groundwater bore needs to take into account the corrosive chemistry of the leaching process, and the likely operational stresses it is intended to receive, such as hydraulic pressures for injection of solutions and waste waters.

Although many roll-front uranium deposits and ISL mining operations are at low depths of the order of 100 to 150 metres, the proposed Crownpoint ISL project near Navajo tribal lands in New Mexico, USA, failed to take account of the significant depths of the deposit (between 300 to 500 metres) (Robinson *et al.*, 1995).

The location of groundwater monitoring bores is critical in being able to detect any excursion that may occur. If the configuration is not well-designed and based on overall groundwater flow directions during operation of the injection and extraction bores, it may be possible for an excursion to migrate between monitoring bores and leave the mining zone undetected (Kasper *et al.*, 1979).

Figure 16 - Groundwater Monitoring and Excursion Movement (Kasper *et al.*, 1979)
(assuming horizontal migration only)



Another fundamental problem in the design of a groundwater monitoring regime for ISL mines is the inherent variability and complexity of the geologic structures that form the ore deposit. By reference to Figures 2 and 3, it can be seen that many of the sand and clay layers in a typical palaeochannel type groundwater system are interfingered in ways which are simply not physically possible to determine. It is not technically possible to identify every sand layer and aquifer in and around the orebody, and thus determine if there has been escape of leaching solutions and a significant impact on groundwater quality.

A further problem in groundwater bore design, is the pump testing undertaken before ISL mining begins. The main idea behind a pump test is to test the hydraulic characteristics of the aquifer, and to ensure that a clay layer does indeed separate or confine the orebody aquifer from surrounding aquifers. However, such tests are not always designed to test the aquifer under the likely stresses that would be found during operation of In Situ Leaching.

For the current trial ISL mining at Beverley, comments of this nature were made concerning the documents and pumping tests done before government approvals were given - the pump tests intended to demonstrate that old exploration bores did not leak were not long enough or designed to stress the clay layer separating the ore zone from the overlying aquifer, which was used for stock watering in the region (Mudd, 1998a & 1998b). Similar problems were pointed out in the proposal at Crownpoint since the depths of the bores created inherent difficulties in the expected operating pressures ensuring stresses were within limits to prevent excursions (Robinson *et al.*, 1995).

The work of Taylor (1979) and USEPA (1995) identified that two of the most common causes of vertical excursions were old exploration boreholes that were not adequately plugged before mining operations began, and ruptured casing or separated joints within the bore construction. They also noted that vertical excursions are more difficult to remedy and require extensive investigative work to isolate the source of the problem. Hence the critical importance of rigorous aquifer testing that simulate the likely operational stresses that will be applied to an aquifer during the ISL mining process.

Retention/Evaporation Pond Design

The retention pond (or evaporation pond, depending on the management option chosen for waste solutions) is used to temporarily store waste solutions arising from the ISL process. Thus the design of the pond needs to ensure that there is no escape of these solutions, and that if an escape occurs, it can be quickly detected and remedial action undertaken. Such designs might incorporate two distinct layers of a chemically unreactive plastic liner material, such as high density polyethylene (HDPE), with sand or porous material in between these two plastic layers. Monitoring devices would be placed in this sand layer, and also below the lower layer, to detect any escape of the stored waste solutions. A layer of suitable clay might then be placed beneath the entire facility to provide a further barrier of low permeability to inhibit the escape of leaching solutions.

It is noted with interest that the original design for the retention pond for the ISL trial at Beverley incorporated none of the above design features, instead being planned as an unlined facility which would allow significant quantities of waste solutions to escape (Mudd, 1998a). The final design approved by the South Australian government included the above concepts.

There can be no guarantee that even if a more stringent design concept is adopted for a retention pond that it will prevent any escape of solutions. Even the best engineering can only lead to a reduction in risk, not removal of risk entirely.

Flood Prediction and Mitigation

By the nature of roll-front uranium deposits, they are typically located in the foothills and plains away from nearby mountain ranges. Due to their low-lying relief, flooding of a mine site can be of significant concern, both in terms of environmental management and operational issues.

Flooding can give rise to many problems at an ISL mine that is poorly designed or equipped to handle such events. These might include a breach of the retention pond and associated wastes, flow into wells that are improperly sealed at the surface (especially monitoring wells), integrity problems for pipes across creeks due to debris flow in the creek during a flood event, erosion of surface soils, and damage to site equipment. Perhaps the most serious possibilities are a breach of the retention pond or water flow into any of the extensive series of wells involved in ISL, as this will lead to a local rise in groundwater pressures and exacerbate the potential for and early detection of excursions, and possibly interfere with groundwater quality monitoring.

Such problems of monitoring and exploration bores exacerbating groundwater problems were among the principal reasons why seepage from the tailings retention system was not detected earlier at the Olympic Dam copper-uranium mine - bores were providing conduits for flow deep away from the tailings system, and the years of high rainfall (one in two-hundred year events twice within three years) hampered seepage problems and early detection of the seepage, since both the tailings system and the groundwater monitoring program were not designed to consider such possibilities (ERDC, 1996).

Clearly, the probability of and potential damage due to flooding needs to be considered very seriously and the design of an ISL mine carefully engineered to minimise potential problems.

The Scaling Problem

The process of ISL involves a number of often competing phenomena, and it is the engineer's job to exercise appropriate judgement to use laboratory scale data to design and construct a full scale facility. This is by no means an easy task.

In order to develop an ISL deposit to commercial production, samples from the orebody are first subjected to column leaching tests in a laboratory. The lixiviant chemistry, before, during and after leaching, the ore chemistry and physical properties are all monitored very closely during a column test. Such testing may also include different configurations, such as different oxidants or leaching solutions on alternate ore samples. The data collected from these tests is then used to plan design the overall ISL mine, beginning initially with small scale trials.

However, the problem of scaling laboratory data to a full size facility is a fundamental engineering problem, whether used for the design of multi-storey buildings, or even water supply dams. In ISL, the laboratory data may tend to underestimate the chemical or physical aspects involved, such as the quantity of acid required to leach a certain amount of uranium, the permeability of the material and problems of clay swelling, or the degree to which other contaminants may leach.

A good case in point is the ISL trial of sulphuric acid at the Nine Mile Lake site near Casper, Wyoming in the United States, reported in Nigbor *et al.*, 1981 & 1982. The uranium deposit was thought to be amenable to the use of sulphuric acid leaching chemistry since the deposit contained less than 0.1% calcite ($CaCO_3$, a strong acid consumer), thereby avoiding the restoration problems of sodium or ammonia-based lixiviants. Laboratory tests conducted on samples with sulphuric acid and carbonate lixiviants indicated that savings in chemical costs could be made by the use of sulphuric acid. These results and calculations were shown by field trials to be misleading.

In the laboratory, only 800 mg/l of acid was required to obtain a pH of 2.0; but in the field trials, 3,000 to 5,000 mg/l of acid was required to attain the same pH. This significant difference was explained by the higher concentration of gangue minerals in the field which consume the lixiviant, and the lower water content (or liquid-to-solid ratio) in the field compared to the laboratory. A similar case was also presented for the oxidant used (hydrogen peroxide, H_2O_2).

The case demonstrates that despite the best indications laboratory data can give, they are not by their nature the most effective method to scale and engineer the design for an ISL mine or trial.

3.5 Human Error

There is simply no human endeavour that is without the possibility of accidents or problems due to human error. The occurrence of a massive reactor explosion at the Chernobyl nuclear power plant in the former Soviet Union, the accident at Three Mile Island in the USA, the tailings dam breach at Church Rock in New Mexico and other nuclear-related accidents serves as a powerful reminder of the consequences of any failure. The operation of an ISL mine site is not immune to such failure, as is no industrial enterprise undertaken.

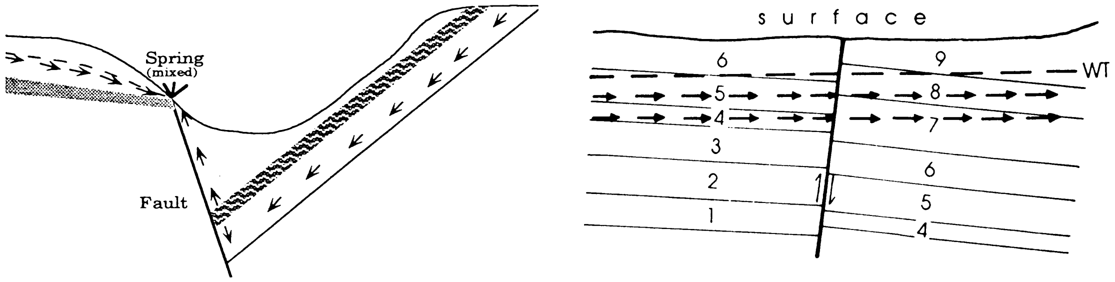
3.6 Complex Geologic and Hydrogeologic Behaviour

Although mining is often presented with idealised diagrams and figures outlining the geologic strata and essential processes involved, the basic concepts are always based on simplified theory and the reality of geological and hydrogeological systems are that they are inherently complex and often difficult to interpret and predict. Some of the principal concerns could be the small scale variability present within a palaeochannel (such as seen in Figure 2) leading to undetected excursions or problems in leaching, the behaviour of faults in regional groundwater flow, and the presence of fractures (or dolines in limestone or karstic terrain) causing unpredictable contaminant migration away from a site.

The nature of braided river palaeochannels are that they are highly variably, and contains numerous layers of sands that can act as individual aquifers. It would be physically impossible to identify and monitor the pressures and quality of all such sand layers. No rational engineer therefore could give a perfect guarantee that the groundwater is isolated and also well monitored. There will always be a reasonable risk involved in any endeavour undertaken in such a system and this needs to be acknowledged.

The behaviour of faults in groundwater flow can often be unpredictable or at least underestimated (Mazor, 1997). A fault is where the position of a layer of rock or sediment has been altered due to tectonic movements causing the layer to shear and the two halves move apart on a plane. The soil or rock material existing along a fault plane can either promote or inhibit the flow of water along the fault, and thus faults can act as important controls on the flow of groundwater through aquifers which contain faults.

Figure 17 - Idealised View of Some Typical Faults (Mazor, 1997)

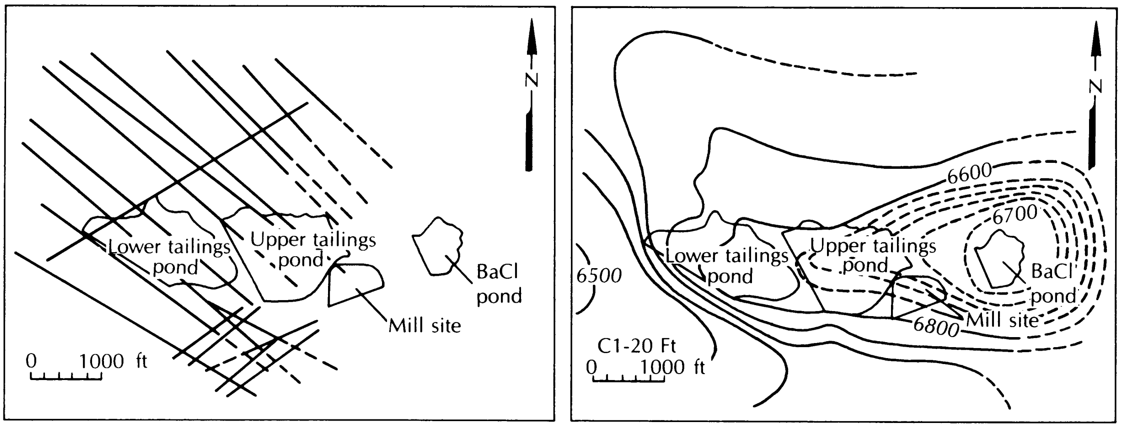


Frequently, by undertaking pump testing of the aquifer in the vicinity of the fault, it is possible to determine if that fault allows the flow of water across it or not by monitoring the relative aquifer pressures. However, if the fault is not stressed at the same pressures that a wellfield planned for the aquifer will function at, a conclusion of impermeable may be reached which may not be justified for the actual operation of the wellfield.

A case in point would be the water supply borefield for the Olympic Dam mine, which is located on the south-western margins of the Great Artesian Basin (GAB) directly to the north of the mine. The first borefield (known as Borefield A), is located within a sub-basin separated from the nearby GAB aquifer units by the impermeable North-west Fault Zone. This was intended to keep the drawdowns from the borefield isolated from the nearby Mound Springs, sites of great ecological and indigenous significance (Keane, 1997). However, the operation of the borefield saw much greater drawdowns than the initial hydrogeological testing was performed at, and hence the pressure across the fault was much greater and this is now recognised to have induced flow across the fault and cause greater than predicted impact at several Mound Spring sites (Mudd, 1998c).

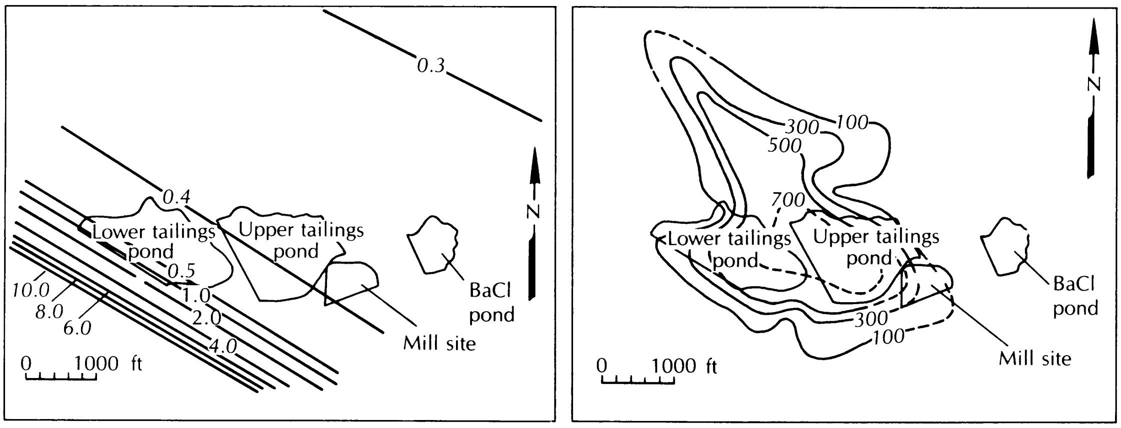
The presence of fractures within a rock layer can also lead to unpredictable hydrogeologic behaviour. A famous case in point is a uranium mine and mill in Utah, USA. The tailings facility of the mine was located on highly fractured sandstone, and the direction of groundwater flow was to the southwest. The primary direction of fractures was northwest. Despite the direction of groundwater flow, seepage led to the migration of radionuclides away from the tailings facility along fracture lines, and not with the flow of groundwater (White & Gainer, 1985; Fetter, 1994).

Figure 18 - Utah Uranium Mine Tailings Seepage Plume Along Fractures (White & Gainer, 1985)



Location of fractures and joints delineated by the VLF survey

Elevation of the potentiometric surface in February 1984



Baseline natural uranium activity (μCi/mL × 10^7)

Elevated activity of natural uranium in the summer of 1983 (μCi/mL × 10^7)

4 American Experience with ISL

4.1 Overview

The United States of America has been the principal pioneer of the In Situ Leach mining technique, applying it first to sites in Texas and Wyoming in the 1960's. The US Bureau of Mines (USBM) initiated detailed research on In Situ mining techniques in 1974, which covered In Situ Leach uranium mining as well as other In Situ mining techniques (such as borehole slurry mining), with the view to establishing ISL as a cost-competitive alternative mining method and to increase available domestic reserves of many minerals and metals (Pugliese & Larson, 1987). There have also been limited trials and research conducted on ISL-amenable deposits in Colorado, New Mexico, Utah and Nebraska.

Figure 19 - Location of ISL Sites in the USA (Underhill, 1992)

* - Grants/Churchrock - now known as the Crownpoint ISL Project

The first large scale commercial ISL uranium mine was opened in Texas at Clay West, during 1975, capable of producing 450 tonnes of U_3O_8 per year.. The ISL technique was arguably accepted and adopted so readily in Texas since the state already had oil and gas operations which operated with analogous principles (Underhill, 1992). By May 1980 a total of 18 ISL uranium mine sites and 9 trial sites could be found principally in Texas and Wyoming, with a pilot-scale plant each in New Mexico and Colorado (Larson, 1981). By May 1984, this number had increased even further to 21 commercial sites and 8 pilot scale operations.

The various ISL mines have consistently and gradually increased their proportion of the production of US uranium, increasing from 1.2% in 1975, 11.5% in 1981, 17.4% in 1985, 27.4% in 1991 to 94% in 1996 (Underhill, 1992, USDoE, 1997). The number of ISL mines respectively is 1, 14, 10, 6 and 4 (Underhill, 1992).

Table 5 - Summary of ISL Uranium Sites to 1991 (Underhill, 1992)

State	MTU	(%)	Commercial Projects	Pilot Projects	Planned Projects
Texas	16,872	82.3	20	30	4
Wyoming	3,483	17.0	3	25	7
Nebraska	140	0.7	1	1	1
New Mexico	0		0	6	3
Total	20,495	100	24	62	15

Due to the present status of the depressed world uranium market, many of the conventional mines have been placed on standby and a care-and-maintenance basis and the only six operating uranium mines are the ISL mines Kingsville Dome and Rosita in Texas, Highland, Christensen Ranch and Smith Ranch in Wyoming and Crow Butte in Nebraska, with the Smith Ranch ISL project commencing during 1997 (USDoE, 1998).

Underhill (1992) noted the stark reality of the global uranium market, stating that even low-cost ISL producers are not immune to such forces and that it was remarkable indeed that ISL production had continued in such circumstances. Underhill (1992) also pointed out that the current producers were generally based on larger ore bodies with a higher grade, and more automated process plants with fewer staff.

Underhill (1992) emphasised, however, that by 1984 there had been more unsuccessful ISL projects than successful ones. Also, there had only been one trial of sulphuric acid ISL (although two have been noted for this report), several pilot scale facilities trialling acid but no commercial facilities.

Table 6 - Average Leach Solution Composition - Minor Elements (mg/l)
(Underhill, 1992)

Element	Acid	Alkaline
Arsenic	<0.05	<0.05
Copper	1.00	0.04
Zinc	4.30	0.10
Lead	0.70	0.20
Iron	25.40	0.60
Nickel	0.60	0.06
Chromium	0.15	0.07
Strontium	3.70	1.50
Zirconium	3.30	0.90
Selenium		1.60
Manganese	1.20	
Molybdenum		0.90
Radium-226[1]	390	1,750
Vanadium	1.00	
Cobalt	0.20	

[1] - pCi/l

There has been a concerted attempt to develop the deep Crownpoint ISL deposit in north-western New Mexico, in the midst of the Navajo-Diné tribal community (Diehl, 1998). There remains significant indigenous opposition to this project, due to the mining and extraction of uranium and the fact that the aquifer that is proposed to be mined supplies over 90% of the communities drinking water supply (Robinson, 1995).

By August 1997, the regulators in Wyoming were yet to receive a submission on the restoration of a full scale commercial ISL mine (Chancellor, 1997).

However, there were many significant technical and environmental problems at the early trials which has a direct bearing on why the industry in the USA operates with the methods it uses today. As such, a review of these early test sites is important to place the ISL technique in the appropriate light.

Table 7 - Main Characteristics of US In Situ Leach Deposits (Montgomery, 1987)

State	Depth (m)	Characteristics	Special Problems
South Texas	60 to 245	• high permeability • thicker ore intercepts • clean sands	• low levels of Mo in some ores • faulting • saline water in some areas
Wyoming & Nebraska	60 to 300	• lower permeability • thin high grade ore intercepts • good groundwater quality	• varying levels of vanadium • insufficient groundwater levels in some cases • winterisation required and remote locations
New Mexico	245 to 760	• intermediate to high permeability • very thick host sands (30 m plus) • multiple mineralised intervals in one sand	• deep ore • high Mo concentrations in some areas • high humate concentrations in some areas

4.2 Regulatory Requirements

This review is based on Miller-Corbett *et al.* (1992).

The regulation of ISL mines in the United States is controlled by the US Nuclear Regulatory Commission (USNRC) in conjunction with specific state requirements. Under the direction of the US Congress, the USNRC administers the Atomic Energy Act 1954, as amended, and Titles I and II of the Uranium Mill Tailings Radiation Control Act (UMTRCA) 1978, as amended.

Any proponent of a new ISL uranium project must submit a licence application in conjunction with an Environmental Report (ER). The ER must characterise the proposed ISL site, processing facility, operational plans, environmental protection and management plans and a radiation safety plan. The ER must also contain plans for the post-mining restoration of groundwater at the site, land reclamation and plant decommissioning. The proponent, through the ER, must demonstrate that the proposal will not cause harm to human health or the environment.

The information presented in the ER forms the basis for the NRC’s preparation of an Environmental Assessment (EA) and Safety and Evaluation Report (SER).

The EA comprises an evaluation of the potential environmental impacts of a proposed ISL facility. In compliance with the National Environmental Policy Act (NEPA), if the conclusion of the EA is that there will be no impact to the environment, the USNRC publishes a Finding of No Significant Impact. Publication in the Federal Register provides notice to the public, and solicits comments with regards to the proposed project. If the USNRC finds a significant impact may occur as a result of proposed facility operations, a more detailed document, and Environmental Impact Statement is required, a publicly released document.

The SER is an evaluation of the prospective workforce and site occupant radiation safety at an ISL facility. This evaluation is based on proposed site operations and the predicted sources of accompanying radiation hazards. The SER includes a description of the applicant’s radiation safety program to limit radiation exposure from gamma emitters as well as ingestion and inhalation of airborne radionuclides. The SER also includes a description of an in-plant monitoring program to ensure that the workers’ environment is adequately characterised.

An ISL mine operator is required to provide proof of financial surety arrangements prior to commencement of operations. This requirement assures that there are sufficient funds available for decontamination, decommissioning and reclamation of the facility in the event that the operator is incapable of performing these tasks.

The ER covers important environmental information, including geography, demographics, geology, hydrology and local meteorology. The site must also undergo detailed characterisation, such as aquifer flow properties, and define the mineralised zone and all aquitards (confining units) and aquifers above and below the ore zone. Another critical factor is the collection of baseline groundwater quality data before mining begins. These need to be statistically derived and are used in later groundwater monitoring to determine if there is control of leaching solution flow. The baseline data is also critical in determining the requirements for groundwater quality restoration.

The USNRC also requires that detailed assessment of airborne radioactive emissions be characterised and their impact on surrounding human health and the environment quantitatively modelled (using the MILDOS system). They must include all sources and vents of radon gas, uranium dust and other radionuclide emissions.

In addition, the USNRC requires that prospective licencees prepare Standard Operating Procedures (SOP) for all work involving radioactive materials. The SOP’s must be available at all times and to all employees. Similar procedures are required for all equipment and programs developed for environmental protection and monitoring.

The reclamation of a former ISL mine site must include the decontamination of all buildings, foundations, and equipment prior to release to unrestricted areas. Alternatively, contaminated materials may be transferred to another licencee for radioactive source materials (eg - an ISL mine site). All injection, extraction and monitoring wells must be cut off below the surface and appropriately abandoned to prevent cross contamination of aquifers.

The radioactive wastes, such as piping, contaminated soils, and decommissioned equipment, must be disposed of at facilities licensed for such material. Currently, tailings piles at conventional uranium mills serve as receptors, although state facilities are also acceptable. All waste waters are generally required to be evaporated, unless the operator holds a permit from the USEPA for deep well disposal.

An issued In Situ Mining Licence is generally for 5 to 7 years, and need to be renewed near the end of this period. At this time, a new Environmental Report must be submitted detailing the operating history of the ISL mine and address any significant changes from the previous licence approval. A licence amendment may also be considered, covering aspects such as process plant alterations, environmental management plans or corporate organisation. An updated financial surety arrangement must also be included.

There are also state specific regulatory requirements that must be met before an ISL proposal is able to commence construction and operation. A review of Wyoming and Texan regulations are provided in their respective sections.

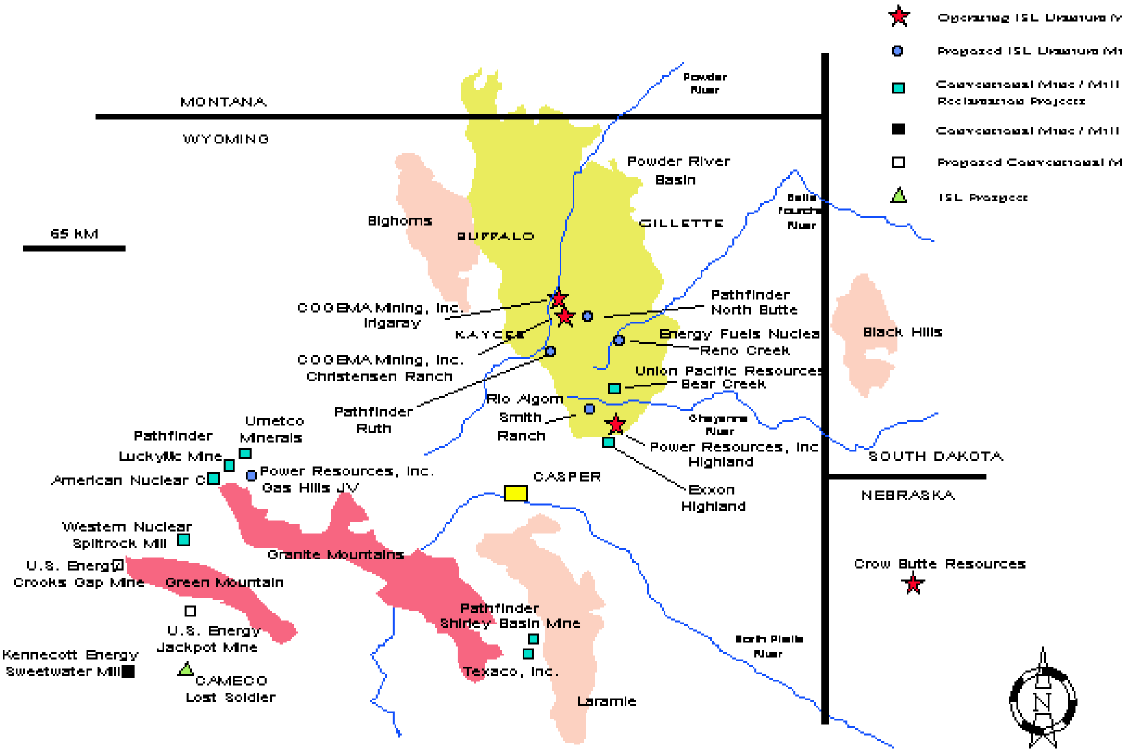
Upon meeting all of the above regulatory requirements, an applicant receives a source material licence authorising operation the proposed ISL facility.

4.3 Wyoming and ISL

Overview

There are several districts in central and north-eastern Wyoming where uranium has been found, namely the Shirley Basin, Gas Hills, Crooks Gap and the Powder River Basin.

Figure 20 - Map of Wyoming Uranium ISL Deposits and Projects[1]



The first ISL trial to begin experimentation was by Utah Construction and Mining Company (later Utah International Inc. and now Pathfinder Mines Corp.) between 1961 and 1963 at Shirley Basin, central Wyoming (Larson, 1981; Charbeneau, 1984, Underhill, 1992). The company experimented with many techniques, especially looking at operational procedures for wells and leaching chemistry (Larson, 1981, Underhill, 1992). By 1963, the company had experimented with 5 generations of wellfield designs and had drilled over 100 wellfield patterns in an attempt to optimise uranium recovery (Larson, 1981).

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[1] - Map from the Wyoming Mining Association website (http://www.wma-minelife.com/).

However, although the ISL method was used for the production of uranium during 1963 to 1969 experimenting with sulphuric acid (Underhill, 1992), an adjacent open cut operation in was begun in 1969 and the ISL mine was replaced by this operation in 1970, which continued to produce uranium until it's closure in 1992 (Larson, 1981; Charbeneau, 1984, Underhill, 1992). A total of 750 MTU of uranium was produced between 1963 and 1970 (Underhill, 1992).

Encouraged by the apparent success of in situ leach uranium mining, many companies committed to further research and development and by May 1980, a total of nine sites were under various stages of development (Larson, 1981).

Table 8 - ISL Proposals, Trials and Mine Sites in Wyoming[1]

Site	**Company**	**Notes & Status** (2)
Battle Springs	Union Energy Mining	Unknown
Bill Smith	Kerr-McGee	Unknown
Bison Basin	Ogle Petroleum	Unknown (for sale in 1984)
Collins Draw	Cleveland Cliffs JV	Unknown, apparently restored in 1982 and put on standby
Highland	Converse County Mining Venture (CCMV)	Operating facility Early trial had restoration problems
Christensen Ranch / Irigary	Cogema Mining	Operating facility
Leuenberger	Teton Exploration (3) now Power Resources	Awaiting commercial scale
Nine Mile Lake (Casper)	Rocky Mountain Energy Joint Venture	Early trial of sulphuric acid ISL, current status unknown
North Butte	Pathfinder	Wellfields undergoing restoration, plant decommissioning
North Platte	Uranium Resources Inc	
Smith Ranch / Q Sand / O Sand	Rio Algom	Brought into commercial production in 1997
Peterson	Arizona Public Services	Unknown, on standby in 1984
	Kerr-McGee	Unknown
Radon Springs	Texasgulf	Unknown
Red Desert	World Nuclear	Unknown
Reno Ranch	Rocky Mountain Energy	Trial of sulphuric acid in 1979, unknown results
Ruth	Uranerz USA	Wellfields undergoing restoration, plant decommissioning
S-I-7	Wyoming Minerals	Unknown
Sundance	Nubeth JV	Unknown

[1] - compiled from Humenick *et al.*, (1984), Larson (1981), USEPA 1995, USDoE (1995, 1997 & 1998), Riding *et al.* (1979) & Underhill (1992)

[3] - This is the same company behind the original development of the Honeymoon Uranium Project.

Humenick *et al.* (1984) summarised the main hydrogeologic properties of many Wyoming uranium ISL deposits, compiled below.

Average Sand Thickness	5 m to 100 m
Ore Thickness	2.1 m to 25 m
Average Porosity	20% to 30%
Formation Depth	33 m to 203 m (minimum to maximum)
Permeability	0.09 to 1.43 m/day
Groundwater Velocities	0.41 to 17 m/year

4.4 Wyoming Regulations

The state of Wyoming has specific regulations within it's legislation that relate to In Situ Leach mining, administered by the Department of Environmental Quality (DEQ). These are found within the Wyoming Environmental Quality Act (WEQA, 1996) and the Land Quality Division's (LQD) Noncoal Rules and Regulations (NR&R, 1993 & 1997). A brief review of the more important aspects of each are given.

Wyoming Environmental Quality Act (WEQA)

Before a licence can be issued by the DEQ, the conditions and detailed site characterisation data as required by the USNRC must be presented. As with general mining requirements, the WEQA specifies that all data and sampling records are to be kept and submitted in an annual report, a financial bond must be kept, and any excursion must be verbally reported to the DEQ, followed by reasonable written notification.

One important point concerns the status of abandoned wells. All such wells after the completion of mining are to be subject to the NR&R.

Noncoal Rules and Regulations (NR&R)

The section directly dealing with In Situ Leach Mining in the NR&R is Chapter XI. The DEQ recently proposed amendments to these regulations, in August 1997, and the current status of these are currently being confirmed. The NR&R contain many prescriptive requirements for ISL mining permits, but it does contain many points that are specific to the operation of ISL mines. There are some important differences between the NR&R (1993) and the proposed NR&R (1997), and these will be highlighted.

Some of the more important points of NR&R (1993) are :

- reclamation shall be completed within 2 years following groundwater restoration;
- the operator shall verbally report any confirmed excursion to the DEQ within 24 hours, and shall submit a written report to the DEQ within 7 days detailing plans for mitigating or controlling the excursion;
- if an excursion is not controlled within 60 days, the DEQ may terminate or modify a permit or licence.

For permit applications (Section 3), the following specific information is required, in addition to general and project data :

- location and present owners of all wells in use within the permit and adjacent areas, and all salient information relating to those wells;
- a tabulation of all abandoned wells and drill holes, including location, depth, type of use, condition of casing, plugging procedures and date of completion for each well or drill hole within the permit and adjacent areas;
- a groundwater pressure map for all aquifers potentially affected by the ISL mining process;
- tabulated water quality analyses for all groundwaters, including variability;
- procedures to verify that injection and recovery wells are in communication with monitoring wells, and not in communication with other aquifers;
- procedures to check the mechanical integrity of injection wells at a minimum of every 5 years;
- procedures to protect topsoil from excessive compaction, degradation and wind and water erosion;
- a subsidence analysis (ie - ground settlement due to reduction of groundwater pressures), including procedures for mitigating or controlling it’s effects;
- descriptions of chemical reactions that may occur during recovery solution injection;
- the information necessary to demonstrate that the operation will return all affected groundwater within the permit area to a condition such that it’s quality of use is equal to or better than, and consistent with, the uses for which the water was suitable prior to the operation by employing the best practicable technology :
    - the condition and quality of all affected groundwater will be returned to background or better, or
    - in the event that the above cannot be achieved, the condition and quality of all affected groundwater will at a minimum be returned to a quality of use equal to and consistent with uses for which the water was suitable prior to mining.

The new NR&R regulations, proposed in August 1997, have some important differences. Some of the main points are noted below :

- pilot scale In Situ Leach Mining taking place in an area previously unmined are termed experimental technologies;
- an excursion is defined as any unwanted and unauthorised movement of recovery fluid (leaching solutions) out of the production zone as a result of in situ mining activities;
- reclamation of surface disturbances in any mining area shall be completed within 2 years following the approval of groundwater restoration in that area and reclamation of all mining related disturbances shall be completed within 2 years following approval of final groundwater restoration within the permit area;
- if the DEQ determines that a well lacks mechanical integrity, they shall give written notice to the owner or operator of the ISL mine, and the owner/operator shall cease injection into the well within 48 hours of the receipt of the notification;
- procedures to insure that the installation of all types of wells will not result in hydraulic connection between the production zone and other stratigraphic horizons;
- monitoring of injection pressure at least weekly and flow volumes at least daily;
- where disposal via injection wells is into a groundwater system which contains water with less than 10,000 mg/l salinity (TDS), monitoring wells shall be completed in the production zone;
- where disposal via injection wells is into a groundwater system which does not contain water with less than 10,000 mg/l salinity (TDS), monitoring wells shall not be required;
- except during well stimulation for integrity testing, well injection pressures must be kept so that the pressure in the production zone during injection does not initiate new fractures or propagate existing fractures. In no case shall injection initiate fractures in the confining zone.

An aquifer is only exempt from restoration requirements by meeting these criteria :

- it does not currently serve as a source of water;
- it cannot now and will in the future serve as a source of water because :
  - it is mineral, hydrocarbon or geothermal energy producing or contains a mineral or hydrocarbon of economic value that can be expected to be commercially predicable;
  - the depth of the water makes recovery economically and technologically impractical;
  - the water is so contaminated that it would be economically and technologically impractical to render that water fit for human use;
- the salinity level is between 3,000 and 10,000 mg/l and is not expected to supply a public water system.

4.5 Texas and ISL

The Texas uranium district is found in the sandstones of the south-west of the state, and contains both open cut and many ISL mines.

Texas shortly followed Wyoming and the first test was conducted by City Service between 1967 and 1971 at the Dueterstat Site in Gonzales County, north of Yorktown (Taylor, 1979). Other test sites during the early 1970's included the Bruni Site in Webb County, and the Burns and Clay-West Sites in Live Oak County (Taylor, 1979; Charbeneau, 1984). Most of these sites used alkaline leaching chemistry, with only one permit issued in the mid 1970's authorising the use of acid leaching chemistry (Taylor, 1979).

The Clay West site, developed as a joint venture between Atlantic Richfield, U.S. Steel (USX) and Dalco, was the first commercially run ISL mine to be given approval in the United States, effective January 1975 (Charbeneau, 1984; Larson, 1981). A second site across the highway from the Clay West site, the Burns Ranch site, was given approval in October 1976 (Charbeneau, 1984). By 1980, 9 companies were using ISL at 25 sites and 6 further sites were awaiting approvals from government (Charbeneau, 1984).

However, as the uranium market plummeted in the early 1980s, many projects were put on hold or the facilities converted to standby on a care and maintenance basis. Despite a total of 17 sites having approval for ISL uranium mining, there are currently only two active ISL mines in Texas, the Rosita and Kingsville Dome mines operated by Uranium Resources Inc. (URI) (USEPA, 1995; USDoE, 1997).

Table 9 - ISL Proposals, Trials and Mine Sites in Texas[1]

Site	Company	Notes & Status
Alta Mesa	Cogema Mining	Announced plans
Benavides	Uranium Resources Inc.	Wellfield undergoing restoration, plant decommissioning
Besar Creek	Rocky Mountain Energy	Early 1970's trial of sulphuric acid
Boots/Brown	U.S. Steel	Unknown
Bruni / Sulfur Creek	Westinghouse	Wellfield restored, plant decommissioning
Burns Ranch / Clay West	U.S. Steel	Wellfields undergoing restoration, plant decommissioning
Dunderstadt	Cities Service	Trial of sulphuric acid ISL, operated from 1969 to 1970.
Hobson / Gruy	Everest Minerals	Wellfield undergoing restoration, plant on standby
Holiday-El Mesquite	Malapai Resources	Wellfield undergoing restoration, plant on standby
Kingsville Dome	Uranium Resources Inc.	Operating facility
Lamprecht / ZamZow	Intercontinental Energy	Wellfield in restoration, plant decommissioning
Las Palmas	Everest Minerals	Wellfield restored, plant decommissioning
Longoria	Uranium Resources Inc.	Unknown
McBride	Caithness Mining	Unknown
Moser	U.S. Steel	Unknown
Mt Lucas	Everest Minerals	Wellfield undergoing restoration, plant decommissioning
Nell	Malapai Resources (3)	Unknown
O'Hern	Malapai Resources (3)	Wellfield and plant on standby
Palangana	Chevron (Union Carbide)	Unknown
Pawlik	U.S. Steel	Unknown
Pawnee	Intercontinental Energy	Unknown
Piedre Lumbre	Malapai Resources (3)	Unknown
Rosita	Uranium Resources Inc.	Operating facility
Santonino	Urex Inc.	Unknown (at trial stage in 1984)
Tex-1	Everest Minerals	Wellfield undergoing restoration, plant decommissioning
Trevino	Conoco Inc.	Unknown
West Cole	Cogema Mining	Wellfield undergoing restoration, plant decommissioning

[1] - compiled from Charbeneau (1984), Larson (1981), USEPA 1995, Underhill (1992), Nigbor *et al.*, (1982), USDoE (1995), USDoE (1997) & USDoE (1998).

[3] - Exact current ownership unknown, assumed Malapai Resources acquired the sites when they bought out Mobil's interests in uranium (Moody, 1992).

4.6 Texan Regulations

The regulation of In Situ Leach uranium mining in Texas is covered by the jurisdiction of the Texas Water Commission (TWC) for the prevention of surface and groundwater contamination, and the jurisdiction of the Department of Health, Bureau of Radiation Control (TBRC) to regulate and license radioactive materials, although between March 1993 and July 1997 complete jurisdiction was transferred to TWC in the Texas Natural Resource Conservation Commission (McBurney, 1997). There was new legislation proposed in September 1997 to regulate uranium ISL mining (TBRC, 1997), and these were expected to be adopted in February 1998 (McBurney, 1997). They cover many general aspects that would be required for permit applications, but do have some interesting facets. A review of the proposed regulations is given below.

The most important points of note are (TBRC, 1997) :

- licence applications submitted will be made available for public inspection;
- the applicant has demonstrated financial capability to conduct the proposed activity including all costs associated with decommissioning, decontamination, disposal, reclamation and long-term care and maintenance;
- the applicant shall provide a closure plan for decontamination, decommissioning, restoration, and reclamation of all buildings and the site to levels that would allow unrestricted use;
- operations shall be conducted so that all effluent releases are reduced to as low as is reasonably achievable;
- the licencee shall immediately notify the TBRC if :
  - any failure of a radioactive material retention system which results in a release of radioactive material into unrestricted areas;
  - any release of radioactive material which exceeds the specified concentrations for water and which extends beyond the licensed boundary;
  - any spill which exceeds 75,000 litres and which exceeds the specified concentrations for water;
  - any release of solids which exceeds the contamination limits and that extends beyond the licensed boundary;
- the licencee shall notify the TBRC within 24 hours if :
  - there is any spill that extends -
    - beyond the wellfield monitor well ring;
    - more than 122 m from an injection or production well pipe artery to or from a recovery plant;
    - more than 61 m from the recovery plant.
  - any spill which exceeds 7,500 litres and which exceeds the specified water concentrations;
- the licencee shall maintain in effect all decommissioning financial security arrangements, and must be increased, or may be decreased, as appropriate, to cover the detailed cost estimate for decommissioning;
  - the security must also cover the payment of the charge for long-term surveillance and control of radioactive waste disposal areas;

- decommissioning shall be completed within 24 months;
- the disposal of radioactive wastes shall incorporate payment into the Radiation and Perpetual Care Fund (RPCF), determined on a case-by-case basis;
- a minimum charge of $250,000 (1978 dollars), shall be paid into the RPCF to cover long-term care and maintenance, assuming the charge shall yield interest to cover annual costs of site care, surveillance, and where necessary, maintenance;
- the design requirements for radioactive waste disposal sites must incorporate :
  - the upstream rainfall catchment areas must be minimised to decrease erosion potential by flooding;
  - the topographic features shall provide good wind protection;
  - the embankment and cover slopes shall be relatively flat after final stabilization to minimise erosion potential and to provide conservative factors of safety assuring long term stability. Slopes shall not exceed 5 horizontal to 1 vertical (5h:1v);
  - a full self-sustaining vegetative cover be established;
  - any waste disposal facility shall not be located near a capable fault that could cause a maximum credible earthquake larger than that which the facility could reasonably be expected to withstand;
- all waste disposal facilities shall be lined to prevent any migration of wastes to adjacent soil, groundwater and surface water;
- seepage control systems shall be installed;
- for the cover and closure of radioactive disposal areas, which :
  - be effective for 1,000 years to the extent reasonably achievable and, in any case, for at least 200 years;
  - limit releases of radon-222 and radon-220 from radioactive wastes to the atmosphere so as to not exceed an average release rate of 20 pCi/m^2, throughout the design life of the waste facility;
  - direct gamma exposure should be reduced to background levels;
- prior to any major site construction, a preoperational monitoring program shall be conducted for one full year to provide complete baseline data for the site and it's environs;
- no new site shall be located in a 100-year floodplain or wetland.

Table 10 - Maximum Values for Groundwater Protection[1] (TBRC, 1997)

Arsenic	0.05	Mercury	0.002
Barium	1.0	Selenium	0.01
Cadmium	0.01	Silver	0.05
Chromium	0.05	Radium-226 & 228	5
Lead	0.05	Gross α[2]	15

[1] - all mg/l, except Radium 226 & 228, Gross α pCi/l.

[2] - excluding radon and uranium in uranium mines, or radon and thorium in thorium mines.

4.7 Other States

There has been a limited number of proposals, trials and commercial mines in other states across the mid-west. In New Mexico, these include the North Windup/Jackpile Paguate sulphuric acid ISL trial run by Anaconda from 1969 to 1970, and the Crownpoint trial in run by Mobil in the early 1980's (Underhill, 1992). The Keota ISL project in Colorado was run by a joint venture between Union Oil and Power Resources Inc in the late 1970's (Larson, 1981). Wyoming Minerals were also developing the Grover ISL mine in Colorado although the current project status is uncertain (TEA, 1987a). Lomex Corporation also proposed an ISL mine at La Panza in California within the Los Padres National Forest in the late 1970's (Broadwater, 1979). The current status of the Keota and La Panza projects is unknown.

Crownpoint is currently under significant pressure for development by Hydro Resources Inc (HRI), a subsidiary of Uranium Resources Inc (URI) of Texas. As the Crownpoint Project is within the Navajo tribal community, there remains considerable indigenous concern and opposition over this proposed development (Robinson *et al.*, 1995, ENDAUM, 1997).

Table 11 - Miscellaneous ISL Trials and Proposals[1]

Site		**Company**	**Notes & Status**
North Windup / Jackpile Paguate	NM	Anaconda	1969-70 trial of sulphuric acid, project discontinued.
Crownpoint / Churchrock	NM	Mobil (trial), now Uranium Resources Inc	Current ISL proposal
La Panza	CA	Lomex Corp.	Unknown
Keota	CO	Union Oil / Power Resources Inc	Unknown
Grover	CO	Wyoming Minerals	Unknown
Big Red	NE	Ferret Expl. of NE	Awaiting commercial development

[1] - compiled from literature as cited above.

4.6 General Environmental Problems at the Early Sites

As discussed previously, there are many potential environmental problems with the In Situ Leaching mining technique. A review of some of the problems known to occur at the early trial and production sites is presented, with detailed case studies of some sites.

The main problems encountered at many of these early sites can be broadly summarised as (compiled from Kasper *et al.*, 1979; Nigbor *et al.*, 1982; Charbeneau, 1984; Tweeton & Peterson, 1981, Underhill, 1992) :

- precipitation of minerals, such as calcite ($CaCO_3$) and gypsum ($CaSO_4$), causing pipe blockages and solution control problems;
- reprecipitation of uranium;
- buildup of toxic heavy metals in solutions;
- difficulty of restoring groundwater quality after ISL mining ceases for all environmentally sensitive elements;
- clogging of the aquifer and well screens by bacterial growth;
- inadequate engineering design of the processing plant and associated infrastructure, such as the evaporation pond;
- leaking bore casings and well completion and construction;
- clogging of the aquifer formation near production wells;
- control of solution movement due to the above problems;

4.7 Environmental Problems at Early Wyoming Sites

Irigary - Recalcitrant Problems and Excursions

One of the most famous ISL projects with consistent environmental problems was the Irigary ISL project, operating in the late 1970’s to early 1980’s. A review of this site provides many interesting insights into the operational and environmental problems associated with ISL facilities.

The Irigary ISL mine was operated by Wyoming Mineral Corporation (a subsidiary of Westinghouse), designed to operate at 500,000 lbs per year U_3O_8 (225 tonnes) (Moody, 1992). For three years the facility was plagued by fire and “persistent excursions” of solution chemicals which not only slowed down production but caused one unforeseen shut-down (Moody, 1992).

The Department of Environmental Quality (DEQ) in the state produced a detailed report on the Irigary operation which comprises a fairly effective indictment of uranium solution mining (Peterson, 1979). This report revealed a disturbing chronology of misfortune :

- *March 14, 1979* - chloride levels in a shallow monitor well were above the “upper control limit” (UCL);
- *March 27* - chloride conductivity and total alkalinity were above the "upper control limits" and one well was thought to be leaking;
- *2-3 weeks later* - over-pumping failed to correct the problem : the cause and indeed the location of the “excursion” remained unknown;
- *April 12-20* - two units shut down and two other wells identified as leaking into the same area;
- *May 25-27* - a pump couldn't be put into the leaking well because of casing damage;
- *July 5* - the leaks were "coming under control" after scientists postulated that injection (of the solution) was cracking the casing of some of the wells.

The DEQ found that basic tests had not been carried out by the company: the integrity of the cases had not been checked, nor were injection pressures monitored or recorded. It took more than five months to discover “problems previously unencountered with in situ uranium mining”, and, even then, little could be done to prevent them (Peterson, 1979; Moody, 1992).

Nine Mile Lake/Casper, Wyoming - Sulphuric Acid ISL on Trial

Rock Mountain Energy Co., in conjunction in with US Bureau of Mines, conducted a pilot-scale In Situ Leaching experiment near Casper, Wyoming, of sulphuric acid leaching chemistry, summarised in great detail in Nigbor *et al.*, 1981 and Nigbor *et al.*, 1982. The principal aim was to determine if there were any cost advantages in using such lixiviants over the more conventional alkaline agents used principally in Texas and at other sites in Wyoming. The trial showed that while sulphuric acid is indeed an effective lixiviant, there were no overall cost advantages, and many environmental problems became evident also.

The Nine Mile Lake (NML) site is situated in the Powder River Basin, where the geology is principally described as Precambrian to Quaternary. The uranium orebody at the NML site is found within the Teapot Sandstone, which consists of upper and lower sands separated by 0.6 to 1.2 metres of semipermeable shale and lignite. The uranium mineralization was of the roll front type, with an average thickness of 3 metres. The dominant uranium mineral was uraninite (UO_2) with minor amounts of coffinite ($U(SiO_4)_{1-x}OH_{4x}$) present also. Minor amounts of mica, glauconite, carbonaceous fragments are also contained in the sandstone. The major clay mineral is kaolinite, with minor amounts of the reactive clay montmorillonite identified. Overall carbonate content is low, less than 0.1%.

A processing plant was built in 1976, using equipment from an earlier acid leaching test in Texas at Besar Creek. The design capacity of the plant was 150 litres per minute (lpm or 2.5 litres per second, l/s), although it was run as high as 230 lpm. The uranium extraction technique used was ion exchange. The bleed stream was up to 10% to 15% of the production flow, to control the buildup of contaminants. During restoration, when the flow diverted to the evaporation pond was as high as 113 lpm, the pond did not contain enough capacity. Capacity problems were also encountered during winter as the pond was ice-covered.

A total of four experimental patterns of different arrangement were drilled at the site, and different lixiviant options tried on each pattern. A basic summary of patterns 1, 3 and 4 is provided below in Table 7. Pattern 2 is the detailed subject of Nigbor *et al.*, 1981 & 1982.

The second wellfield pattern, known as Pattern 2, was constructed in the lower sand and began leaching with sulphuric acid in December 1977. One of the observation wells drilled for the pattern was thought to be damaged, as a borehole inspection camera showed excessive sediment in the bottom of the bore and the water chemistry was markedly different from other bores. This was thought to be due to poor construction of the bore allowing flow of water from the upper sand to interfere with the bore. Only the remaining two bores were used for monitoring purposes.

Table 12 - Baseline Groundwater Quality with Standard Deviation[1]

pH	6.7 ± 0.3	Arsenic	0.040
Redox	-120 ± 200	Boron	0.67 ± 0.40
Total Dissolved Salts	4,300 ± 550	Chromium	0.01
Dissolved Oxygen	1	Copper	0.01
Bicarbonate	290 ± 30	Manganese	0.31 ± 0.18
Chloride	46 ± 4.3	Mercury	0.01
Sulphate	2,510 + 244	Molybdenum	0.008 ± 0.018
Sodium	830 ± 145	Phosphorous	0.2
Potassium	14 ± 3.6	Radium-226 [2]	510 + 29
Calcium	207 + 43	Selenium	0.002
Magnesium	92 ± 31	Thorium-230 [2]	0.084 + 0.005
Iron	1.07 ± 0.4	Uranium	0.23 ± 0.10
Silicon	4.2 ± 4.0	Vanadium	0.5 ± 0.2
Aluminium	0.13 ± 0.05	Zinc	0.02 ± 0.02
Fluoride	0.77 ± 0.25		

[1] - all values in mg/l, except pH, Redox (mV).

[2] - Radium-226 and Thorium-230 are in pCi/l.

Table 13 - Performance of Nine Mile Lake ISL Patterns

Pattern 1	- 7-spot pattern (15 m radius), wells penetrating both upper and lower sands, leached with acid in 1976, although results were "disappointing" - problems included the PVC well casing, cements, pumps, gypsum scale buildup on the injection well screens (possibly due to the acid attacking the well cement) gave poor injection rates, possible channelling of flow - lixiviant averaged 4,000 mg/l of sulphuric acid (pH 1.7), 500 mg/l of hydrogen peroxide and 150 mg/l ferrous sulphate - restoration took almost a year to bring quality within baseline
Pattern 3	- modified 7-spot pattern, with wells completed in both the upper and lower sands - the production flow rate was about 117 lpm and the uranium concentration 75 mg/l - leached both sands with sulphuric acid simultaneously, with various oxidants trialled, including hydrogen peroxide, oxygen and a compound known as Caro's acid (H_2SO_5) also tested (an effective acid & oxidant) - leaching in the upper sand was stopped after an excursion was found (not immediately) escaping to the south between monitoring wells - the excursion was caused by unequal injection rates between the upper and lower sands (it was wrongly assumed that the permeability of both sands was the same), despite packers and other devices that were installed to fix the situation, problems persisted, added to by fungal growth in some of the injection wells
Pattern 4	- a 5-spot pattern, completed in the lower sand - planned to use sodium carbonate-bicarbonate lixiviants at 1,000 to 3,000 mg/l, with gaseous oxygen as the oxidant - the expected production rate was 75 to 100 lpm - was starting leaching trials at the time of writing (Nigbor *et al.*, 1982)

As the leaching process continued for approximately eleven months during 1978, the changes in groundwater/lixiviant chemistry was monitored. The strength of solution was gradually increased from 150 mg/l of acid to 5,000 mg/l where the pH was maintained at about 1.6 (although the pH did reach as low as 1.08). Many heavy metal and radioactive elements increased in concentration up to several orders of magnitude due to the high concentration of acid used. These are summarised below in Table 9.

The restoration phase for Pattern 2 was continued for nearly one year, from November 1978 to September 1979. A Reverse Osmosis (RO) process plant was used, and the solution used was 75% native groundwater from 400 m from the pattern, and 25% treated lixiviant solution. The TDS of the restoration solution was actually lower than the native groundwater, with the hope it would reduce the time required to achieve full restoration. The process encountered numerous difficulties and the process plant was modified several times to account for these.

Table 14 - Leaching Phase Water Quality[1]

	Conc.	Factor		Conc.	Factor
pH	1.6		Silicon	46	11
Redox	~200		Aluminium	44	338
Total Dissolved Salts	7,400	1.72	Fluoride	1.6	2.08
Dissolved Oxygen	1.5	1.5	Arsenic	0.064	1.6
Bicarbonate	20	0.07	Manganese	1.0	3.23
Chloride	45	0.98	Molybdenum	0.012	1.5
Sulphate	7,200	2.87	Phosphorous	0.6	3.0
Sodium	740	0.89	Radium-226 [2]	10,000	19.6
Potassium	18	1.29	Selenium	0.055	27.5
Calcium	258	1.25	Thorium-230 [2]	49,000	583,333
Magnesium	155	1.68	Uranium	90	391
Iron	150	140	Vanadium	800	1,600

[1] - all values in mg/l, except pH, Redox (mV), radium and thorium.

[2] - Radium-226 (± 170) and Thorium-230 (± 3,200) are in pCi/l.

The most common problem found was that the capacity of the process plant was not adequate, such as poor performance of the thickener hampering the RO unit and the capacity of the evaporation pond (leading to transport of excess solutions to an alternate site by RME). Other problems were the formation of gypsum scale (calcium sulphate, $CaSO_4$) at various points leading to blockages of filters or well screens, inadequate capacity in the evaporation pond, interference from fungal growth, and the flow rates needed adjusting for areas of lower permeability. The groundwater quality after restoration is given in Table 10.

A borehole that was drilled following the completion of leaching showed that significant amounts of uranium remained, averaging approximately 1,100 mg/kg (or 0.1%).

Table 15 - Restoration Water Quality[1, a]

	Conc.	Factor		Conc.	Factor
pH	6.0	0.8	Silicon	16	3.81
Redox	104		Fluoride	0.8	1.04
Total Dissolved Salts	3,000	0.70	Arsenic	0.010	0.25
Chloride	26	0.57	Manganese	0.23	0.74
Sulphate	2,200	0.88	Phosphorous	0.11	0.55
Sodium	1,320	1.59	Selenium	0.013	6.50
Potassium	5.0	0.36	Uranium	1.3	5.65
Calcium	700	3.38	Vanadium	14	28
Magnesium	37	0.40	Zinc	2.0	100
Iron	6.8	6.36			

[1] - all values in mg/l, except pH, Redox (mV).

[a] -Not all elements are presented in the water analyses, especially radium and thorium.

It is argued that the overall restoration was successful, according to Department of Environmental Quality[2] guidelines for In Situ Leach Mining, but there some issues are unclear and remain unresolved.

Firstly, the many elements were significantly higher following the completion of the restoration phase, with zinc, vanadium, selenium, iron, uranium and calcium increased by factors of 100, 28, 6.50, 6.36, 5.65 and 3.38 respectively. According to the water quality criteria presented earlier (refer to Tables 2 to 4), such increases would change the beneficial uses of this water. One of the objectives of the DEQ's regulatory requirements is that (in Nigbor, *et al.*, 1982) :

> "The condition and quality of all affected ground water will be returned to a quality of use, equal to or better than and consistent with uses for which the water was suitable prior to the commencement of the operation."

Secondly, the chemical state remains oxidising and slightly acidic (the final pH was still below the minimum background pH and was the last parameter to return to agreed baseline values during restoration). This could allow a degree of continued mobilisation of many elements, such as uranium, compared to the less acidic and reducing conditions existing before the trial, evidenced by the 5.65 times higher residual uranium content after restoration. There was no geochemical data or processes presented to demonstrate that this redox potential and acidity would be consumed as this groundwater flowed away from the ISL pattern through the aquifer. Given that sulphuric acid was used because there was a general absence of acid consumers, such as calcite, one could expect little opportunity for geochemical reactions between sediments and groundwater to alter the overall chemistry, thereby minimising any attenuation.

Thirdly, the time and volume of groundwater needed to be pumped in order to achieve successful restoration was much higher in the field trial than was predicted by laboratory column experiments. The laboratory work predicted 13 pore volumes for restoration, whereas over 20 pore volumes were required in the field study running for nearly one year.

Nine Mile Lake/Casper - Summary

It is not known whether this site was upgraded to a commercial mine site. It would appear not, as it is not listed in any recent USDoE or USEPA literature. The ISL trial very clearly showed that there were many significant operational and environmental problems with sulphuric acid leaching chemistry. These include the mobilisation of extremely high levels of radioactive thorium, the buildup of mineral precipitates (such as gypsum), the mobilisation and buildup of many trace elements during leaching and the difficulties of groundwater quality restoration.

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[2] - DEQ is the Wyoming government department with the statutory responsibility, along with the US Nuclear Regulatory Commission (USNRC), to monitor and regulate ISL uranium mining in Wyoming.

4.8 Environmental Problems at Early Texan Sites

Texas has been the dominant producer of uranium from ISL mines for nearly 25 years. However, contrary to the industry view, independent monitoring of some of these facilities by the Texas Energy Alliance (TEA) has showed that there were many excursions, surface spills and breaches of Texan regulations. A review of their work is therefore considered quite important to note. The following reviews are based on TEA 1989a, 1989b, 1988, 1987a, 1987b & 1982.

Overview

In Texas, the level of background radiation is generally well below the national average for the United States. Although there are spots where significant levels of radon and radium occur in groundwater, the quality of groundwater surrounding a uranium deposit is generally free of the high contamination levels that exist within the ore zone. The TEA argued that the natural steady state conditions that exist prior to mining are arguably capable of containing the migration of radionuclides, such as uranium and radium.

Another significant problem identified by the TEA was that only 65% of the uranium was extracted during ammonia-based ISL, and 96% of the radioactivity remained within the ore zone. The reducing agents that existed before mining were oxidised during the ISL process, and thus significant potential remained for radionuclides to migrate free from the controlling influence of reducing agents that existed prior to ISL mining.

The principal problem associated with the use of ammonia-based leaching solutions was that ammonia was adsorbed by the clays within the aquifer, and this bound ammonia is undetectable by standard groundwater monitoring techniques. One estimate suggested that after mining, approximately 2 tonnes of ammonia remained adsorbed within an aquifer zone only 12x12 metres in area.

The presence of hundreds, or sometimes thousands, of old exploration boreholes was identified as one of the key causes of excursions into the shallow groundwater systems of an ISL mine site. The TEA also note that the deeper groundwater systems below a mined aquifer were generally not allowed to be monitored, and significant questions regarding the escape of leaching solutions into these systems along old oil exploration wells or fault zones are simply unanswered.

Due to the alkaline solutions used, the radon levels were extremely high, with one value of 167,000 pCi/l noted. This radon was vented to the atmosphere. It was thought that the exposure of workers to radon progeny would be consequently high.

Another serious problem facing various ISL mines across Texas was the decommissioning stage. An ISL mine generates a significant volume of solid radioactive wastes, including pipes, machinery, buildings, pond liners, filters, salts, etc. There was simply not enough capacity within Texas to accept this volume of waste, and yet there was no comprehensive waste management program in place to accept and manage such radioactive wastes.

Although companies such as Wyoming Minerals confidently presented their technical ability to restore groundwater quality after ISL mining, with one quote suggesting it would only take “a few weeks”, by the late 1970’s to the early 1980’s they were admitting that “developments in restoration technology have not advanced as far as was hoped, and after several years experience in mining and restoration, we now have a more realistic understanding of the limitations of this technology”. “Original standards were known to be strict but were accepted with the expectation that the state-of-the-art would solve some problems and the standards could be renegotiated (especially the standard for NH_4) in light of further experience and understanding”.

One advancement in restoration technology was the use of Reverse Osmosis (RO) to treat the groundwater before recirculation through the ore zone. Although RO could lower the ammonia levels from 100 mg/l to 32 mg/l, the dilemma was the production of a highly concentrated waste stream that would be disposed of down a deep injection well. The number of pore volumes of groundwater required was between 30 to 50, and thus the quantities of waste involved reached billions of litres. The restoration requirement for ammonia, however, was only 0.8 mg/l.

The regulators and companies, after amending the restoration requirements, argued that due to the slow movement of groundwater in the area the contaminants will not migrate any significant distance. They argued that it will take between 3,000 and 3,500 years for the ammonia to break down naturally, and given the average groundwater velocity of 0.3 metres per year, will only migrate a total of 1 km before returning to background. However, there was no evidence proving such mechanisms, and the companies were simply waiting for the problem to develop before addressing the fundamental questions concerning environmental impacts on the groundwater environment.

After ISL mining has been completed, the companies were required to plug or cap all monitoring wells. Thus there could be no long term monitoring of the migration of both the ammonia and the radioactivity. The companies could thus adopt a least-cost/walk away approach without serious commitment to the protection of groundwater quality in the region.

Bruni - Wyoming Minerals

The Texas Energy Alliance reviewed the operation of and environmental releases from the Bruni ISL mine from December 2, 1974 through to January 22, 1989.

The history of the Bruni mine is described as one of uranium leachate spills, uncontrolled migration of radioactive water off site and violations of regulations for storage of radioactive materials. The violations and accidents recur over the years, and ultimately resulted in a large fine for Westinghouse.

The Bruni mine was first developed through laboratory studies in 1971-72 by Wyoming Mineral, and a pilot scale facility was built and operated during 1973. Application for the mine was sought in March 1975, and given by Texan regulatory authorities in June of the same year. Mining, at 113 tonnes U_3O_8 per year, began almost immediately, as did the environmental problems.

One of the primary problems at Bruni were recalcitrant excursions, and began almost immediately the same time as mining began. The first excursion was noted on December 23, 1975, and led the Texas Dept. of Water Resources (TDWR) to order mining to stop. Between this time and August 13, 1981, a total 23 incidents of leachate spills were recorded by the TDWR. At one point the TDWR cited Wyoming Minerals for 14 excursions, of which the company had only reported 5.

The TDWR also noted other spills mostly from wastewater ponds onto the ground surface or into shallow zones above the ore zone. Between November 1978 and August 1981, they four such spills. The spill for September 18, 1979 states that the wastewater ponds have damaged plastic liners. The largest pond, Pond 5, began leaking in late 1976, less than a year after mining began, and continued to contaminate groundwater until October 1977, although the company reported it in February 1978.

The TDWR also noted four storage violations of the storage of radioactive waste materials (relating to radioactive filters, ore storage barrels and waste storage barrels). The violations became so excessive that on November, 1977, the TDWR requested fines be levied against Wyoming Minerals for a variety of violations. The company eventually settled out of court for a fine of $42,500.

In June 1981, Wyoming Minerals requested that they be allowed to suspend operations at the Bruni mine. They told the TDWR that they had attempted restoration of the mining zone using over 25 aquifer pore volume changes of water. Ammonia levels that had been 0.75 mg/l before mining remained at 120 mg/l or 160 times the baseline after restoration. A similar problem was noted for uranium, where the baseline level was 0.21 mg/l and after restoration was still 5 mg/l. Wyoming Minerals guaranteed they would restore the site and asked that no restoration be required for 5 years in order to preserve the ore reserves for future recovery.

After years of experimentation and testing Wyoming Minerals began full-scale restoration of the Bruni mine in January 1986. In January of 1987 the TDWR granted Wyoming Minerals a permit amendment changing the original restoration table to allow 14 parameters of groundwater contamination to be raised. Wyoming Minerals sent their final water sample to the TDWR and, as of the time of TEA (1989), the TDWR was not satisfied that the Bruni site was restored to an acceptable level and were expecting Wyoming Minerals to undertake further restoration work.

The Bruni mine highlights many problems concerning the environmental impact from an ISL operation. Firstly, the mine had continual problems with surface spills and excursions contaminating the soils and groundwater of the site, often recurring at exactly the same location. For all of these direct environmental releases, the company was only fined once by the TDWR. Secondly cleanup efforts were ineffective and ultimately the company had to request that the restoration standards be altered to allow higher residual contaminants within the groundwater. After several years of restoration, the company even had significant problems meeting those standards.

The case clearly shows that the costs of good restoration are prohibitive, if such restoration is possible at all given the nature of In Situ Leaching, and that the companies are reluctant to invest the amount of money to adequately restore the sites. There is no return on investment for cleaning up contamination, and such problems are therefore transferred to the taxpayers once a company is allowed to walk away from a site.

Clay West & Burns - U.S. Steel, Dalco Oil & Atlantic Richfield

In 1973 and 1974 a joint venture between U.S. Steel (USX), Dalco Oil and Atlantic Richfield began experimental ammonia In Situ Leach mining at the Clay West site in Texas. The site was opened in 1975 as the first large scale ISL uranium mine in the USA. USX then expanded their operations and opened the adjacent Burns site, rated at 180 tonnes of U_3O_8 per year.

Niagara Mohawk, a nuclear power company from northern New York state, became a 50% partner with USX by purchasing a portion of the ore deposit. They invested $86 million (US) to insure a fuel supply for their two nuclear power plants, Nine Mile One and Two. It was revealed in 1987 that Niagara Mohawk was charging customers at $40 per pound for uranium from the mine although it could be bought on the open market at $16 per pound. By the late 1980’s Niagara Mohawk was on the verge of bankruptcy because of many failed nuclear ventures.

The exposure of workers at both the Clay West and Burns mines has been a noted problem. The largest overexposure recorded by the Texas Bureau of Radiation Control (TBRC) was in August 1982. The Nuclear Regulatory Limit for internal uranium exposure was 30 mg/l, and one worker was discovered to have a uranium level in urine of 50.5 mg/l. The company merely dismissed the result as a contaminated sample and immediately fired the worker concerned.

During September 1980, the TBRC asked USX to explain excessive radiation exposures at the Clay West and Burns sites. They replied by admitting that uranium dust in the plant loading areas was a problem, and were attempting to rectify the problem. An inspection during September revealed that gamma radiation levels were so high that they "pegged the meter".

A further inspection of the Burns plant by the TBRC in November 1980 revealed that the company routinely transferred liquid uranium from one plant process to another by dumping the slurry on the concrete floor of the plant, where workers would shovel it into the closest sump it so that it could be pumped to the next process. The plant was built without any method of product conveyance and this contrary to the procedures submitted for licence approval. The TBRC noted this was a violation of their permit, but refused to fine the company.

The same November 1980 inspection by the TBRC also revealed that uranium fluids were flowing off the concrete pad onto the ground. A solid yellow sheet of dried uranium was observed covering the ground. An inspection of the control room found a chair seat coated with yellow uranium, measuring 1,300 counts per minute (cpm) of alpha radiation.

Over time, the acids in the uranium slurry at the Burns plant had eaten away the concrete in the sumps allowing uranium to leak into the ground. On September 12, 1980, during excavations for a foundation at the plant, the company noticed that the holes had filled up with uranium fluid and on further investigation it was discovered that the entire plant was floating on ground saturated with uranium. Monitoring wells drilled around the plant during December 1980 showed levels of uranium from 32 to 3,060 mg/l. The TBRC required the company in January 1981 to correct the problems at the plant and to dispose of the contaminated soil, but again refused to fine the company. By 1989 the plant and the soil underneath the plant were still in place at the Burns site.

The TBRC, in March 1981, still felt that worker's radiation exposure were still too high and required the company to come up with a firm schedule to show when corrective actions would be completed. The company admitted by April 1981 that uranium dust at the plants were still a problem. They planned to enclose the buildings that were responsible for the dust so that they would be air tight. Uranium buildup outside the filter buildings was to be kept to a minimum and several monitoring programs were to be installed. However, by October 1981, the company blamed the workers for the continued high exposure rates, arguing that poor personal hygiene was to blame. In December 1981, the company is still admitting high dust levels are a significant problem.

During February 1982 USX announced they had incinerated radioactive waste at the Burns site and dumped over 220 kg of radioactive ash, remaining after incineration, at the nearby George West town dump. A survey of the incinerator at the Burns plant showed a reading of 30 to 60 μrem/hr. The company then removed the ash from the dump and disposed of it at the Conoco operated Conquista mill tailings dump in Falls City, the only licensed facility for radioactive waste in Texas.

USX announced their intention to progressively close down the Burns plant in stages in August 1982, proposing to “review the prospects for enhanced clean up of the affected subsoils”.

While digging a pit at the Burns plant on August 31, 1983, a plastic sewer line was discovered that used to service the old employee change room. The interior of the pipe was lined with yellow uranium. Further investigation revealed that the entire drainage field and septic tank were coated with uranium. A TBRC inspector on April 17, 1984, and surveyed the area, by which stage the company had already removed the pipe, septic tank and drainage field pipes and disposed of them at the Conoco radioactive waste dump. The radiation reading showed 5,000 cpm.

The TBRC wrote to USX on November 14, 1983, stating that they have committed 17 violations of their radioactive materials licence. USX replied on November 30, 1983, blaming the poor radiation safety program, management, and inadequate environmental and occupational monitoring programs as the cause of their problems. They proposed to make each employee responsible for their own monitoring, and assign a clerk to make sure samples are collected and organise files so records can be kept track of. USX admits that dust is still a problem and that the areas responsible are still not enclosed. They also admit that their radioactive waste is not properly stored. Yet again the TBRC did not levy any fines against the company.

An inspection in March 1985 by the TBRC accidentally discovered that three companies in the town of Corpus Christi had been exposed to radioactivity while repairing a machine for USX. The company attempted to clean up the uranium contamination that had occurred before the TBRC discovered the problem. The TBRC gave notice of violation to the company in April 1985 for releasing radioactive materials into unauthorised areas. Again no fines were issued.

The nature of ISL mining leads to literally kilometres of solution distribution pipes across the surface of an ISL mine. The materials generally used were plastic or fibreglass, since the solutions are highly corrosive with metal pipes. These pipes were known to break easily with weathering, expansion and contracting. A total of over 22 spills have been reported by USX at the Clay West and Burns sites, releasing an estimated 4,541,160 litres of radioactive and toxic chemicals at the surface.

The largest single spill occurred at the Burns site on June 19, 1981, when a fibreglass pipe ruptured. A total of approximately 3,216,655 litres of leaching fluids flowed from 4 am to 8 am before workers noticed it. This particular solution already had the uranium mostly removed. USX originally reported to the TBRC that only 378,430 litres had been spilled. The original owners of the land were shocked to learn of the spill via the newspapers, neither the company or the TBRC had notified them.

However, many of the spills occurred before the solutions were processed, and as such the uranium content was quite high. One such spill of 340,587 litres on July 1, 1980, contained high uranium levels. The gamma radiation of muds in the area made the radiation meter go off the scale.

A further problem at the Burns site was noted on June 26, 1980, when ammonia and uranium levels rose in a perimeter monitoring well. Later in September and October of that year, USX announced that the uranium levels were increasing because a natural uranium deposit existed in this area and it was being oxidised either by leaching solution from the mine or because “oxygen diffuses rapidly in this area due to the scarcity of species (mainly reactive forms of marcasite, FeS_2) that consume it”. However, ISL mining began in this area in 1978 and it is unknown why the uranium waited two years to begin migration.

Other USX Sites

The U.S. Steel Co. operated many other ISL sites which had consistent problems with contamination. Some examples and sites are listed below :

- December 22, 1977 - “bad water” was noticed above the ore zone at the Boots mine area;
- March 17, 1978 - excursion detected on the east side of the Moser I ISL mine area, the cause was an abandoned well;
- March 17, 1978 - excursion detected on the west side of the Moser I ISL mine area, the cause was leaking well casing;
- March 20, 1979 - uranium had migrated outside the mining zone of the aquifer to the far east of the Moser I perimeter monitoring well system. As these wells are the last stage of possible detection, any further migration beyond these points is undetectable. As USX planned to mine this area (Moser II), regulators allowed USX to ignore this excursion.
- May 16, 1980 - a perimeter monitoring well in the Moser II area showed an increase in contamination, just east of the earlier contamination noted on March 20, 1979.

Surface Irrigation at Mt Lucas - Everest Exploration

In October 1983, Everest Exploration was illegally given permission to begin disposing of untreated radioactive wastewater from their Mt Lucas ISL uranium mine on Lake Corpus Christi by merely spraying it on top of the ground. For the next three years, until April 1986, Everest surface irrigated a 22.5 acre plot located less than 275 m from the shoreline of Lake Corpus Christi.

Corpus Christi and a total of 38 communities depend on the water from Lake Corpus Christi as their only source of water.

By 1987, the level of radioactivity in the surface soils was 47 times above normal, and 6 times higher than the Mt Lucas operating licence allowed. In some areas the levels had risen 173 times above background. Half of the irrigation water used at the site has percolated into the water table, and government experts have expressed very grave concerns about the extent of surface and groundwater pollution.

In a further demonstration of their cavalier attitude and sheer contempt for public and environmental safety, Everest was again given permission to irrigate a new 83 acre plot adjoining the original site, nearly four times the original area. The permit was granted against the explicit advice of the Bureau of Radiation Control’s own experts. During 1987 Everest were trying to convince the regulators to increase the pollution limits for the site so they would not be in violation of the law. However, significant questions of groundwater pollution, surface runoff, air quality and plant process integrity still remain unresolved.

4.11 Decommissioning of ISL Uranium Production Facilities

In order to understand the ongoing environmental impacts that are possible after an ISL facility is decommissioned, a review of a recent USDoE report on the decommissioning of uranium production facilities is important. The information below is summarised from USDoE (1995).

Overall, the decommissioning process for an In Situ Leach mine site generally involves about 5 main steps, in no particular order :

1) Dismantling and decontaminating the uranium process plant, disposing of equipment and materials at approved sites, and restoring;

2) Restoration of the grounds including roads and building foundations and removing contaminated ground;

3) Wellfield Restoration - cleaning groundwater in the leached zone in the sand formation by flushing it with large volumes of water, perhaps augmented by chemicals to stabilise formation chemistry. Original groundwater characteristics must be taken into consideration in this activity. The primary techniques of water treatment for groundwater restoration are reverse osmosis (RO) and groundwater sweep;

4) Removing wellfield equipment, including drillhole casings, equipment, and pipes (which may already be buried) to and from the recovery plant, and related solution collection and monitoring facilities;

5) Evaporation ponds are used to dispose of waste liquids from the uranium recovery plant, from excess water recovered from the leaching field, and from groundwater restoration. Residue must go to an approved disposal site, commonly the tailings pile of a conventional uranium mill.

Many of the above components are highly site specific, and the amounts and types of wastes will vary widely from site to site.

A critical component of the overall decommissioning process is the financial surety in place to ensure sufficient funds are available for long term monitoring and radiation protection. A summary table is given below.

Table 16 - ISL Mines and Decommissioning Financial Sureties[1] (USDoE, 1995)

Name	Company		Surety[2]
Benavides	Uranium Resources Inc.	TX	604
Bruni	Wyoming Minerals[3]	TX	6,131
Burns Ranch/Clay West	U.S. Steel (USX)	TX	25,030
Christensen Ranch/Irigary	Total Minerals	WY	8,022
Crow Butte	Ferret Exploration	NE	5,000
Highland	CCMV[3]	WY	4,821
Hobson	Everest Minerals	TX	636
Holiday/El Mesquite	Total Minerals	TX	12,231
Kingsville Dome	Uranium Resources Inc.	TX	1,577
Lamprecht/Zamzow	Intercontinental Energy	TX	14,050
Las Palmas	Everest Minerals	TX	249
Mt. Lucas	Everest Minerals	TX	7,598
North Butte/Ruth	Pathfinder	WY	163
Rosita	Uranium Resources Inc.	TX	737
Smith Ranch	Rio Algom	WY	7,500
Tex-1	Everest Minerals	TX	554
West Cole	Total Minerals	TX	3,489
	Total		**98,392**

[1] - as at January 1, 1994.

[2] - thousand dollars.

[3] - Westinghouse subsidiary

[4] - Converse County Mining Venture

The various costs of decommissioning components was estimated by the USDoE (1995) and presented, showing some interesting results. They classified costs into five broad categories - Wellfield, Plant, Groundwater, Ponds & Other, and Indirect Costs. The average cost of decommissioning ISL facilities was $7 million (US), with a range of $600,000 to $35 million. The restoration of groundwater is generally the highest single cost and averages about 40% of the total costs of decommissioning.

The main variables that determine overall cleanup costs include the number of wells per acre, restoration standards, the availability of clean water, the capacity of the wellfields and the process plant, and the condition of the site after mining.

Table 17 - Estimated Decommissioning Costs for ISL Facilities[1, 2] (USDoE, 1995)

Name	Plant Dismantling	Wellfield Restor'n	Groundwater Restoration	Ponds & Other	Indirect Costs	Total Dec.
Benavides	222	343	1,986	351	726	3,628
Bruni	1,153	1,246	3,311	1,176	1,722	8,608
Burns Ranch/ Clay West	3,164	3,808	15,994	5,044	7,003	35,013
Christensen Ranch/Irigary	314	1,130	2,868	2,374	1,672	8,358
Crow Butte	311	742	1,766	513	833	4,165
Highland	815	727	2,243	709	1,124	5,618
Holiday/ El Mesquite	1,017	3,002	5,754	1,308	2,770	13,851
Kingsville Dome	208	270	540	179	299	1,496
Las Palmas	203	173	353	40	192	961
Mt. Lucas	475	633	908	5,106	1,781	8,903
North Butte/ Ruth	231	445	1,668	591	734	3,669
Rosita	101	74	353	74	151	753
Tex-1	84	201	476	0	115	576
West Cole	89	233	1,540	417	570	2,849
Total	**8,387**	**13,027**	**39,460**	**17,882**	**19,692**	**98,448**
Average	**599**	**831**	**2,819**	**1,227**	**1,407**	**7,032**

[1] - as at January 1, 1994. [2] - thousand dollars.

5 International Experience with ISL

Although not as well credited as their North American counterparts, the nuclear industry in many parts of Europe and the Commonwealth of Independent States has also embraced In Situ Leaching technology for the mining and extraction of uranium. However, without rigorous environmental standards, many of these sites are now left as catastrophic legacies of radioactively contaminated sites facing significant environmental cleanup costs and radiological hazards. A review of these sites in Bulgaria, the Czech Republic, Germany, Ukraine, Russia and new projects emerging around the world is presented.

5.1 Bulgaria

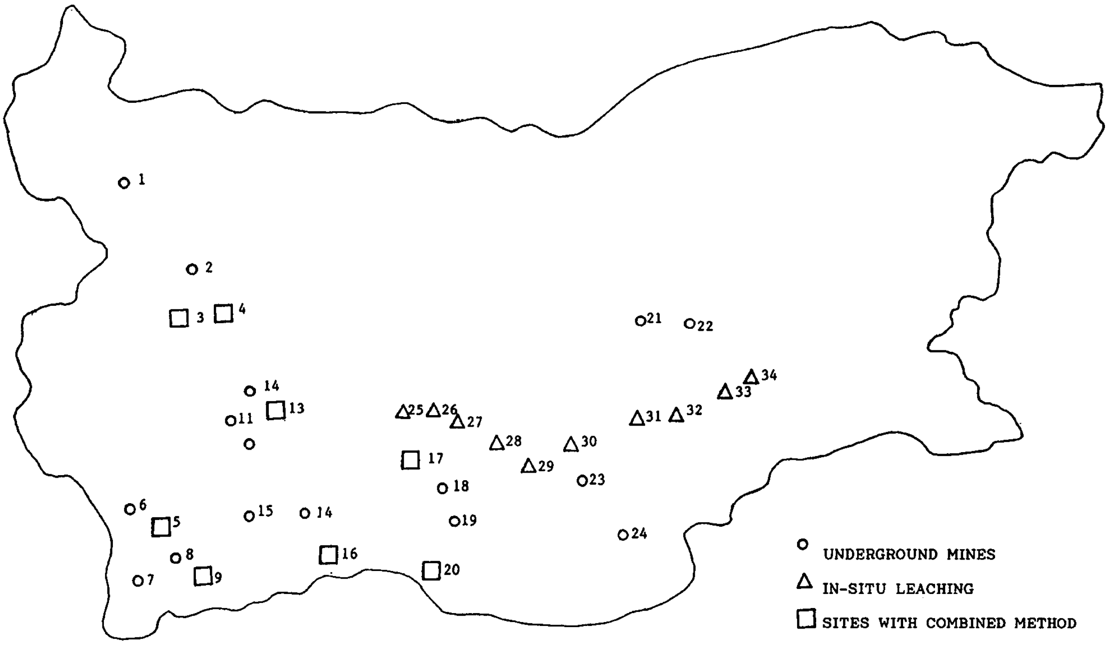
This review is based on the work of Alkov (1996), Dimitrov & Vapirev (1994), Vapirev *et al.* (1993), Kuzmanov *et al.*, (1992) and Tabakov (1992).

All uranium mining and milling in Bulgaria was closed down by government decree on August 20, 1992, and activity since has been aimed at cleaning up and rehabilitating the numerous mine sites. The ISL technique was first applied in 1967 to low-grade deposits (ranging from 0.006 % to 0.03 %) at Orlov Dol and Selishte (a former conventional mine). Given the success of these sites, a revolution was perceived where many previously uneconomic deposits were mineable. By 1990, the share of uranium production from ISL was 70%.

There has been a total of 19 sites where ISL has been applied, and a further 11 sites where the ISL technique was applied within an underground mine. Most of these sites began operation in the late 1960’s to early 1970’s, although poor results from initial trials meant some sites were not continued. These are all concentrated in the southern and western regions of Bulgaria (refer to Figure 21). The deposits also contain high amounts of organic matter, iron and sulphides.

The ISL mines also had a dramatic impact on the workforce in conventional mines, falling from 5,000 workers between 1965 and 1970 to approximately 500 in 1988. The initial chemistry used for leaching was sulphuric acid, although this was later switched to sodium-carbonate and ammonium-carbonate leaching chemistry in deposits with a high carbonate content.

Figure 21 - Bulgarian Uranium ISL Sites



Along the valleys of the Maritsa, Tundzha and Struma Rivers approximately 15 low grade uranium ore deposits were mined with sulphuric acid ISL, which was preferred over alkaline leaching agents. Approximately 16 km^2 of land was bought for ISL mines, with 2 km^2 of this being agricultural land and 3 km^2 forest. A total of 6 km^2 was used by the facilities of an ISL mine, such as surface distribution pipes (covering 0.6 km^2) and processing plants.

The siting and operation of many uranium mining operations across Bulgaria were often neglected to enable fast tracking of projects and minimise costs involved in establishing a project. Only one mine was closed due to contamination of drinking water.

Almost no preventive measures or counter measures were implemented during the whole period of mining for the environmental protection of water, soil and air from mechanical, chemical and radioactive pollution. The secrecy of the uranium and nuclear industry was also identified as a key reason behind this philosophy.

The leaching of uranium was generally progressed in three stages - first, acid was introduced at levels up to 10,000 mg/l (lasting for a few months); second, the base period of acid leaching with acid levels of 4,000 to 6,000 mg/l (lasting for over two years); and thirdly, the closeout period with acid levels of 500 to 1,000 mg/l. The overall time for a wellfield was between 3 to 5 years and the recovered uranium was about 60% to 80%. The radium levels of leaching solutions was generally low. Typical concentrations of some elements in lixiviants are presented below in Table 18 (summarised from 13 ISL sites).

Table 18 - Typical Minor Lixiviant Components (mg/l)

pH	1.4 to 2.0	Calcium	140 to 600
Aluminium	310 to 840	Zinc	2.1 to 7.3
Iron	700 to 2,200	Potassium	30 to 200
Vanadium	1.0 to 18	Sodium	30 to 900
Manganese	6 to 61	Silica[1]	210 to 350
Magnesium	140 to 330		

[1] - Silica as $HSiO_4^-$.

Only three sites are completely depleted by uranium in-situ leaching (Orlov Dol, Madrets and Vladimirovo). The remaining ISL fields were expected to reach about 65% to 75% depletion of the uranium.

The background quality of groundwater in the ore zone aquifers typically was 500 to 2,000 mg/l TDS (salinity), pH of 6.3 to 8.8, iron 0.1 to 648 mg/l, and sulphate 24 to 758 mg/l. This is considered to be good quality drinking water.

There has been significant contamination of groundwater at most ISL sites, with major concerns arising from chemical, radiological and bacterial contamination. For the combined underground-ISL sites, iron, copper, cobalt, nickel, molybdenum, arsenic and some rare earths were several times higher than allowable limits. In the Deveti septemvri ISL mine, molybdenum reaches 13,425 μg/l (limit 500 μg/l, nearly 27 times higher), and manganese reaches values of 13,000 μg/l and 7,600 μg/l in groundwater and 4,200 μg/l in the retention pond. Quantities of boron and mercury were also detected.

At the Orlov Dol site, after six years of monitoring, the acid levels of the ore zone aquifer were declining from 1,300 mg/l to 10 mg/l, although the groundwater still contained elevated levels of uranium despite the increase in pH.

The concentration of sulphate can be very high in surface waters and even in water supply wells of private owners as a result of accidental spilling of solutions in sites of ISL. The average chemistry of contaminated groundwaters ranges in TDS from 15,000 to 20,000 mg/l, sulphate from 10,000 to 12,000 mg/l, uranium between 5 and 20 mg/l, other salts and the presence of heavy metals and rare earths. For the Cheshmata (Haskovo) site, in the valley downstream, sulphate concentration is 1,400 mg/l (limit 300 mg/l), free sulphuric acid 392 mg/l and the pH is 2.2 (over 1,000 times more acidic than the drinking water quality of the surrounding aquifer). The private wells of residents of the area have also been affected with significantly high concentrations of sulphate being noted, demonstrating that the leaching solutions have migrated into drinking water supplies.

A similar case has been recorded in Navusen, where in a valley the sulphate concentration is 13,362 mg/l and almost 5,000 mg/l free sulphuric acid, indicating the water is actually lixiviant or leaching solution. The groundwater quality of such sites has a TDS (salinity) level of greater than 20,000 mg/l, of which sulphate is 12-15,000 mg/l. Heavy and rare earth elements were detected in some cases, such as vanadium (V), tungsten (W), molybdenum (Mo) and lanthanum(La) , due to recycling of the solution.

There were also noted problems due to bacterial contamination, although their exact effects were not able to be predicted and were not studied. It was thought that they were beneficial in the leaching process.

There remains concern that solutions at the various ISL sites could contaminate the deeper groundwater systems, as well as the shallow systems. For the deep systems, which contain the ore being mined, the uranium content can reach 20 to 30 mg/l and radium 1 to 2 Bq/l, with uranium content in shallow aquifers around 3 to 4 mg/l and radium 0.5 Bq/l, despite dilution effects during migration through the aquifer.

At some sites, where there were surface spills due to failure of distribution pipes, the uranium and radium content of soils is 10 and 2-3 times the background level, respectively.

At most of the ISL sites undergoing restoration, the solutions were continually recycled through the mined aquifer without adding acid, and this led to many of the salts depositing within the pipes, and these salts contained increased and significant levels of radioactivity. This process has been now been stopped.

A principal problem of the restoration work currently in progress is that the environmental requirements are quite strict, making uranium production unprofitable. It was argued that achieving an acceptable level of environmental protection required if preventative measures, planning and funds are set aside during the early stages of a project, and during the operational phase of a particular project. As this was not done, the necessary funds are not available and restoration work is thus significantly impaired.

Only one third of the land used by ISL operations has been remediated, and as the land will be returned to the original owners for continued agricultural purposes, there are grave concerns for environmental and public health safety. Some of the ISL sites (such as Bolyarovo, Tenevo, Okop and Gorna Trakiiska nizina) are close to areas where drinking water is extracted by local communities or the groundwater is considered to be an important reserve.

5.2 Czech Republic

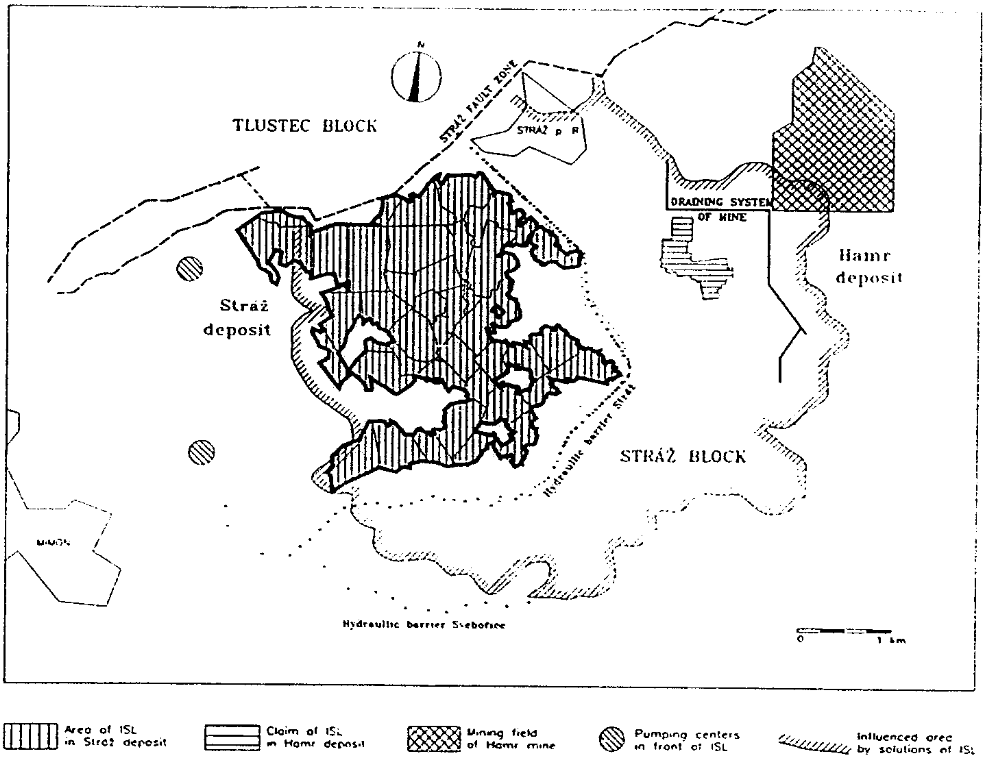
This review is based on the work of Tomas (1996), Andêl & Pribán (1994), Andêl & Pribán (1993), Fiedler & Slezák (1992), Khün (1992) and Benes (1992).

The Bohemian Massif mining district in the Czech Republic has been an important source of uranium for the Russian military and nuclear power programs, with uranium ore from the Jáchymov mine being used to manufacture the first Soviet atomic bomb. A total of more than one hundred uranium mines were developed, including shallow investigation mines. The Stráz Pod Ralskem district consists of sandstone type uranium deposits, and acid ISL has been applied as the mining method since 1968 after successful trials during 1967. The associated mineralisation with uranium is also unusual, with zircon, titanium and phosphorous being present.

The Stráz region is characterised by complex and unfavourable hydrogeological and biological conditions that make the application and success of ISL extremely difficult. The dissolution rates of uranium are quite slow. This causes two principal problems - firstly, large doses of chemicals are required (sulphuric acid at about 5% with nitric acid and nitrate as the main oxidants); and secondly the leaching periods are very long, ranging from 15 to 25 years. The total uranium production by ISL was 13,968 tonnes of uranium (metal, or 16,470 tonnes U_3O_8).

The Hamr deposit was developed at the Hamr and Luzice mines with both underground and combined ISL techniques. The Hamr mine is very close to the Stráz mine, and they are known to have a negative influence on each other. This has led to higher production costs and greater impacts on the environment of the region.

Figure 22 - Outline of the Stráz and Hamr Mines



A principal problem for many of the sites is the density of population across the Czech Republic, with 40,000 people living near the Stráz mine, for example.

After detailed evaluation of the negative impact of uranium mining and milling, a progressive program of declining production from uranium mining has been adopted and an extensive remediation programme implemented by the Czech Government.

Stráz Pod Ralskem

The hydrogeology of the Stráz region is complicated, but can be thought of as two distinct aquifers or groundwater systems - the Cenomanian and the Turonian. The Cenomanian is a deep, confined and artesian aquifer, and the Turonian lies above this, separated by up to 100 metres of thick low permeability clays and siltstones. The Turonian is designated as an important high quality drinking water reserve with a calcium bicarbonate (Ca-HCO_3) type of water quality, and is known to discharge to the Ploucnice River at about 40 litres per second (l/s). The Cenomanian was known to contain elevated levels of radium.

For the Stráz deposit, every tonne of uranium[1] produced :

- 274 tonnes of sulphuric acid was injected;
- 7.9 tonnes of ammonium was injected;
- 7,260,000 litres of contaminated groundwater in the Cenomanian aquifer;
- 1,500,000 litres of contaminated groundwater in the Turonian aquifer;
- 0.95 tonnes of sulphuric acid released to the air;
- 1.18 tonnes of nitrous oxides released to the air;
- 53 GBq of radium released to the air.

By contrast to experience in the USA, the Stráz ore deposit required 50,000 to 70,000 mg/l of sulphuric acid and a leaching period of 15 to 20 years to reach a yield of 60 to 80% of the uranium. This was due to the lower permeability of the aquifer materials.

By 1994, a total of about 100,000 tonnes of uranium (metal) had been produced in the Czech Republic. A total of 32 ISL sites had been commissioned covering a total of 6 km^2 consisting of 7,000 wells. The Stráz mining district, has seen approximately 3,800,000 tonnes of sulphuric acid, 270,000 tonnes of nitric acid, 103,000 tonnes of ammonia and 25,000 tonnes of hydrofluoric acid injected into the wellfields. The Stráz site ceased producing uranium on April 1, 1996.

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[1] - tonnes uranium metal, multiply by 1.1793 to get tonnes U_3O_8.

Table 19 - Lixiviant Composition at Stráz Pod Ralskem (mg/l)

Free Acid (H_2SO_4)	15,000 to 38,000	Phosphorous	50 to 150
Sulphate (SO_4)	40,000 to 65,000	Potassium	40 to 70
Ammonium (NH_4)	1,000 to 2,000	Zinc	30 to 50
Aluminium	4,000 to 6,000	Magnesium	20 to 30
Iron	500 to 1,500	Nickel	20 to 30
Nitrate	200 to 800	Sodium	10 to 15
Fluoride	100 to 300	Vanadium	10 to 15
Calcium	200 to 300	Chromium	5 to 15
Silicon	100 to 200		

The ultimate chemical products of the interactions between the leaching solutions and aquifer sediments are not well defined. That is, the form of many heavy metals and radionuclides remain unstudied. For new wellfields the uranium reached concentrations of 100 mg/l and even 500 mg/l on some wellfields, and about 20 mg/l on older wellfields.

The leaching solutions from the Stráz wellfields were not operated with a bleed system to maintain a cone of depression around the wellfields being leached, and this led to the solutions being dispersed widely through the Cenomanian aquifer in the area, as well vertically into the Turonian aquifer. The excursions occurred mainly through production bores, but also significant excursions occurred at liquid waste disposal bores.

The contaminated water in the Turonian aquifer alone is spread over 245 hectares (43% of the area of the wellfields), and while a complete water balance is not yet available, estimates range between 2 to 20 billion litres of contaminated groundwater.

A total of 200 billion litres of groundwater has been affected, covering a total area of 6 km^2 and the volume of aquifer material affected is thought to 720 million m^3. Approximately 50% of the contaminated water is thought to be residual leaching solutions, with sulphate higher than 20,000 mg/l and salinities between 35,000 to 70,000 mg/l. The remaining 50% is thought to be dispersed solutions, formed by migrating leaching solutions mixing with native groundwater, with a salinity level of 4,500 mg/l.

The urgent need for restoration is governed by the extremely high concentrations of radionuclides and heavy metals in the various solutions and the large volumes of contaminated water involved. The most critical factor is that the Cenomanian aquifer is artesian, and the pressure difference between the Turonian and Cenomanian aquifers will always ensure groundwater flow is vertically upwards, as was the case before ISL mining began.

Table 20 - Radionuclide Content of Stráz Pod Ralskem Solutions[1]

Leaching Solutions		Dispersed Solutions	
Gross Alpha (α)	17,580	Gross Alpha (α)	1,520
Gross Beta (β)	1,930	Gross Beta (β)	305
Beryllium	4,640	Beryllium	160
Ammonium	2,540	Ammonium	300
Arsenic	271	Arsenic	18
Nickel	234	Nickel	33
Chromium	216	Chromium	19
Fluoride	158	Radium	48
Vanadium	121	Vanadium	16
Manganese	100	Cadmium	18

[1] - Expressed as multiples of Czech drinking water standards

The presence of known excursions through boreholes highlights the above problem, and if the bores are not effectively sealed during restoration, there will remain a driving pressure for further excursions and escapes of contaminated groundwater from the Cenomanian into the Turonian aquifer.

The contaminated groundwater in the Cenomanian aquifer is approaching the sanitary protection zone of the Mimon water supply (70 litres per second). The contaminated groundwater in the Turonian is within 1.2 to 1.5 km of the sanitary protection zone of the Dolánky water supply (200 litres per second). The region presently utilizes 1,500 litres per second of groundwater for drinking supplies.

The restoration of the groundwater is proving a difficult task, with 1 pore volume of groundwater only removing about 70% of the contaminated groundwater and 5 pore volumes required for 90% removal. This equates to about 940 billion litres of water. While regulators in the USA require a proven pilot-scale test to demonstrate effective groundwater quality restoration, the Stráz mine only received approvals for liquid waste disposal and restoration requirements in the mid 1990's after three decades of operation.

Currently, restoration programs are aimed at determining the optimal strategy for long term remediation and restoring groundwater quality. The technology being used for restoration is involves pre-treatment, reverse osmosis, volume reduction by evaporation, crystallisation and processing of the concentrated saline solutions or brines. Some of the components are being utilised, such as sulphuric acid, aluminium oxide, ammonia, and gypsum ($CaSO_4$). The presence and removal of radium and other toxic metals of concern is a significant barrier to these programs.

Further options for groundwater quality restoration are being investigated with a view to a compromise between environmental demands and economic feasibility. It is intended to return the Turonian aquifer to it's original quality (as much as possible).

For the Cenomanian aquifer, however, it appears impossible to achieve restoration to it's original good quality. The philosophy being adopted is to ensure that any escape of Cenomanian groundwater will disperse to an appropriate quality and not lead to any impact on either drinking or surface waters. Due to the intransigent irreversibility of the chemical and physical changes caused by ISL, restoration efforts are anticipated to last several decades, or even centuries.

Miscellaneous Environmental Problems

The region, once covered by pine forests, also underwent significant deforestation for mining purposes. Some areas were left with pine cover, generally in the low-lying wetland areas, although this was not thought to have any tangible operational or environmental benefit. The deforestation was undertaken hastily, as many trunks were left in the ground, remnant dead and rotting trees still standing and numerous smaller trees and smaller twigs remain spread across the area. A limited area was used for agricultural purposes.

The surface soils, devoid of tree cover, were therefore exposed and accelerated rates of erosion and weathering. Effects included considerable sheet erosion and wash-down of poorly cohesive sandstones as well as deep furrows. Erosion was also exacerbated by the movement of heavy machinery across the site.

In the low-lying areas near the Ploucnice River, the alteration of surface drainage patterns, together with the removal of vegetation, led to a gradual rise in the water table and the formation of lagoons and wetlands.

In the areas where the pine trees had been left, in order to try and preserve some of the remnant forest, it was found that the forest was weakened and unsustainable since it was no longer continuous. This led to increased exposures of the wells and piping systems as well as high incidences of problems from dead, falling trees.

In the hill areas, wells and piping systems were often built partly on benches and partly on platforms. Together with the spills of solutions from pipes and surface runoff, the siting of these parallel to slopes led to significant rates of erosion and the prevention of further vegetation growth due to the lack of suitable soil.

Although attempts had been made from the mid 1980's to begin addressing many of these problems, such as hydromulching, different seed species, and other techniques, they were of varying short duration and thus limited success.

The failure rate of the wells was about 4%, affecting the older, more primitive wells more significantly. It is thought that the escaping acids remained near the defective well, instead remaining within surface soils.

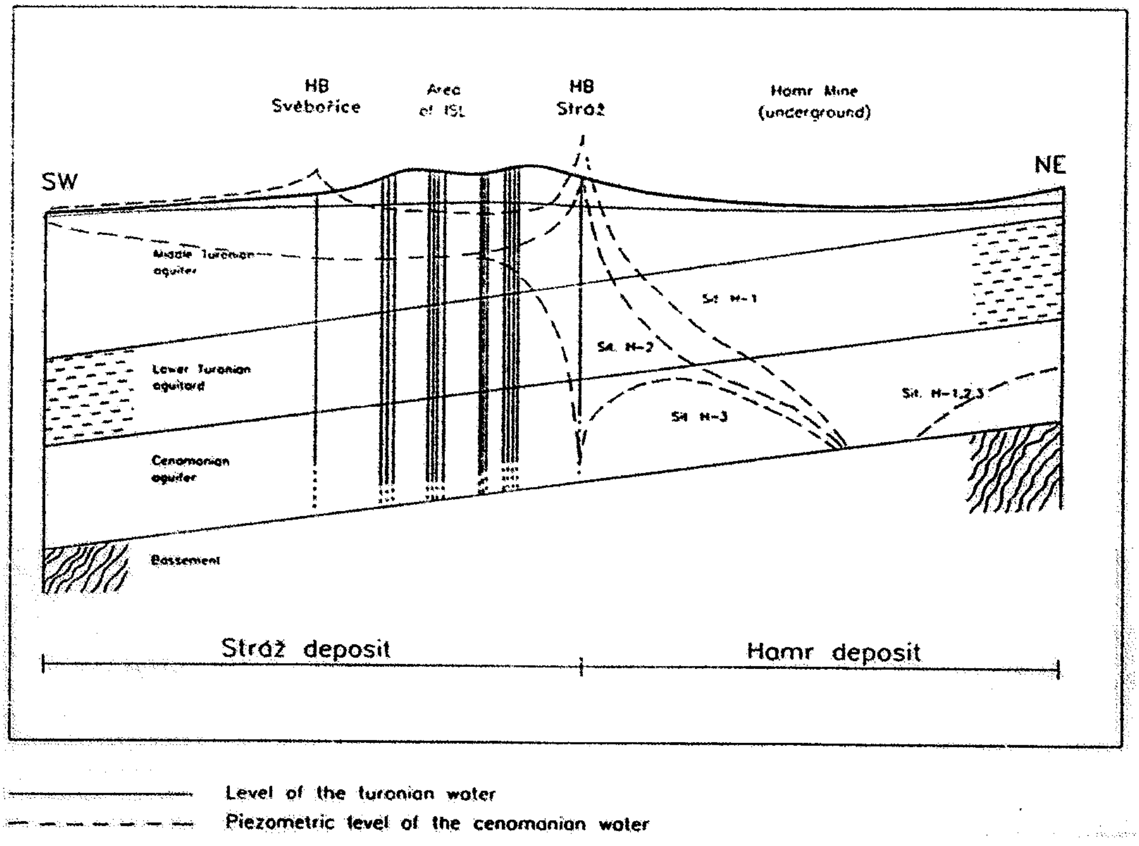
Many of the above problems were made worse by the animosity of many of the workers and ignoring the concern of interested residents.

Problems of Co-Existence of the Hamr and Stráz Mines

The Hamr mine, as an underground mine, needs to maintain an active dewatering program of the Cenomanian aquifer. For the Stráz mine, it is imperative for the solutions to be kept within the ore leaching zone and for pressures to be maintained within certain levels in order to facilitate this. Thus there is a conflict of water use - saturation at Stráz and desaturation at Hamr.

It wasn't until the 1970's, after several years of operation, that a hydraulic barrier was built in between the two mines. This consisted of a series of wells designed to maintain water pressure between the two sites and prevent transport of water from the Stráz to the Hamr mines. However, this was only after the water quality of the Cenomanian aquifer in between the two sites had already been affected by leaching solutions.

Figure 23 - Water Pressures at the Stráz and Hamr Mines



At present, extremely large pumping rates are required to maintain the hydraulic barrier. It is anticipated that by 2005 to 2010 that the leaching solutions at the Stráz mine will inevitably escape towards the Hamr mine. The known excursion problems from the Cenomanian to the Turonian aquifer remains a significant concern for the long term operation of the remedial scheme, as any escape could potentially pollute nearby resident's water supply from the Turonian aquifer.

5.3 Germany

This review is based on the work of Ettenhuber (1996) and Hähne & Altmann (1992) except where noted.

The rich pitchblende uranium deposits of Germany were one of the former Soviet Union's targets for supplying uranium during the late 1940's and 1950's for weapons and nuclear power programmes. Simultaneous work was carried out on uranium deposits in schists, limestones, volcanic rocks, sandstone deposits near Königstein (located near the town of Dresden) and uraniferous hard coal near Freital.

Most uranium mines and mills in Germany were underground, although Königstein, and to a lesser extent Ronneburg, also had underground ISL applied for the extraction of uranium. Underground uranium leaching began in 1968 to take advantage of low grade ores and increasing conventional costs, since leaching costs were only 60-70% of conventional methods.

Ronneburg

Although a less prolific producer of uranium by ISL, repeated attempts were made to increase uranium recovery from 1970. The leaching solutions used included sulphuric acid or alkaline reagents. Between 40-70% of the uranium reserves were recovered at concentrations of sulphuric acid from 3,000 to 10,000 mg/l, pH of approximately 1.5 to 2.5 and uranium content between 20 and 100 mg/l.

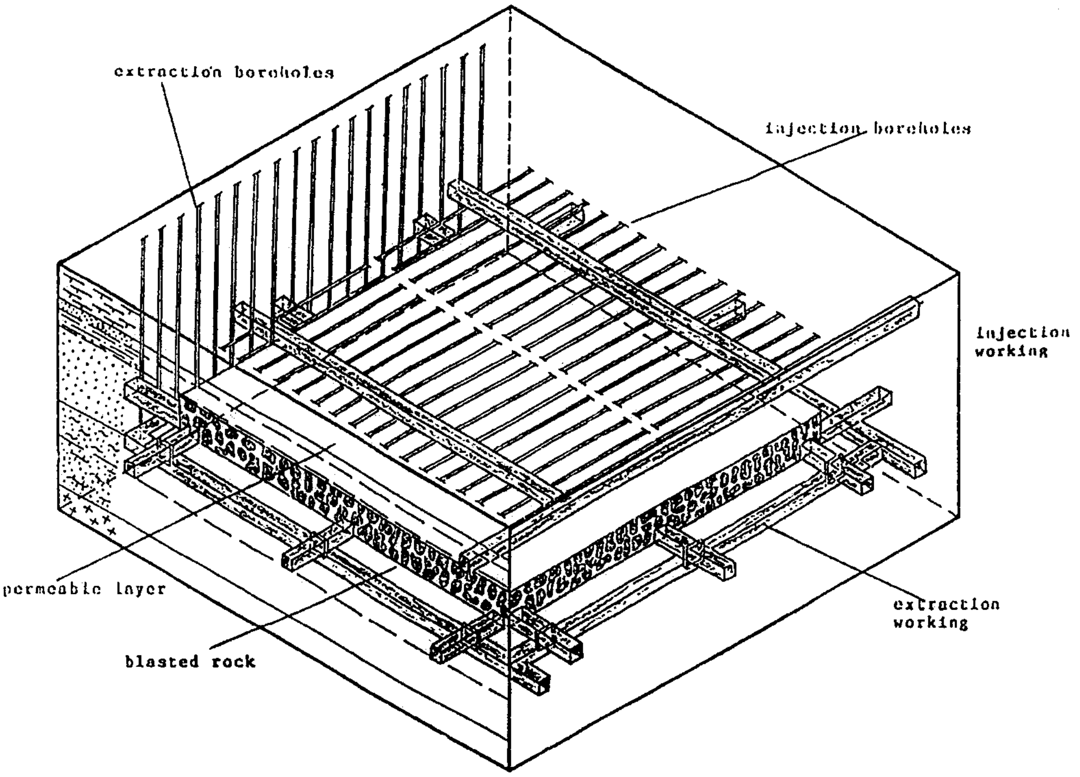
A total of 2,716 tonnes of uranium (metal) was produced by heap and waste pile leaching, with only 90 tonnes produced by underground ISL techniques.

Königstein

From 1971 both underground and in situ leach mining was being used, until ISL mining took over in 1984. The extraction of uranium with ISL operated until 1990, with the total uranium production from the life of the mine being 19,258 tonnes uranium (metal), 5,526 tonnes of which was by sulphuric acid ISL.

The average concentrations of leaching solutions was 2,000 to 3,000 mg/l sulphuric acid, pH 1.5 to 1.8, salinity (TDS) 10,000 to 14,000 mg/l and uranium 10 to 150 mg/l. The uranium recovery was generally about 65-75% within three years. A total of 100,000 tonnes of sulphuric acid was injected into the mine (Diehl, 1998).

Figure 24 - Block Leaching at Konigstein



The uranium mineralisation at Königstein is found within the fourth aquifer of a regional groundwater system. The clay layer separating the third and fourth aquifers was intersected by the underground mine workings. The third aquifer is used by residents of the region for their water supply, as well discharging into the Elbe River 600 metres away from the mine site. The dewatering of the fourth aquifer for the mine led to a decrease in water level of the third aquifer.

The leaching process has chemically affected more then 55 million m^3 of rock and aquifer, while approximately 1,800 million litres containing 1,200 to 1,700 mg/l sulphuric acid and more than 30 mg/l uranium remains circulating or trapped in the pore space of the rocks. A further 850 million litres are circulating between the leaching zone and the recovery plant (Diehl, 1998).

Expressed as multiples of applicable German drinking water standards, the trapped liquids have levels 400 times higher in cadmium, 280 times higher in arsenic, 130 times higher in nickel and 83 times higher in uranium (Diehl, 1998).

The principal concerns for restoration of the site are centred around the flooding of the underground mine workings that will occur after the mine is closed down. There is significant potential for contamination of surrounding groundwater and surface water streams with uranium, radium, sulphate, iron and heavy metals. Although small scale flooding trials are currently being conducted, restoration is still not complete and the mine still represents a threat to the surrounding aquifer, an important drinking water resource for the region (Diehl, 1998).

5.4 Commonwealth of Independent States

There has been an active program of ISL mining across the Commonwealth of Independent States. A brief review of the limited available research is given.

Overview

This review is based on the work of Skorovarov & Fazlullin (1992) and Skorovarov *et al.* (1987).

There has been development of ISL-type mines across former Soviet block countries such as Ukraine, Uzbekistan, Kazakhstan and Russia, since the early 1960's. The ISL technique was typically applied to low grade deposits between 0.03 to 0.05%. Sulphuric acid was the more popular leaching agent, although alkaline carbonate-bicarbonate agents were used at some sites, depending mainly on the carbonate content of the ore.

The leaching pattern of bores used was quite variable, including 10x10 m, 10x20 m, 25x50 m and up to 10x100 metres.

The concentration of sulphuric acid ranged from 2,000 to 5,000 mg/l, with the higher the acidity level the greater the recovery of uranium and shorter the period of leaching. The average acid consumption per 1 kilogram of uranium recovered as an end product varied widely from 18 to 150 kilograms. The recovery rate of uranium was generally between 70 and 90%. No oxidant was needed to ensure dissolution of the uranium. Associated metals were also thought to be extractable, such as vanadium, rhenium, selenium, molybdenum, scandium, yttrium and rare earths.

Some of the main recognised problems of using sulphuric acid was the necessity to use acid-resistant materials and equipment, deterioration of the ore zone permeability due to chemical and gaseous plugging, and the very high salinity levels during mining (ranging from 15,000 to 25,000 mg/l).

Numerous techniques were being trialled to restore the quality of the groundwater, including lime pulp treatment, hyperfiltration and electrosorption.

Table 21 - Typical Sulphuric Acid Leaching Solution Composition (mg/l)

Sulphate (SO_4)	17,000 to 25,000
Aluminium	500 to 800
Iron	800 to 1,500 (Fe^{2+}) 400 to 1,000 (Fe^{3+})
Calcium	400 to 600
Magnesium	300 to 500
Sodium + Potassium	100 to 200
Chloride	400 to 600
Radium (pCi/l)	100

For ores with a carbonate content higher than 1.5 to 2.5%, alkaline solutions were used consisting of ammonium bicarbonate. The concentrations generally varied from 500 to 3,000 or 5,000 mg/l. On some sites sodium bicarbonate was also applied. The alkaline ISL sites used oxygen as the oxidant. The recovery rate of uranium was generally between 50 and 60%. The use of alkaline agents also tended to show much smaller increases of salinity during mining.

The main recognised problems of alkaline ISL were the high degree of solutions escaping outside the mining zone (often due to gaseous oxygen plugs forming), compulsory pre-treatment to soften the water and restoration difficulties following completion of ISL.

Table 22 - Typical Carbonate Leaching Solution Composition (mg/l)

Bicarbonate (HCO_3)	500 to 2,500
Ammonium	400 to 600
Sulphate	2,000 to 3,000
Calcium	700 to 800
Magnesium	100 to 300
Sodium + Potassium	500 to 1,000
Chloride	500 to 1,200

Overall production costs of uranium with ISL were 40-45% of conventional costs, with significantly lower energy and capital costs and reagent consumption.

Ukraine

This review is based on the work of Rudy (1996) and Molchanov (1995).

As another part of the former Soviet block, the Ukraine has had active involvement in the mining and milling of uranium, with over 21 uranium reserves identified in the southern regions of Ukraine. Three sites have also been mined with ISL, namely Devladovo, Bratske and Saphonovo.

The Devladovo deposit, consisting of paleogen clay sandstone rocks at a depth of 80 m, was mined from 1968 to 1983 with sulphuric and nitric acid. The total area of the deposit is 120 ha, with the surface site area being 12 ha. The mined aquifer still contains 7,090,000,000 litres of residual acidic solutions, with the nearest village just 4 km away in the direction of groundwater flow.

Preliminary assessments estimate, that without any remedial measures, the contaminated water would reach the village in 40 years. One assessment placed the rate of migration of the contaminated groundwater at 53 metres per year, having already travelled 1.7 km. It is thought that the contaminated plume of groundwater may reach the nearby village of Devladovo in 24.5 years.

The surface soils of the site are also heavily contaminated due to leaking distribution pipes, totalling about 50,000 m^3.

The same ISL scheme was used for the Bratske and Saphonovo deposits in the Mykolaiv region from 1971 to 1989 and 1982 to 1993 respectively. The total volume of residual acidic solutions is 5,200,000,000 litres, with the contaminated surface soils only partially restored to date. The severe lack of financial resources has led to all restoration activities being frozen in 1996.

Uzbekistan

This review is based on the work of Venatovskij (1992).

The state of Uzbekistan has numerous uranium deposits that are potential or operating ISL mines, concentrated within the large Central-Kizilkum province. They are generally around 300 m in depth and contain uranium ore in several distinct layers. The ore grades vary from 0.03 to 0.70%. Many contain low carbonate content less than 2.5% although some deposits are rich in carbonaceous matter (higher than 5%). The deposits are found mostly in sands, and occasionally in clayey sandstones.

Although associated minerals were ignored for many years, they are now recognised as being important as potentially valuable minerals. These include selenium, rhenium, scandium, yttrium, lanthanoids (rare earths) and many other rare elements. Various leaching agents were used, with sulphuric acid being the preferred acid.

5.5 China

This review is based on the work of Jian & Ning (1992).

Approximately 61% of Chinese uranium is contained within small deposits smaller than 3,000 tonnes, and mostly below a 0.2% grade. The mineralisation varies from granitic, volcanic, sandstone to carbonaceous-siliceous-pelitic. The In Situ Leach technique, for both underground and the more traditional solution mining, has been viewed as the preferential method for economically extracting uranium since the early 1980's, with trials on all types of mineralisation being conducted. Two main ISL projects are currently being actively developed or operated at Tengchong and Yining (Diehl, 1998).

A recent ISL project established in China at Tengchong, where uranium mineralisation is hosted in sandstone units with gangue minerals including pyrite and carbonaceous matter. A trial of sulphuric acid ISL lasting 42 days was undertaken on a pattern of 31 wells, with the uranium content reaching a maximum of 150 mg/l and an effective yield of 62%. The deposit is being developed as a commercial facility.

At Yining, also known as Uranium Deposit No. 512, an ISL facility has been developed since 1989, extracting uranium using sulphuric acid chemistry. The deposit is hosted in sandstone being 4 m thick and is 0.052% in grade. Sulphuric acid levels were initially injected at 2% (or 20,000 mg/l) and gradually increased to 8% (or 80,000 mg/l) with hydrogen peroxide concentrations of 550 mg/l. The ISL trial ran for 92 days, consisting of the injection of 9.8 million litres of solutions, 41.59 tonnes of sulphuric acid, 2.11 tonnes of hydrogen peroxide, and the extraction of 11.7 million litres of solutions (an 18.7% bleed rate) with a uranium content of 40 to 59 mg/l. After further research on controlling solutions, optimum leaching chemistry and bore spacings, an ISL mine was planned for operation in 1995.

Underground stope leaching with sulphuric acid has also been applied to uranium in volcanic and granitic host rocks. Although these are proving slightly cheaper than previous conventional mines, further research and development is being carried out before new mines become established.

5.6 Pakistan

This review is based on the work of Khan & Abidi (1992).

In recent years, the Pakistan Atomic Energy Commission has undertaken extensive laboratory leaching tests and two 5-spot field ISL trials on the Qubul Khel uranium deposit. The laboratory program consisted of both batch and column leaching experiments using numerous different reagents and varying concentrations. A pilot scale ISL trial was then undertaken using the optimum alkaline leaching chemistry determined from these tests.

For the batch tests a total of 40 g of samples of mixed ore were leached in a glass flask (200 ml) and agitated with leaching agents for a total of 50 hours. The column tests were conducted on 10 kg of mixed ore samples in a glass column 110 cm in height and 8.7 in diameter.

Table 23 - Effective Uranium Recovery in Batch Tests

Lixiviant	Concentration (mg/l)	Recovery (%)
$(NH_3)_2CO_3$	5,000	85
$(NH_3)_2CO_3$	10,000	93
$(NH_3)_2CO_3$	15,000	93
$Na_2CO_3 + NaHCO_3$	5,000	65
$Na_2CO_3 + NaHCO_3$	10,000	83
H_2SO_4	5,000	84

Table 24 - Effective Uranium Recovery in Column Tests

Lixiviant	Concentration (mg/l)	Recovery (%)
$(NH_3)_2CO_3$	25,000	96.5
$Na_2CO_3 + NaHCO_3$	10,000 + 5,000	85.1
$NaHCO_3$	10,000	73.6

The results of the column tests indicated permeability reduction with sodium carbonate due to calcite precipitation, although the other reagents used demonstrated that sodium bicarbonate was the most effective in avoiding this problem with respect to uranium recovery. Overall, the most effective leaching agent was considered to be ammonium carbonate, since there were no permeability problems and a high rate of uranium recovery was possible. Restoration generally required up to ten pore volumes to return uranium and pH values close to background.

Two 5-spot ISL field trials were also conducted, firstly using sodium carbonate-bicarbonate at 10,000 and 5,000 mg/l (respectively) and secondly using sodium bicarbonate at 10,000 mg/l, since ammonium carbonate was not locally available in the necessary quantities. A table of background and lixiviant water quality is given below.

The results of the first trial, which lasted 570 days, recovered approximately 65% of the uranium. The oxidant, hydrogen peroxide, was initially injected at 500 mg/l but subsequently decreased to 200 mg/l as the trial progressed and the uranium became depleted. The peak uranium concentration of 160 mg/l was found when an enhanced rate of oxidant injection was trialled at 1,000 mg/l. The high consumption of sodium carbonate was attributed to the high calcium content of the ore.

Table 25 - Background Water Quality and Lixiviant Composition (mg/l)

Component	Pattern 1		Pattern 2	
	BG[1]	Lixiviant	BG	Lixiviant
pH	7.9	9.9 - 10.3	8.3	8.8 - 9.2
Salinity (TDS)	1,097	-	860	-
Aluminium	1	-	-	-
Bicarbonate	210	1,400 - 3,600	190	3,000 - 7,000
Carbonate	-	2,000 - 5,600	30	0 - 250
Calcium	30	-	30	30 - 35
Chloride	380	150 - 300	280	150 - 300
Magnesium	15	-	15	2 - 5
Potassium	8	-	9	-
Silicon	20	-	8	8 - 20
Sodium	500	2,000 - 5,000	200	1,000 - 3,000
Sulphate	150	-	100	-
Uranium	1	30 - 160	3	40 - 90
Hydrogen Peroxide	-	200 - 1,000	-	-
Oxygen	-	-	-	1,000 - 2,500

[1] - Background

Significant amounts of scaling or mineral precipitation were encountered, mainly in the form of calcite ($CaCO_3$) and calcium silicate ($CaSiO_4$) in the production well and the ore strata. Other contaminants present within the scale included magnesium and sulphate. The scale buildup had a detrimental impact on economic recovery rates since frequent cleaning of the production well, airlifting pipe lines and ion exchange plants was necessary.

The second ISL trial, located 20 metres away from the first, with a sodium bicarbonate leaching chemistry. Initially oxygen was used as the oxidant, although when hydrogen peroxide was trialled, uranium concentrations jumped markedly. It was also noted that the uranium leaching rate was directly related to the concentration of carbonate-bicarbonate injected. The lower pH of the trial prevented excessive scaling and buildup of minerals in the production well and associated infrastructure.

5.7 Turkey

This review is based on the work of Öner *et al.* (1987).

Although known uranium reserves in Turkey are small (about 8,400 tonnes U_3O_8), the shallow Yozgat-Sorgun-Temrezli uranium deposit offers the prospect of development with ISL. In a similar line of development as Pakistan and Egypt, Turkey initiated research on it's developing by undertaking extensive laboratory leaching tests on ore samples, including both batch and column type tests.

A series of batch and autoclave leaching tests were conducted on blended ore samples and all leaching agents were investigated. The main acids trialled were sulphuric and nitric acid, while the main alkaline agents trialled were sodium carbonate-bicarbonate, ammonium carbonate-bicarbonate and potassium carbonate-bicarbonate. The oxidants trialled included hydrogen peroxide and manganese dioxide (MnO_2). Batch tests involved placing the 25 g ore sample in a 250 ml glass flask and agitation or shaking for 6 hours. Autoclave tests involved 50 g of ore sample and 500 ml of leaching solution and rotated (agitated) continuously at 600 rpm[2].

The pH of the nitric acid (0.1 M) batch test maintained a low value over the six hours between 1.16 and 1.50, while for the sulphuric acid test (0.1 M) the pH rose quite rapidly from 1.08 to 5.00. The nitric acid test recovered 73.4% of the total uranium while the sulphuric acid test only recovered 20.5%. When an oxidant was added to the sulphuric acid, the recovery increased dramatically to 100% for both manganese dioxide (2,000 mg/l) and hydrogen peroxide (300 mg/l), although manganese dioxide proved to be a considerably faster leaching agent.

A similar approach was adopted for the batch tests with all three alkaline leaching systems, with sodium-, ammonium- and potassium carbonate-bicarbonate used initially without an oxidant. However, it was found that the uranium yields were quite low, and hydrogen peroxide was subsequently added. The yields for sodium-, potassium- and ammonium carbonate-bicarbonate (all 0.1 M) with 600 mg/l of hydrogen peroxide were 33.5, 27.7 and 15.8% respectively. Further tests indicated that the optimal levels of carbonate and bicarbonate were 0.085 M and 0.015 M (sodium based agent) with hydrogen peroxide at 2,000 mg/l. A yield of 56.3% uranium was then achieved.

The autoclave tests also demonstrated that sulphuric acid and hydrogen peroxide or sodium carbonate-bicarbonate and hydrogen peroxide were the most effective lixiviants.

These two leaching solution combinations were then used in further column tests. The sulphuric acid column was run at 0.5 litres per hour for 18 hours, while the alkaline carbonate column was run at the same flow rate for 30 hours. They achieved yields of 95% and 57%, respectively. There was significant ore swelling with the sodium based leaching solution, resulting in decreased permeability, as well as the pregnant solution after leaching retaining small amounts of suspended solid matter and sediments.

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[2] - rpm is revs per minute.

5.8 Egypt

This review is based on the work of Mahdy *et al.* (1992) and Mahdy (1987).

Uranium and copper mineralisation has been found in a sedimentary sequence near the western Wadi Nasib area of Egypt, near the Gulf of Suez. The uranium and copper is found within a sedimentary sequence of silts, sands, gravels and shales. The uranium is found mostly as secondary minerals precipitated from groundwater.

The arid region is also very dependent on groundwater for drinking water, especially the numerous springs.

A number of laboratory leaching studies have been undertaken to assess the use of different leaching reagents, including sulphuric and nitric acid, and sodium carbonate and bicarbonate. The ore samples were crushed to a finer particle size, and for the silty samples sand was also added. By crushing the ore, greater contact between the leaching solutions and the ore could be achieved, but will tend to bias the results compared to leaching processes in the field.

The results indicated that uranium and copper could be leached from the ore material, as well as manganese, although selenium and arsenic were considered problematic as potential groundwater contaminants. However, the fine nature of the siltstone where the mineralisation is found within is a significant barrier to ISL mining due to it’s very low permeability.

6 Australia’s Trial Experimentation with ISL

There has been very little experience with In Situ Leach uranium mining in Australia. To date there have only been two trials - the highly publicised and controversial trial at Honeymoon in South Australia during 1982, and the lesser known trial at Manyingee in Western Australia during 1985. However, with the perceived resurgence of the potential of uranium mining in Australia during 1996, new trials were established at Beverley in South Australia (where planned trials in the early 1980’s were never realised) and again at Honeymoon. Both of these trials commenced in January 1998 and April 1998 respectively. With their purchase of the Manyingee deposit in June 1998, Paladin Resources announced their intention to propose development of another ISL mine.

However, it is important to know the history of ISL in Australia, especially that behind Honeymoon, to understand the current proposed development of the Beverley and Honeymoon projects, and potential further projects waiting in the wings.

6.1 Overview of In Situ Leaching In Australia

As discussed briefly above, there have been two trials of ISL in the past in Australia, and there are currently two undergoing evaluation. A basic timeline is presented in Table 26.

The first uranium deposit that was targeted for mining development using In Situ Leaching technology was the Honeymoon deposit, in north-eastern South Australia. The second phase of the Beverley Project was also targeted as an ISL mine in the early 1980’s (refer to Section 6.4). Honeymoon was able to progress to a field trial of ISL in 1982. The leaching chemistry used was sulphuric acid with ferrous sulphate as the oxidant. Documents from the trial showed significant problems were occurring due to the buildup of jarosite in the bores and excursions of the leaching solutions (refer to Section 6.3).

In May 1982, Australia’s first national anti-uranium blockade was co-ordinated at the Honeymoon site, with environmental and anti-nuclear groups from across Australia arriving in Broken Hill to stage a 24-hour occupation of the mine site.

By March 1983 the then Labour South Australian government refused to upgrade the projects to full mineral leases, citing the following reasons (Mudd, 1998d) :

- many of the economic, social, biological, genetic, safety and environmental problems associated with the nuclear industry were unresolved;
- endorsement of the Government's position by a wide range of community groups, including the Australian Democrats;
- commitment to the Roxby Downs project;
- community disquiet at the nature of the ISL process.

Total Mining, in a joint venture with Urangesellschaft and Triako Resources, pushed ahead with plans for an ISL trial at Manyingee in 1985, using alkaline leaching chemistry. The main chemicals used were sodium bicarbonate as the leaching agent, and hydrogen peroxide and hypochlorite as the oxidants. Paladin Resources bought the deposit in June 1998, and have immediately proceeded with plans for a new mine.

During the late 1980's, there was very little interest in developing or exploring for ISL-type uranium deposits. Many of the known deposits changed ownership several times, and old proposals stayed on a care and maintenance basis.

6.2 The Current Context of ISL in Australia

It wasn't until early 1996, with the election of the Howard Coalition government and the removal of the Three Uranium Mines Policy of the former Labour government, that interest was again rekindled. A flurry of activity has now resurged around Australia, with the most notable and certainly most controversial work being the new proposals to develop the Beverley and Honeymoon deposits. Both are running (or have run) Field Trials of ISL in 1998.

The Manyingee and Oobagooma deposits, after being placed on the market by Cogema in February 1998 (Poissonet, 1998), was purchased by fully owned Paladin Resources subsidiary in June 1998 (UIC, 1998a). They announced immediate plans for commercial development (a full history and review of the Manyingee deposit is found in Section 6.3).

Other deposits across Australia are waiting on further exploration or commercial commitment. A map of Australian ISL uranium deposits is given in Figure 25, and their respective size and grade given in Table 27. A modern timeline is found in Table 28.

Table 26 - ISL Timeline in Australia[1]

1969		Uranium mineralisation discovered at Beverley by the OTP group[2]
1970	July	Formal outline of Beverley orebody announced, after a joint venture between OTP and Western Nuclear
1970		Sedimentary Uranium NL[3] find the East Kalkaroo and Yarramba uranium deposits
1972	Nov.	Honeymoon uranium deposit discovered by a Teton Exploration-Mines Administration JV
1973		Angela[4] deposit discovered by MIM, 25 km south of Alice Springs
1973		Gould's Dam deposit discovered by the Teton-MINAD JV
1974	June	Beverley project mothballed, planned as open cut operation, due to low uranium price in the market
		Engineering appraisal of Honeymoon demonstrates that an open cut or underground mine would be uneconomic, options turn to ISL
		Manyingee deposit discovered in north-western WA by Total Mining
1977		Alkaline (ammonia bicarbonate) Push-Pull ISL tests conducted at Honeymoon
1979		Further Push-Pull ISL tests conducted at Honeymoon, including sulphuric acid and other alkaline reagents
1980	Nov.	Draft EIS released for Honeymoon
1981	March	Supplement (or Final) EIS released for Honeymoon
		South Australian Uranium Corporation (SAUC) bought the Beverley deposit, proposing it as an ISL mine
	Nov.	Honeymoon JV's commit to pilot plant
1982	May	National Anti-Uranium blockade of the Honeymoon site
	July	Draft EIS released for Beverley
		ISL trials commence at Honeymoon, lasting about 6 months on one 5-spot pattern at 1 l/s. Many problems were noted, including fungal growth and jarosite formation.
1983	March	South Australian government refuses to upgrade the Beverley and Honeymoon exploration leases to mineral leases
	Dec.	Total submit plans for a single 5-spot ISL trial at Manyingee to the WA government
1984	March	WA EPA approve ISL trials at Manyingee, only after Total resubmit their plans resolving certain issues
1985		Total begins ISL trials at Manyingee (WA), lasting about 6 months
	Dec.	Total abandon pilot plant due to technical problems
1986		Pilot plant dismantled at Manyingee
1990	Nov.	Heathgate (through General Atomics, USA) acquire the Beverley deposit, with a view to developing the ISL mine in the future
1991		Heathgate undertake further exploration and metallurgical testing of the Beverley deposit
1993		Ownership of Manyingee transfers to Cogema (Aust.) from Total

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[1] - Compiled from cited papers (see text), UIC, SEA-US, media reports, and official documents.

[2] - OTP - Oilmin - Transoil - Petromin were a group of companies influenced by the infamous ex-premier of Queensland, Joh Bjelke-Peterson.

[3] - Sedimentary Uranium now called Sedimentary Holdings NL, primarily a gold mining company.

[4] - The Angela deposit is also referred to as "Pamela".

Figure 25 - Roll Front (ISL-type) Uranium Deposits in Australia

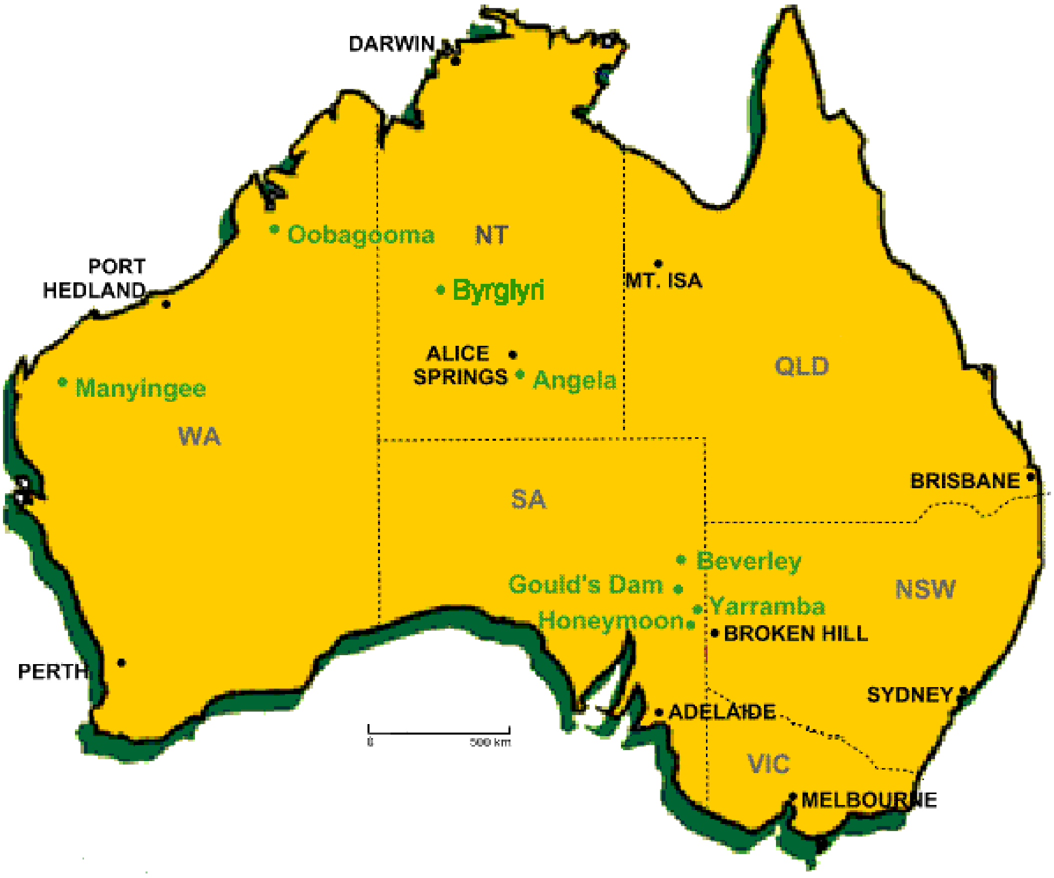

Table 27 - ISL Uranium Deposits Across Australia[1]

Deposit		Tonnes U_3O_8	Grade	Company
Manyingee	WA	7,860	0.12 %	Paladin Resources
Oobagooma/Yampi	WA	9,950	0.12 %	Paladin Resources
Bennett's Well	WA	1,500	0.16 %	Eagle Bay Resources
Ponton Creek	WA	Prospect		Uranium Australia
Honeymoon[2]	SA	4,600	0.15 %	Southern Cross Resources
East Kalkaroo	SA	900	0.14%	Southern Cross Resources
Gould's Dam	SA	17,600		Southern Cross Resources
Beverley	SA	21,000	0.18 %	Heathgate Resources
Oban	SA	Prospect		Uranium Australia
Angela[3]	NT	11,500	0.13 %	Uranium Australia
Byrglyri	NT	2,700		Joint Venture[4]
Napperby[5]	NT	6,000	0.036 %	Uranium Australia

[1] - compiled from UIC, SEA-US and industry information, tonnes U_3O_8 includes total resource, not ISL amenable resource.

[2] - includes resources east at East Kalkaroo and north at Yarramba, both now owned by SCRA.

[3] - Also referred to as "Pamela".

[4] - Central Pacific Mining / Resolute 42%, Yunandumu Mining 35%, AGIP Australia 18%, & Southern Cross Resources 5% (old source).

[5] - It is unclear if this deposit is the same as Byrglyri from Borshoff (1998).

Many small exploration and mining companies, such as Eagle Bay Resources (EBR, 1997), Uranium Australia (Thom, 1998), Acclaim Uranium (Acclaim, 1997) and Paladin Resources (Borshoff, 1998), are specifically targeting roll-front or ISL-type uranium deposits in their exploration programs. These are directed within the basins containing known roll-front deposits or in regions with known uranium mineralisation and prospective geology for the formation of roll-front deposits. Established deposits are also undergoing further exploration, such as Gould's Dam and Honeymoon in SA.

Current exploration is being undertaken by Paladin Resources-Uranium Australia[1] with three projects in the northern and eastern parts of the Lake Frome Basin (Curnamona geologic province), Napperby in the Ngalia Basin in the Northern Territory (150 km north-west of Alice Springs), and Ponton Creek on the edge of the Yilgarn Craton in Western Australia (Thom, 1998; Borshoff, 1998). In early 1998, Paladin bought into the Kayelekera uranium deposit in Malawi, Africa, (80% Paladin and 20% Perth-based company Balmain Resources), containing 11,700 tonnes of U_3O_8 at 0.187%, and is proceeding with a full assessment of the deposit as an ISL mine (UIC, 1998b).

Another active uranium exploration company is Acclaim Uranium NL (AUNL), a subsidiary of Acclaim Exploration NL (Mason & Grigor, 1998). AUNL have compiled a total of 5 projects specifically looking for roll front deposits (Acclaim, 1997). These are located near the know uranium deposit at Mulga Rock (south-eastern WA), Oobagooma (north-east of Derby), Myroodah (western Kimberleys), Gascoyne (west of Carnarvon) and Mundong prospect (300 km south-south-east of Karratha) (Acclaim, 1997).

Eagle Bay Resources are also planning exploration projects in the Ashburton region of WA (near the known Manyingee and Bennett's Well deposits), although the project was contingent on capital being raised through a Joint Venture (EBR, 1997 & 1998).

The market is also speculating about the activities of these small companies, with companies like Sedimentary Holdings (35% interest in the Honeymoon Project), Paladin Resources and Uranium Australia seeing a marked increase in their share price over the past year (Treadgold, 1997). It is uncertain though how this perceived "boom" in the volatile and speculative mining market will sustain itself. To date, the Beverley and Honeymoon Projects remain the most advanced, with Manyingee soon to follow.

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[1] - Uranium Australia acquired the capital of Brightstar Power Corporation in 1997, including the JV exploration projects with Paladin Resources, known as PBJV or Paladin-Brightstar JV (Thom 1998).

Table 28 - Modern Timeline of ISL in Australia

1996	May	Heathgate commit to developing the Beverley ISL deposit
	May	Sedimentary Holdings NL commission a feasibility study of the Honeymoon and surrounding uranium deposits
	Oct.	Heathgate Resources designated as the project proponent for an EIS
	(late)	Canadian company Southern Cross Resources (SCR) come to agreement with Mt Isa Mines (MIM) to acquire the Honeymoon and Gould's Dam deposits and nearby exploration lease EL2310 as well as Sedimentary Holdings interests in EL2310.
1997	(early)	Heathgate undertake further exploration, completing boreholes as groundwater monitoring wells
	(mid)	Further drilling to install two 5-spot ISL patterns at Beverley
	June 20	SCR purchase the Honeymoon, Gould's Dam and associated deposits, with Sedimentary Holdings taking 35% equity in SCR
	Sept. 5 & 25	Heathgate submit a "Declaration of Environmental Factors" (DEF) application and Supplement to Mines & Energy SA for a Field Leach trial, to test the amenability of the Beverley deposit to ISL
	Oct.	Southern Cross submit a "Declaration of Environmental Factors" (DEF) for a new ISL trial at Honeymoon
	Nov. 14	SA Minister for Mines & Energy approves the Field Trial of ISL at Beverley
1998	Jan. 2	ISL trials begin at Beverley
	Feb.	Heathgate announce the upgrade of the Beverley deposit to 21,000 tonnes of U_3O_8, almost twice the size of previous ISL estimates
	Feb.	Cogema (Australia) places their Manyingee and Oobagooma ISL deposits on the market
	Feb.	Eagle Bay Resources looking for an exploration Joint Venture partner for more drilling work near Manyingee
	Feb.	Southern Cross submit a Supplement to the DEF
	March 16	Paladin Resources buys 80% share in Kayelekera uranium deposit in Malawi, proceeding with feasibility studies for an ISL mine
	March 23	SA Minister for Mines & Energy approves a new Field Trial of ISL at Honeymoon. SCR immediately announce that "production" has started with new ISL trials at Honeymoon
	April 29	SCR announce an upgrade of the resource estimate for the Gould's Dam deposit to 17,600 tonnes of U_3O_8, nearly ten times higher than the previous estimate of 2,300 tonnes of U_3O_8, with a revised estimate for the various Honeymoon deposits to be completed soon
	June 9	Paladin Resources purchase the Manyingee and Oobagooma deposits and announce plans for commercial development of Manyingee
	June 29	Heathgate release their EIS for their proposal at Beverley
	June 30	Heathgate announce the signing of a 150 tonne per year sales contract with a US utility, before federal approval of their EIS

[1] - Compiled from UIC, SEA-US, media reports, and official documents.

Figure 26 - South Australian Uranium ISL Deposits (Dobrzinski, 1997)
(Oban added from Borshoff (1998))

6.3 The Honeymoon Story

Historical Overview

The Honeymoon story is unique among the Australian mining industry, and is extremely important in understanding the hard sell behind ISL uranium mining technology in Australia in the early 1980's and the current wide range of activities being undertaken across Australia.

There are several small uranium deposits found within the Honeymoon region. The first to be discovered were the East Kalkaroo and Yarramba deposits by exploration company Sedimentary Uranium, although they were too small for stand alone mines (Ackland, 1997). During November 1972 an exploration joint venture between Mines Administration (MINAD, a subsidiary of CSR Ltd) and Teton Exploration (an exploration company from the USA) discovered the Honeymoon deposit just 75 km north-west of Broken Hill (Ackland, 1997). There are known extensions to this deposit and satellites to the east (Bush, 1998). The Gould's Dam deposit further to the west was discovered later in 1973 (Ackland, 1997). There was considerable exploration undertaken at the Honeymoon site during 1973 to 1979 with about 250 exploration bores drilled (MINAD, 1980), and as the uranium deposit was small and saturated, it was quickly realised to be uneconomic with conventional methods (Bush, 1998). The total uranium resource at all deposits and extensions was estimated to be about 4,600 tonnes of U_3O_8 (Ackland, 1997).

Subsequently, the experimental mining technique of In Situ Leaching was proposed to develop the deposit and extract the uranium (Bush, 1998). The first ISL experiments were a series of push-pull tests on a single well using ammonia bicarbonate and hydrogen peroxide (Dobrowolski, 1983a). The results, however, were not encouraging as the uranium concentrations were considered too low for economic recovery (Dobrowolski, 1983a). With encouraging results from a series of push-pull tests in 1979 which used sulphuric acid solutions, the Joint Venturers, Mines Administration Pty Ltd (MINAD, 25.5%; a subsidiary of CSR Ltd), Teton Australia[2] (25.5%) and MIM Holdings Ltd (49%), agreed to develop the deposit as an ISL mine (Dobrowolski, 1983a).

A Draft Environmental Impact Statement (DEIS) was released in November 1980 (MINAD, 1980), and the Supplement or Final EIS (FEIS) released in March 1981 (MINAD, 1981). Following SA government approval in May 1981, a 25 l/s pilot plant was built and four 5-spot wellfield patterns drilled (SCRA, 1997). An experimental field trial of In Situ Leaching was begun in 1982, using sulphuric acid and ferrous sulphate as an oxidiser. There were many noted problems with the trial, discussed in detail below. However, the environmental movement began to organise a targeted and highly successful campaign against the Honeymoon Project. In December 1981 it was decided that Australia's first national occupation of a uranium mine should occur at Honeymoon in May 1982.

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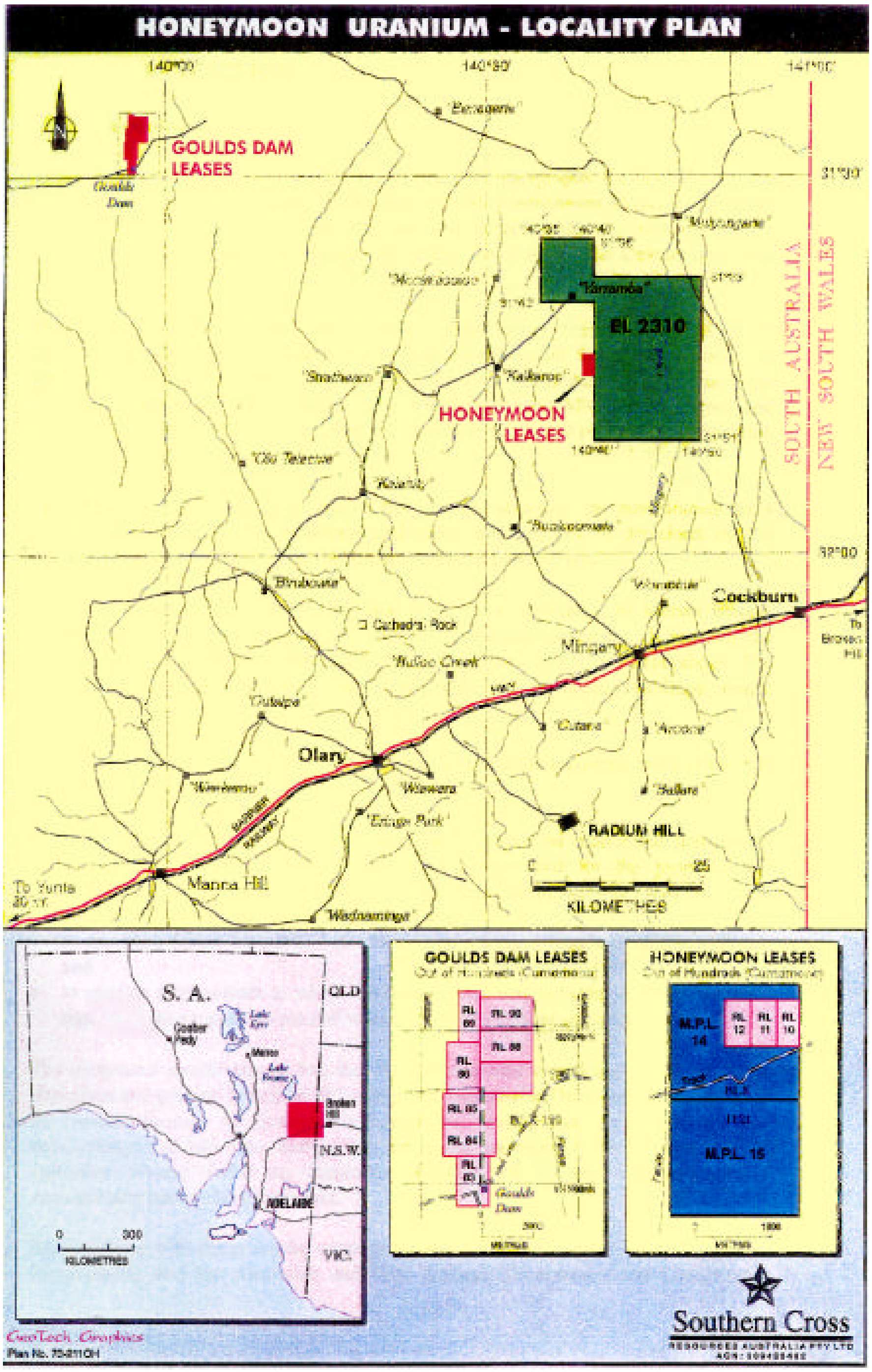
[2] - the same company involved in ISL trial mines in the USA.

Figure 27 - Location of the Honeymoon Uranium Project (DHUD & EA, 1998)



A national campaign was directed at the Honeymoon site, and between May 14 to 16, 1982, a 24 hour blockade of the site was conducted. It proved to be a pivotal point in the Honeymoon Project's history.

The following year, in March 1983, the newly elected Labour government of South Australia, under the leadership of John Bannon, refused to upgrade the leases at both Beverley and Honeymoon to full mining leases, citing these reasons (Mudd, 1998d) :

- many of the economic, social, biological, genetic, safety and environmental problems associated with the nuclear industry were unresolved;
- endorsement of the Government's position by a wide range of community groups, including the Australian Democrats;
- commitment to the Roxby Downs project;
- community disquiet at the nature of the ISL process.

The Honeymoon project was thus stopped by the SA government for legitimate reasons, ***NOT THE THREE MINES POLICY***. The Three Mines Policy was not formally adopted by the federal Labour Party until their 1984 National Conference (Smith, 1998).

For the following 15 years, the Honeymoon pilot plant remained mothballed. In May 1997, Canadian company Southern Cross Resources Inc (SCR) purchased the project through their Australian subsidiary Southern Cross Resources Australia (SCRA) and agreement was reached between MIM and Sedimentary Holdings to consolidate the numerous small deposits into one project, including the Gould’s Dam deposit, 60 km to the west of Honeymoon. Sedimentary acquired a 35% shareholding in SCR as part of the agreement. The total uranium resource now approximately 6,800 tonnes of U_3O_8.

SCR have immediately and rapidly re-established the Honeymoon Project, having submitted Declaration of Environmental Factors documents to the SA government by late 1997 and early 1998 (SCR, 1997 & 1998). After SA government approval of the DEF’s in March 1998, new field trials of ISL began at Honeymoon in April 1998, planned to run for the full year the DEF authorisation allowed for. A new Environmental Impact Statement is also being prepared to include the additional deposits now incorporated into the Honeymoon Project, and is anticipated to be released by the end of 1998 while field trials are ongoing.

Geology & Mineralisation

The Honeymoon region contains up to 120 metres of sediments, consisting of clays and sands, overlying intrusive and metamorphic basement rocks (MINAD, 1980). The bottom sequence of the sediments contain numerous palaeochannels, delineated by extensive drilling of the area (MINAD, 1980). The presence of uranium mineralisation within many of these palaeochannels is common (refer to Figure 26) and the Honeymoon and Gould’s Dam deposits are considered to be of an economic size for ISL extraction.

The Honeymoon uranium deposit is contained within the Yarramba palaeochannel, which consists of three sub-horizontal sand layers (aquifers) separated by clay layers (MINAD, 1980). The uranium is found within the basal sands, identified as uraninite and coffinite (Dobrowolski, 1983a). The major gangue minerals are quartz (sand) and kaolinite (clay), although the ore does contain 7% pyrite and 0.3-3% total organic carbon (TOC) (Dobrowolski, 1983a).

Brief Review of Hydrogeology

The Yarramba Tertiary age palaeochannel represents the only source of groundwater within the broader Honeymoon area. Concurrent with geology, there are considered to be three distinct aquifers within the channel, separated by layers of clay. The water chemistry of the three aquifers is distinctly different, suggesting that significant mixing does not currently occur (MINAD, 1980). However, accurate measurements of groundwater levels from all three palaeochannel aquifers have shown that the pressures are approximately the same, suggesting the occurrence of a hydraulic connection between the aquifers (MINAD, 1980). The results from drilling have shown that although the two separating clay layers are generally continuous over the Honeymoon deposit, the clay is absent at some places within the palaeochannel (MINAD, 1980).

The quality of all three aquifers is generally saline, with the basal sands being quite poor quality water with radionuclides present (Bush, 1998).

Recharge to the palaeochannel is considered to be via extremely weathered and fractured metamorphic and granitic basement rocks which outcrop to the south (MINAD, 1980). The velocity of groundwater within the basal sand unit is thought to be up to 18 metres per year, towards the north and the evaporative sink of Lake Frome (MINAD, 1980).

The Early ISL Field Trials

Three series of small pilot scale tests have been carried out at Honeymoon. A series of push-pull tests were conducted first conducted in 1977, using ammonia bicarbonate solutions based on experience in the USA (Dobrowolski, 1983a). A total of 20,000 litres of leaching solution was injected into the ore zone via a single well, and recovered 24 hours later (Dobrowolski, 1983a). The concentrations of uranium proved too low to be considered economic (Dobrowolski, 1983a).

During 1979, a further series of push-pull tests were conducted, intended to give an indication of aquifer permeability and the level of uranium that might be extracted during continuous leaching with a 5-spot pattern using sulphuric acid and some minor alkaline solutions (Dobrowolski, 1983a; Bush, 1998). The success of the sulphuric acid tests led to the commitment by the joint venturers involved, and the Draft and Final EIS's were subsequently released (MINAD, 1980 & 1981).

A continuous trial of In Situ Leaching was first conducted on a small scale at Honeymoon in 1981, after approvals were granted following the Final EIS (Dobrowolski, 1983a). The trial highlighted the problem of possible gypsum precipitation due to high calcium and sulphate concentrations in the groundwater and calcium bound on the clays (Dobrowolski, 1983a). It was found that the ore zone aquifer needed a "pre-flush" with upper aquifer water low in calcium, and a 5-15% bleed to dilute the ore zone calcium concentration (Dobrowolski, 1983a).

A Field Leach Trial consisting of one 5-spot pattern operating at 1 litre per second (l/s) was undertaken during 1982 (Bush, 1998). Although the main goal of the pilot operation was to achieve effective uranium dissolution without any significant plugging of the ore zone (Bush, 1998), this was not achieved and significant operational and environmental problems were encountered.

The leaching chemistry used was sulphuric acid with ferrous sulphate as the oxidant. Such chemistry, with the high iron and sulphate levels involved, is likely to lead to the precipitation of jarosite, a hydrated ferric sulphate mineral with associated cations of sodium or potassium (eg - formula $KFe_3(SO_4)_3.9H_2O$) (Appelo & Postma, 1994). The formation of jarosite has been noted at uranium mines and tailings dams at Elliot Lake in Ontario, Canada, and was thought to involve the action of bacteria (Ivarson, 1973). Consequently, the field leach trial encountered problems with the precipitation of jarosite and fungal growth (Bush, 1998), leading to aquifer plugging, injectivity loss and minimal control of leach solution movement.

A series of documents were obtained in early 1983 from MINAD by the Campaign Against Nuclear Energy (CANE), and they proved that the 1982 trial was closed due to many significant operational and environmental problems (Wecker, 1983a, 1983b & 1983c; Dobrowolski, 1983b, 1983c & 1983d). The trial on the 5-spot test pattern was stopped due to injectivity losses resulting from decreased aquifer permeability, thought to be due to either mineral precipitation, siltation or bacterial growth (Dobrowolski, 1983c).

A core sample was retrieved in October/November 1982, and sub-sampled for detailed mineralogical and chemical analysis (Dobrowolski, 1983c). The dominant problem was quickly identified by separate laboratories as jarosite formation within the ore zone aquifer sediments from reactions with gangue minerals and chemical precipitation from the leaching solutions (Dobrowolski, 1983b & 1983c). Minor amounts of elemental sulphur and the mineral gypsum ($CaSO_4$) were also found (Dobrowolski, 1983c). The reduction of ore zone permeability began almost immediately upon commencement of the field trial, although problems with the analytical accuracy of the onsite Honeymoon chemical laboratory were also noted (Wecker, 1983b).

The formation of jarosite was seen to occur slowly, but it's effective reduction of the ore zone permeability was cumulative (Wecker, 1983b). The main concern was that if the problem was not resolved, both the trial and future wellfields could be plugged within only a few months of operation (Wecker, 1983b).

The main chemical parameters that can control the formation of jarosite are pH, redox potential (Eh), and the sulphate and total iron concentrations. Initially, the Honeymoon operators were unable to determine from available technical literature what was likely to influence jarosite formation with their specific leaching chemistry (such as pH, redox or iron levels) (Wecker, 1983b).

Dobrowolski (1983c) suggested that the most significant factor in jarosite precipitation during the trial were temporary excursions in the leaching solution pH which produced seed crystals of jarosite and slow precipitation on ore zone gangue minerals at injection pH values higher than 1.8. It was also presented that jarosite formation could be correlated with pH in trial leach solution samples - where the pH rose above 2.2 jarosite could be seen in the sample bottles (Wecker, 1983a; Dobrowolski, 1983b). The formation of jarosite was exacerbated by various equipment failures that saw the pH during the trial rise above 2.3 on several occasions (Dobrowolski, 1983c).

The exact formation of jarosite was considered to arise from either changes in the pH of the leaching solutions or reactions between gangue minerals leading to jarosite growth on quartz or kaolinite. The first mechanism was considerably rapid, and appeared to be dispersed after the pH was adjusted to a lower value, although it was not realised at the time of the field trial that the fine jarosite created at this stage was plugging the well screens (Dobrowolski, 1983c).

The second mechanism was much slower, and at the temperature and pH conditions in the Honeymoon ore zone aquifer, was likely to occur with the order of weeks (Dobrowolski, 1983c). Although jarosite precipitation was noted in some geochemical environments at a pH of 1.0, it was thought that if the pH was maintained below 1.8, this stage of formation could be prevented or minimised to the point where the growth would occur over months, and therefore not interfere with the short-term operation of a wellfield (Dobrowolski, 1983c). Suggested parameters were thus an approximate pH of 1.7, total iron less than 3,000 mg/l and a redox potential of 500 mV (Dobrowolski, 1983c).

In order to verify the above hypotheses, a series of laboratory experiments were begun by Australian Mineral Development Laboratories (AMDEL) in March 1983 (Wecker, 1983a). Upon authorising the AMDEL studies in mid-March, Wecker (1983b) stated clearly that significant uncertainty still remained about the future of the Honeymoon Project. On March 22, 1983, the SA government announced it’s intention to refuse mineral leases for both Honeymoon and Beverley, effectively stopping the projects (Mudd, 1998d). It is unclear if these studies were subsequently completed.

The use of oxygen was also being investigated at this time as an alternative to ferric sulphate (Wecker, 1983a; Dobrowolski, 1983b & 1983c), although it is unclear what stage this reached. This would avoid altogether the jarosite problem, and had been successfully demonstrated by that stage at the Zamzow ISL project in Texas, USA (Dobrowolski, 1983c). The use of oxygen injection systems is now considered routine in the USA and all current ISL mines use oxygen as their primary oxidant.

There has yet to be any public release of documentation or reports on the various field trials of In Situ Leaching conducted at Honeymoon up to and including 1982.

Current Proposal and Activities

Having purchased the Honeymoon Project and re-established it as a potential new uranium mine, SCRA immediately prepared a Draft Declaration of Environmental Factors (DEF) for a new Field Leach Trial (FLT) at Honeymoon (SCRA, 1997). The DEF was finalised on October 31, 1997, and submitted to Mines & Energy Department (or MESA[3]) on November 5, 1997 (Bush, 1998). An application for a radioactive source material licence was submitted to the SA Health Commission, Radiation Protection Branch, in late November (Bush, 1998). A number of technical concerns were raised by various state and federal government departments after reviewing the Draft DEF and SCRA subsequently prepared a Final DEF as a response, submitted to MESA on February 4, 1998 (SCRA, 1998). Both DEF's are a simply a re-presentation of the 1980 and 1981 DEIS and FEIS, with no new analyses or data from the current proposal or results from the 1982 field ISL trial.

A review of the two DEF's by Mudd (1998g) has highlighted the following concerns :

- by using available geochemical models (eg - PHREEQC by Parkhurst, 1996), it can be demonstrated that the chemistry presented in the DEF will increase the potential for precipitation gypsum and other minerals;
- although potassium concentrations are not included in the given water chemistry, by assuming a range of values to input to PHREEQC, it can be demonstrated that jarosite precipitation will remain a significant problem;
- appears deliberately ambiguous concerning earlier work and avoids the issue of jarosite precipitation;
- inadequate characterisation of the hydrogeology, with contradictions in the DEF concerning the hydraulic connections between the three aquifers noted;
- misrepresents the reasons behind the 1983 SA government decision to refuse further approvals for the project;
- concentrations of potentially toxic heavy metals are ignored, such as selenium, lead, cadmium, and others;
- is dismissive of radiation concerns, especially radon emanation from leaching solutions;
- problems with the complexity geology have been noted, especially since the fourth 5-spot pattern drilled for the pilot plant was not completed due to intersection of lower permeability clays and silts and little or no uranium mineralisation, yet such problems remain unresolved;
- problems of silt building up in the bottom of bores and potential screen blockages are ignored;
- no restoration of groundwater quality will be undertaken.

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[3] - MESA is now merged as PIRSA, Primary Industries and Resources, South Australia.

The SA government approved the new Field Trial of ISL on March 17, 1998 (Reuters, 1998a; UIC, 1998c). The new Field Trial began operation in April 1998, with SCR intending to gradually increase the throughput of the pilot plant to it's design capacity of 115 tonnes per year U3O8 (Reuters, 1998b). Although the DEF's argued that a new trial was warranted to enable input into the pending EIS, SCR were calmly talking about "production beginning at Honeymoon" (Reuters, 1998b), not evaluation of the deposit for ISL amenability or further refinements on leaching solution chemistry (such as to avoid jarosite precipitation). The rate of 115 tonnes per year is 25% of the projected full scale plant, and SCR plans to increase the production rate up to this level to the point where the Commonwealth and South Australian governments consider the new EIS. There is no approvals from the Commonwealth for sales contracts as the basis for export, nor export permits yet SCR are gradually increasing the production capacity of Honeymoon to levels in excess of some ISL uranium mines in the USA. This cannot be considered to be good faith corporate management and certainly relegates due environmental assessment processes and environmental management to a poor standard.

The new resource estimate for the Gould's Dam deposit was announced by SCR in late-April, and the size of the deposit was almost an order of magnitude larger than previous estimates. Originally thought to contain 2,300 tonnes of U_3O_8, the new resource estimate for Gould's Dam was now thought to contain 17,600 tonnes U_3O_8 at an average grade of 0.098% (Reuters, 1998c; UIC 1998d). A particularly high grade section of the deposit is planned as a stand alone pilot ISL trial upon the raising of $20 million funds by SCR (Reuters, 1998c; UIC 1998d). The proportion of the uranium that is extractable with ISL is uncertain, and so the actual productive capacity of the deposit may be significantly less.

It would appear that the current proposals, from an independent view, are merely repeating the old proposals for In Situ Leach mining of uranium from the Honeymoon deposits, and no literature appears to take into account much of the experience in the USA with ISL mining, especially acidic solution mining. Many of the environmental problems of the past appear destined to continue, and without public scrutiny.

6.4 The Beverley Story

This review of the Beverley uranium deposit is based on Mudd (1998e) and an extension for this report.

Overview

The controversial Beverley uranium deposit is located on the plains between the northern Flinders Ranges and the north-western Lake Frome plains, approximately 600 km north of Adelaide and 300 km north-east of Port Augusta (refer to Figures 17 & 18). It has seen three phases of proposed development by different companies, with the third phase currently progressing.

The deposit was first planned as an open cut mine in the early 1970's, although the second attempt at development planned to use the controversial technique of solution mining techniques or In Situ Leaching (ISL) to recover approximately 11,600 tonnes of U_3O_8 (SAUC, 1982). It is a small to medium-sized uranium deposit, initially thought to contain about 16,200 tonnes U_3O_8 at an average grade of 0.27% in a sand-filled paleaochannel about 110 to 140 metres below the surface (SAUC, 1982). Recent exploration and a revised resource estimate that includes lower grades of uranium ore has increased the size of the deposit extractable by ISL to 21,000 tonnes of U_3O_8 (Graham, 1998). It is not clear whether this is using acid or alkaline ISL chemistry.

The project was decisively rejected by the South Australian government in March 1983, as can be demonstrated by the numerous media reports of the day (Mudd, 1998d). However, upon return of the Liberal-National Coalition to federal government in early 1996, current owner Heathgate Resources (subsidiary of US nuclear multinational General Atomics) re-applied for development of the project in mid-1996.

The Beverley area is an area of great significance for the local Adnyamathanha Aboriginal community, a fact which has been long recognised since the 1930's-40's (CCSA, 1996; Marsh, 1998).

Heathgate have now finished a trial of ISL at Beverley, and the EIS has just been released.

Geology & Mineralisation

The uranium mineralisation is contained in three main ore lenses within friable sands and clays of the Tertiary Namba Formation (refer to Figures 18 & 19) (Heathgate, 1997a). The mineralisation occurs within a semi-isolated aquifer zone that resembles a concealed fluvial system or palaeochannel. The uranium mineral is coffinite, a uraniferous hydrosilicate mineral. It is believed to have been derived from known uranium mineralisation in older rocks of the Mt Painter region of the Northern Flinders Ranges 10 km to the north-west (SAUC, 1982).

Figure 28 - Beverley Uranium Deposit Location (Heathgate, 1997b)

Figure 29 - Regional Geological Cross Section near Beverley (Heathgate, 1997b)

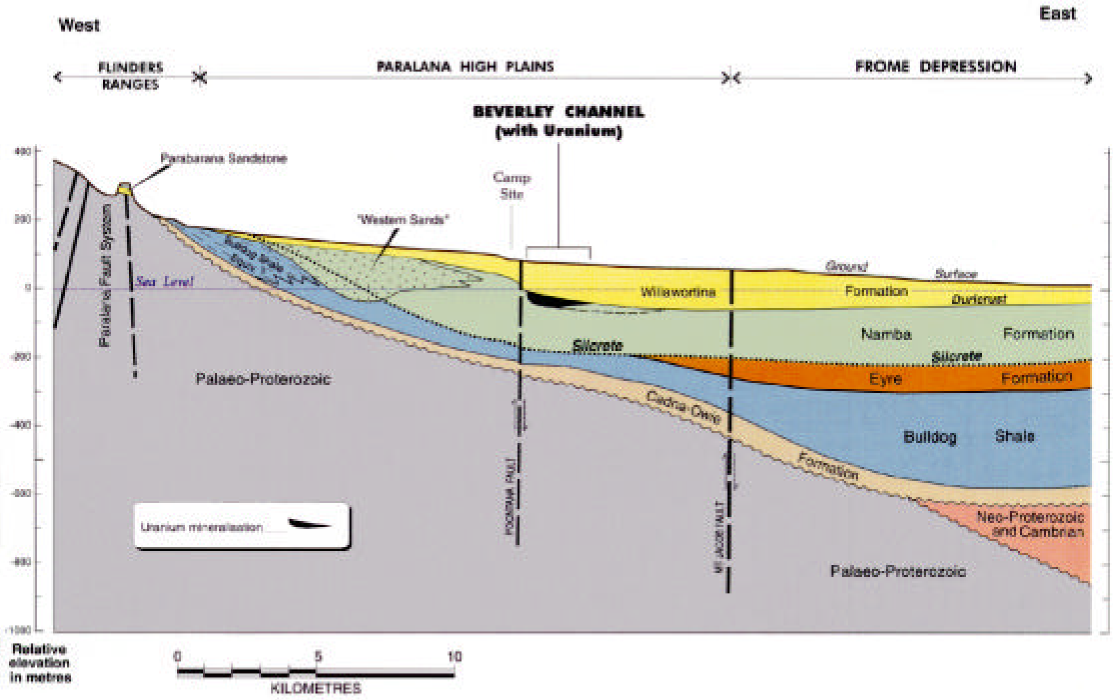
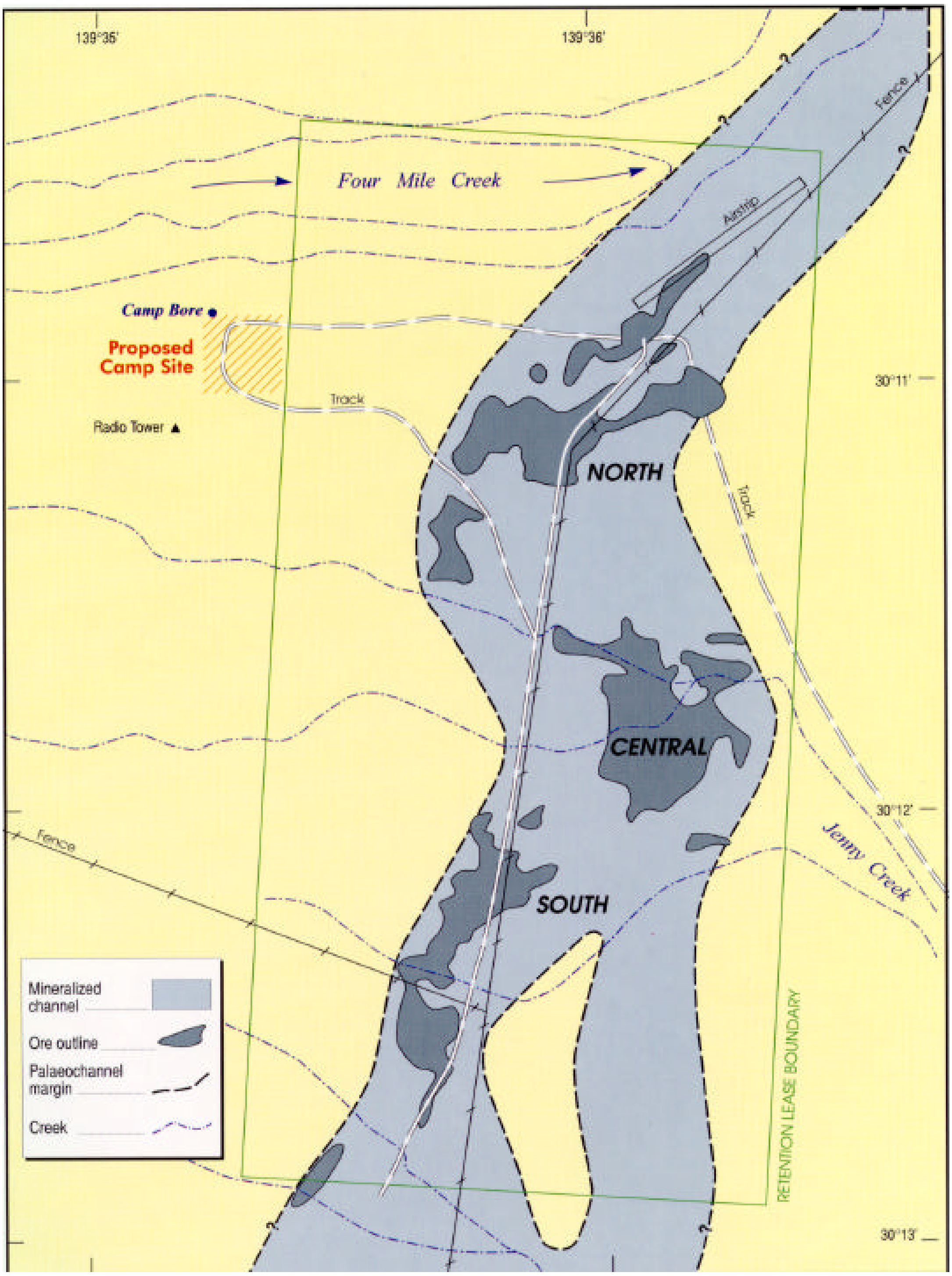


Figure 30 - Outline of the Beverley Uranium Deposit (Heathgate, 1997b)



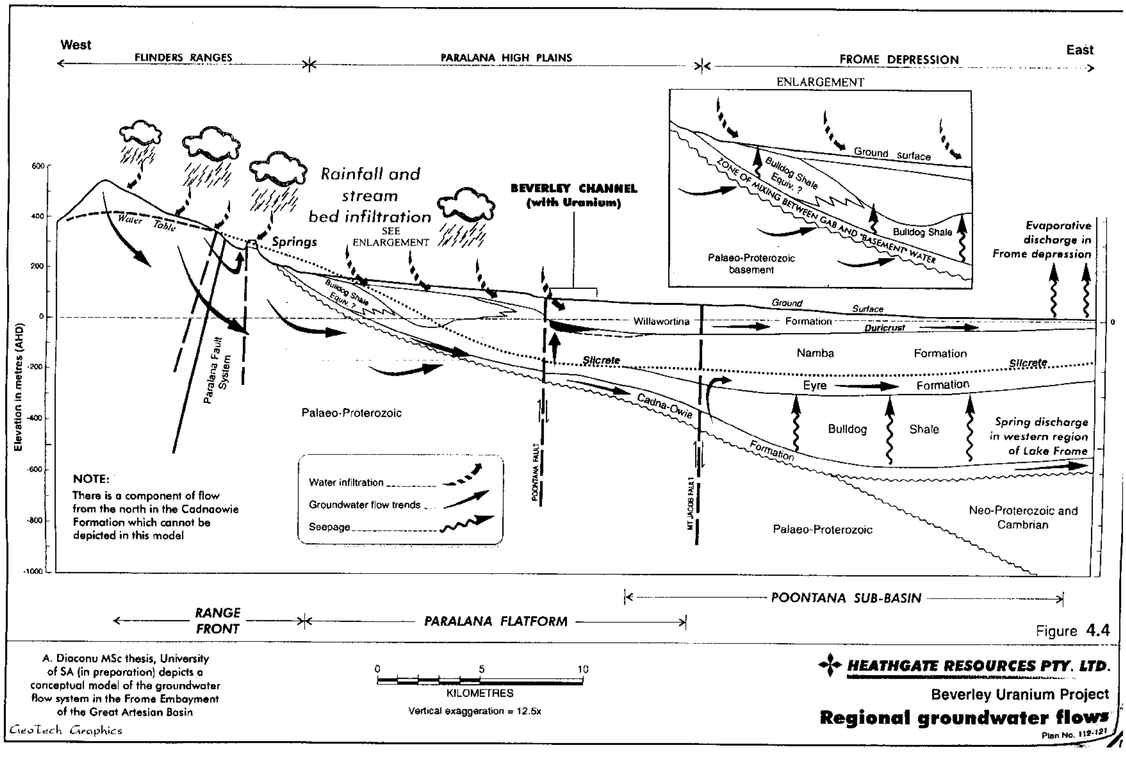
Brief Review of Hydrogeology

There are four major geological formations where groundwater can be found (Heathgate, 1997a; SAUC, 1982; Mudd, 1998f) :

- the Great Artesian Basin at about 300 to 400 m (the Cadna-Owie Formation aquifer). The water quality is quite good, with a TDS about 2,150 mg/l;
- within the sands of the Namba Formation at moderate depths between 100 to 200 m. The Beverley uranium deposit occurs within one of these aquifers, a sand-filled palaeochannel (river bed). The water quality is moderately saline, with an average TDS of 6,500 mg/l and ranging from 2,700 to 9,900 mg/l. There is residual radionuclides within the water, with high variability;
- the regional Eyre Formation - at depths between 250 to 300 m. This is not present locally at the Beverley site, but is thought to be an important discharge zone from the GAB via the Mt Jacob fault. No water quality data available;
- at shallow depths from 10 to 90 m, within sand units of the Willawortina Formation. This is a reasonably good source of water, with an average TDS of 4,500 mg/l, but extremely variable ranging from 700 to 23,000 mg/l.

A conceptual diagram of what is believed to be the regional flow system is shown below, although there is no field data to verify this.

Figure 31 - Regional Hydrogeology of Beverley (Heathgate, 1997a)



Mine History

The first discovery of uranium mineralisation at the Beverley deposit was in 1969 by the OTP group of companies (Oilmin-Transoil-Petromin, a corporation influenced by the well-known racist ex-Premier of Queensland, Joh Bjelke-Peterson). Detailed drilling investigations undertaken as a Joint Venture between the OTP group and Western Uranium Ltd[1] led to formal discovery of an economic orebody in July 1970.

An intensive drilling program was undertaken from 1971 to 1972 by Western Nuclear, which was closely followed by metallurgical and engineering studies aimed toward an open cut mining operation. Further exploration was also undertaken. The fall in the uranium market in the early 1970s caused the project to be mothballed in June 1974 (Heathgate, 1997a).

The South Australian Uranium Corporation (SAUC) bought the Beverley deposit in 1981 and began studies towards an Environmental Impact Statement (EIS). The SAUC undertook further intensive drilling, although results and activities over this development and the previous 1970's era were not always well documented (Heathgate, 1997a).

The relatively new and, at that stage, experimental technique of uranium extraction by In Situ Leaching (ISL) or "Solution Mining" was planned to be used. The Draft EIS was submitted in July 1982, and received overwhelming criticisms from environment groups, institutions, and numerous concerned citizens. A total of 222 submissions were made to the Draft EIS.

Some selected comments by Dr Dennis Matthews (Matthews, 1982b) :

- lack of clarity concerning the nature of the proposal and activities, such as the pilot plant versus a full scale commercial mine;
- no published guidelines for the EIS, nor were they available prior to the EIS being released;
- economic viability was not assured, especially given the economic analysis assumed twice the 1982 spot price for yellowcake - 1982 prices were not sufficient to cover capital and production costs;
- extremely poor hydrogeological information, unable to accurately assess the nature of the risks involved;
- it assumed groundwater was not of sufficient quality to require rehabilitation following in situ leach mining - despite the environmental value of groundwater in a semi-arid climate;
- inconsistent published flow rates for waste-water disposal, leaving excess quantities of water to be disposed of presumably back into the mined aquifer;
- inaccurate estimation of severe flash flood potential;

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[1] - Acquired by Phelps Dodge Corporation in 1971, becoming Western Nuclear (Moody, 1992)

- to be discussing excursions of leaching solutions while actively promoting the disposal of waste water by re-injection into the mined out aquifer shows a complete lack of environmental concern;
- project assumed adequate dispersal of radon gas, yet ignores the wide meteorological variability for the region, and the fact that radon decays into other radioactive solids that create radioactive fallout in the receiving area;
- mathematical models are not validated;
- the toxicity and carcinogenicity of the tertiary amine solvent to be used was not discussed, nor of the high radiotoxicity of ammonium diurinate in body fluids (part of the process stream).

Due to the poor quality of the EIS, the Environmental Assessment process was delayed and combined with it's decision on Honeymoon, the South Australian Government refused approvals in March 1983, citing at the time (Mudd, 1998d) :

- many of the economic, social, biological, genetic, safety and environmental problems associated with the nuclear industry were unresolved;
- endorsement of the Government's position by a wide range of community groups, including the Australian Democrats;
- commitment to the Roxby Downs project;
- community disquiet at the nature of the ISL process.

A Supplementary EIS was not prepared[2] and the Beverley Project was shelved for a second time, due to the SA government refusing to issue a mineral lease, ***NOT THE THREE MINES POLICY***. The Three Mines Policy was not formally adopted by the federal Labour Party until their 1984 National Conference (Smith, 1998). This can be demonstrated from the many newspaper articles of the day, listed in detail in Mudd (1998d). The then leader of the SA Liberal Opposition, Mr John Olsen, said that a Liberal government would allow the project to go ahead according to procedures outlined in the EIS (Mudd, 1998d). Mr Olsen, now Premier of South Australia, has waited 15 years to carry out his threat.

Heathgate Resources Pty Ltd, an Australian company, was established by General Atomics in 1990 when the Beverley deposit was acquired (November 1990), specifically to manage it's development and any future acquisitions or ventures which General Atomics might consider in Australia (SSCUMM, 1997). New studies were initiated into potential mining of the deposit using ISL based on USA experience (Heathgate, 1997a) (although perhaps it should be pointed out that experience with the proposed acidic solutions is quite limited, and all past and present commercial ISL mines use alkaline leaching solutions). Initially, two cored boreholes were drilled through the ore zone in 1991, with the core samples being used for geological and confirmatory metallurgical testing (Heathgate, 1997a).

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[2] - Environment Australia website, *Australian EIA Network : EIA In Australia - Projects Assessed under the Environment Protection (Impact of Proposals) Act 1974*, April 22, 1997 (http://www.environment.gov.au/portfolio/epg/eianet/).

In late 1995 and early 1996, General Atomics were keen to develop a new uranium production operation and were engaged in a worldwide evaluation of potential projects to develop (SSCUMM, 1997).

General Atomics therefore do not have any history of direct involvement with uranium mining, and none whatsoever with the In Situ Leaching (ISL) technique (SSCUMM, 1997).

In May 1996 Beverley was chosen as the first major project to begin development, having the "...right combination for both short-term development, moderate production costs and long-term productivity" (SSCUMM, 1997). With the election of the conservative Howard federal government in early 1996 and the subsequent scrapping of the ALP Three Mines Policy, Heathgate accelerated their development program. They were formally designated as the project proponent by the Commonwealth government on October 4, 1996 (DTUP&A & EA, 1998), to undertake Environmental Impact Assessment procedures with a view to establishing a full-scale commercial uranium mine at the Beverley site.

Current Proposal and Activities

Development of the Beverley deposit to a full scale mine is proceeding according to a five stage process, with each stage purposely designed to build towards the final full-scale facility :

- Stage One - further exploratory drilling and desktop feasibility studies;
- Stage Two - the installation of two "5-spot" borehole systems for pump testing of the aquifer;
- Stage Three - Field Leaching Trials (FLT) of in situ leaching (ISL) using the previously installed "5-spot" patterns;
- Stage Four - Environmental Impact Assessment, public review and comment on the EIS, Native Title Agreements negotiated, government decision on the proposal;
- Stage Five - final approval, uranium export permits issued and full-scale commercial uranium mine.

Under South Australian mining legislation, Stages One to Three are regulated by mining companies submitting a "Declaration of Environmental Factors" document which detail their proposals. This is primarily a process between the proponents and Mines and Energy South Australia (MESA, now part of Primary Industries and Resources or PIRSA) with no direct public input as to the suitability of where mining exploration takes place, the elements and minerals that should be mined nor the type of mining technique should be encouraged. The Environment Protection Authority (within the SA Department of Environment, Heritage & Aboriginal Affairs) has no statutory say in the environmental regulation of such activities. The fourth stage is controlled by both the Commonwealth and South Australian governments, while the fifth and final stage is controlled only by the Commonwealth government.

Heathgate have thus been progressing their development of the Beverley Project through private consultation with the South Australian government with no public scrutiny, despite the significant environmental problems associated with uranium mining and especially the in situ leaching technique.

Before final mining licences and uranium export permits can be issued, Heathgate must come to Agreement with all registered Native Title claimants of the region (discussed in more detail below).

A proposal to undertake further exploratory drilling was submitted to MESA in late October 1996 (the Stage One Declaration of Environmental Factors) (Heathgate, 1996). The work was intended to "improve knowledge of ore distribution and geochemistry" (Heathgate, 1997a). This work commenced in early 1997 with a total of ten boreholes being drilled across the three main ore zones. The boreholes were completed as observation wells for ongoing groundwater monitoring.

The approval for Stage Two was sought in a Declaration of Environmental Factors document submitted to MESA on March 7, 1997 (Heathgate, 1997c). This approval was forthcoming from MESA in early May 1997. A further drilling program was thus begun to install two "5-spot" borehole patterns for hydrogeological testing and later Field Trials of In Situ Leaching (ISL) (Heathgate, 1997c). This consisted of one "5-spot" borehole pattern on the Northern ore zone and one "5-spot" pattern on the Central ore zone. There was a need for a detention pond for this pump testing due to the high volumes of water involved. The original design presented in Heathgate Resources (1997b) (Heathgate, 1997c) was for an unlined construction, which would allow excessive seepage from the pond of moderately saline and radioactive groundwater. After MESA approval on June 30, 1997 (MESA, 1997), the design was upgraded to incorporate a liner and leak detection system, which could later be used in the Field Leach Trial (FLT) (Heathgate, 1997a).

The approvals relating to these developments were refused to be released to the public by MESA, despite continuing community concern on uranium mining. The ACF asked on May 8, 1997, (ACF, 1997a) :

> “What measures are being taken to protect the environment, to prevent contamination of the Great Artesian Basin, to protect the public and to protect workers ? The uranium industry is inherently dangerous yet Government are acting as though it is only interested in protecting General Atomics from public scrutiny by trying to keep their operations secret. There must be a full disclosure and public scrutiny of General Atomics' operations at Beverley.”

Heathgate responded by saying that “philosophical opposition to uranium mining (has) blurred the AFC’s vision”, with “the uranium mining industry (being) the most regulated industry in Australia” (Heathgate, 1997d). Heathgate stated that if the ACF was seeking information, “all it has to do is call Heathgate” (Heathgate, 1997d). However, this was not quite the case. The ACF wrote to Heathgate requesting such information (ACF, 1997b), yet no such hospitality was forthcoming.

Following the completion of pump testing, Heathgate have now begun Stage Three of development of the Beverley deposit by undertaking a Field Leaching Trial (FLT) - a small scale mining operation using in situ leaching (ISL) to recover uranium from the ore by injecting corrosive chemicals into the groundwater and then pumping them back to the surface with the dissolved uranium.

The effective decision to proceed with this type of mining was first made in May 1997, with the MESA claiming “little environmental damage” is expected from the ISL mining proposal (Bromby, 1997). This is despite the fact that for environmental reasons, and based upon overseas experience with the (ISL) technique, in situ leaching has never been used for commercial production before in Australia (Cowell, 1997). The “obvious conflict of interest” that MESA face in both promoting mining and regulating it's environmental performance was very quickly pointed out by the Conservation Council of South Australia - “The department is not an authority on environmental matters” (Matthews, 1997).

The Federal Environment Minister, Senator Robert Hill, quickly tried to deny that the FLT was actually mining and that only an evaluation trial was taking place : “I do not think we would describe it as ***trial mining***.” (emphasis added) (Hansard, 1997). Perhaps another important point to note is that various Commonwealth departments have made no environmental assessments of uranium in situ leaching mining proposals since 1982 or 1983 (DEST, 1997), and thus their expertise in regulating this form of mining is quite limited[3].

The extraction of the uranium from the Beverley orebody by ISL is unequivocally mining - uranium is being extracted (CCSA, 1997).

Another significant issue is the use of United States privacy laws to restrict public disclosure of information by Heathgate Resources. Initially in June 1997, the federal government could not guarantee that it would prevent Heathgate from using such laws (Hansard, 1997). By September 1997 Heathgate had confirmed “...that they will comply with all Australian laws in relation to the operation of the proposed Beverley uranium project, and will not use any restrictions in public disclosure that might apply in the USA” (DEST, 1997).

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[3] - A parliamentary research paper was recently completed by Kay (1998), and represents the first detailed research undertaken by the federal government on ISL-type mining. It maintains a broad perspective.

From July to August 1997, public attention was now starting to increase concerning Heathgate's secret development of the Beverley deposit. Several people and organisations were now starting to highlight the uranium mine by writing to the media, politicians and Heathgate requesting information and challenging various assertions made with regards to potential environmental problems at Beverley (Student's Ass., 1997; FoEA, 1997; CCSA, 1997). The main points addressed in were :

- the level of secrecy which was occurring;
- the threat of contamination of the Great Artesian Basin and surrounding groundwater systems;
- lack of public consultation;
- the developing of field leaching trials without a proper, transparent environmental impact assessment process;
- consultation with the broad Adnyamathanha community.

Heathgate responded by September stating that (Heathgate, 1997e, 1997f & 1997g) :

- there was no potential for contamination of the Great Artesian Basin;
- the public will have opportunities to comment through their EIS;
- there was no secrecy surrounding the project;
- the community has a right to a say in the management of State and National resources, but this needs to be based on the community being "properly informed" and not being alarmed with misinformation (naming the Conservation Council of South Australia, Friends of the Earth and others, inferring that the general public were being alarmed - "either deliberately or accidentally" - without determining the "veracity of claims");
- they have "...a commitment to keeping the community informed" (Heathgate, 1997f);
- the majority of South Australians supported the mining and export of uranium under stringent safeguards.

It is worth pointing out that :

- the two Declaration of Environmental Factors documents supporting Heathgate's initial exploratory drilling and two "5-spot" bore installations remain unpublished and thus unavailable to the wider public, and field trials are operating outside of public debate;
- there is potential for contamination of the Great Artesian Basin and especially the surrounding groundwater resources of the Lake Frome region, and many of these issues remain scientifically unresolved;
- the majority of Australians have not supported the mining and export of uranium for some decades.

Thus it would be easy to infer the "veracity" of Heathgate's claims.

The Beverley Project is now undertaking a Field Leach Trial, discussed in detail below.

The Adnyamathanha Aboriginal community, traditional owners and Native Title claimants of the region, are also deeply concerned about the pace of development of the Beverley site and consultation processes Heathgate are currently undertaking with respect to Agreements for proposed mining.

The Field Leach Trial (FLT) of In Situ Leaching

The Declaration of Environmental Factors (DEF) document for the proposed Field Leach Trial (FLT) was submitted by Heathgate to MESA on September 5, 1997 (Heathgate, 1997a). A Supplementary DEF, concerning the results of recent pump testing near two old exploration boreholes, was submitted on September 25, 1997 (Heathgate, 1997h). These documents formed the basis for Heathgate's assessment - not that of an independent consultant as one would expect from the spirit of the Environment Protection (Impact of Proposals) Act 1978 - of the potential environmental impacts of the FLT.

Formal approval for the Field Leaching Trial at Beverley was given by Rob Kerin, South Australian Minister for Primary Industries and Natural Resources, on November 3 (Kerin, 1997). The documents were not made available to the public until December 19, 1997.

The actual ISL trials finally began on January 2, 1998 (AFR, 1998).

A detailed critique of the DEF and Supplement was undertaken by Mudd (1998a). Many deficiencies were highlighted, summarised below :

- there is a decisive lack of detailed qualitative and quantitative information on regional groundwater movement;
- there is a lack of clarity concerning data requirements;
- it did not conclusively prove the Beverley orebody aquifer was completely isolated from surrounding groundwater systems;
- references are made to old exploration boreholes that leaked and went unnoticed, and still fails to adequately address current management of these old boreholes and preventing the escape of the highly toxic leaching solutions via these boreholes;
- there is a lack of geochemical data to justify assumptions on groundwater chemistry;
- it exaggerates current groundwater quality of the Beverley orebody (Namba) aquifer;
- the groundwater monitoring regime is poorly designed;
- the excess solutions from pump testing are to be re-injected back into the orebody aquifer with no plans for rehabilitation;

- it underestimates the potential problems of flash flooding inundating parts of the Beverley site;
- it underestimates the risks of high background radiation levels given the identified atmospheric inversions that are known to occur;
- poor environmental design of the Field Leaching Trial;
- the FLT contains extremely high concentrations of dissolved uranium;
- excess waste water solutions are to be re-injected into the Beverley aquifer;
- it ignores the possibility that the re-injected solutions could mobilise higher concentrations of radionuclides and heavy metals orders of magnitude above background levels;
- there are no plans for rehabilitation of groundwater after trials, even if full scale mining were not to proceed;
- solid wastes were planned to be disposed of at the old Radium Hill underground workings;
- the original design for the detention pond was unlined;
- numerous assumptions are made without the scientific data presented to justify such assumptions.

Heathgate were invited to respond to these points in February 1998, but by June had failed to reply.

The trial mining of uranium at Beverley by In Situ Leaching (ISL) techniques is thus proceeding without many of the fundamental questions about environmental and operational safety being addressed in technical detail, without responsible solid and liquid waste management programs and under a veil of secrecy.

Concerns of the Adnyamathanha Aboriginal Community

The broad Adnyamathanha community have been expressing concern over uranium mining developments in the Northern Flinders Ranges for nearly 50 years (FRAHCC, 1997). “Traditional Adnyamathanha cultural history details a very important warning about the Beverley area and in fact wherever other deposits have been 'discovered' by mining exploration. These areas are described in oral history as “tabu zones” and “poisonous ground” and the gases and water sources in these areas likewise” (FRAHCC, 1997).

> “Our predecessors before us opposed the mining of uranium back in the 1950's and again in the 1980's, based on these oral history accounts. Our oral history provides us with knowledge about the formation of the Flinders Ranges, and provides warnings about areas such as Mt Painter. Our history dates back well before the arrival of Europeans to this land, and remains a very real and very credible part of our fundamental beliefs.”

Heathgate are required negotiate with Native Title Claimants. Until late 1997, this meant two claims - a small group of members from the Adnyamathanha community and one from the Kuyani community. Heathgate has signed Agreements with these two Native Title Claimants, agreements which involve the transfer of money. Neither claimants share the support of the broader Adnyamathanha community (FRAHCC, 1997). In fact, the Flinders Ranges Aboriginal Heritage Consultative Committee (the statutory body designated to look after Aboriginal Heritage issues for the region) stated that they feel it was their

> “responsibility to stand strong on this issue and denounce the authority of these people who falsely claim their spiritual connection with the land, and respect for the wisdom for their elders. Instead we will continue (as our elders did) to resist the pressure of mining companies wishing to unearth uranium at Beverley and elsewhere in our area.”

There is a clear message of opposition from the Adnyamathanha people to the proposed Beverley project. There are now a total of four Native Title Claimants, with the second two claims lodged on behalf of the broad Adnyamathanha community. Heathgate has signed an Agreement with one of these claimants, but not the fourth.

The Adnyamathanha have been put under enormous pressure by Heathgate, who argue that the community is going to miss any legal right to compensation if they do not have a formal Agreement with the company. Heathgate argued that if the ALP were to get back in power with the looming federal election the mine would presumably be vetoed by the current ALP “No New Mines” Policy (Smith, 1998), or if the Liberals were to get back in then all Native Title rights would be removed by the Coalition's Wik Amendment Bill and the company not forced to negotiate with the Adnyamathanha. Either way, it was in the community's best interest to have a signed agreement with Heathgate to ensure they were in the best position possible, regardless.

There were weekend meetings nearly every week for almost three months ranging from Port Augusta to the Beverley site to Hawker. In March the Adnyamathanha decided to avoid already intense fracturing within the broad community and open negotiations with Heathgate. As yet, due to the complexity of competing Native Title claims, community disquiet and lack of government funding for lawyers, no progress has been made on negotiations with all claimants.

Without broad Agreements in place with the all Native Title Claimants from the Adnyamathanha community, Beverley will not be able to proceed to a full scale mining project.

Present Plans and Activities

With the commencement of the “trials” on January 2, 1998, the year has apparently begun well for Heathgate. In mid February, they announced that the size of the Beverley orebody was actually twice that previously calculated. The new size was 21,000 tonnes of U_3O_8 mineable by In Situ Leaching (Graham, 1998).

Public knowledge of the operation of the FLT has been very carefully controlled, although Heathgate have made repeated claims at meetings with the Adnyamathanha about it's better than expected success but with no public release of the supporting technical data. The FLT was apparently stopped in late April or early May, although this cannot be confirmed.

The Environmental Impact Statement was finally released on June 29, 1998, nearly four months after Heathgate announced their intention to release it. It is uncertain why the delay was so long, especially given Heathgate’s publicised concern at the possible re-election of the Labour Party in the upcoming federal election.

Environmental Issues

Clearly, the current proposal for development of the Beverley uranium deposit with In Situ Leach mining techniques entails many significant risks that are not adequately being addressed. Based on the extensive review of international and industry literature presented within this report, the following potential problems can be expected at the Beverley site :

- excursions through old exploration boreholes (about 1,000 were drilled) (Mudd, 1998a);
- potential for mineral buildup and pipe and aquifer blockages, leading to significant potentials for excursions and other problems;
- problems with flash floods;
- problems with toxic heavy metals, widely known to be significant with acid ISL overseas;
- the Great Artesian Basin (GAB) could be contaminated if the pressure is lowered enough at the Camp Bore (used for process and potable water at the site) to reverse the flow of groundwater across the Poontana Fault;
- drawdown within the GAB could lead to regional drop in artesian levels for other users of GAB water in the region;
- there are no plans for restoration of groundwater after ISL mining - in complete contradiction to requirements in the USA. Given the recalcitrant problems identified internationally where solutions have migrated, it would be in Heathgate’s best interests to at least restore the site to background levels;
- there is no guarantee that leaching solutions will remain isolated within the Namba formation, especially since the extent of the palaeochannel is not known 500 m both to the north and south of the ore deposit (Fig. 29);
- radiation problems are not treated with scientific rigour.

6.5 The Manyingee Deposit - History & Future ?

Discovered in 1974 in the north-western corner of Western Australia, the Manyingee uranium deposit is located 75 km south of Onslow in an old dry bed of the Ashburton river. The uranium occurs up to 100 metres below the surface and is contained within sandstones and siltstones over two main orebodies totalling 7,860 tonnes of U_3O_8 at an average grade of 0.12 % (Armstrong, 1998). The first major orebody is over 1.5 km in length, 1 km wide and over 40 metres thick. The second orebody is only 500 m by 300 m but over 50 m thick (SEA-US, 1998).

The site is the traditional Dreaming of the Talandji people of the Ashburton river, some of whom live in Onslow (Moody 1992).

The background quality of groundwater, orebody chemistry and other important environmental information remains elusive, since there has been no public release of documents on Manyingee. It is thought there are no users of groundwater in the vicinity,

The deposit was originally developed as a Joint Venture between Total Mining Australia (82%), Triako Resources (10%) and Urangesellschaft (UG of Germany; 8%) (Moody, 1992). Initially, plans were well advanced to develop a trial ISL mine at the site, and a formal application was submitted to the West Australian EPA in December 1983. However, the application had to be resubmitted to the EPA and approval was only given in March 1984 after a number of questions were resolved (EPA (WA), 1984). All of these documents remain highly confidential, with no public access or scrutiny before, during or after the trials were conducted. It was claimed that they were sensitive corporate documents and therefore commercially confidential (Parker, 1986a).

The EPA also stated that the proposal and environmental approvals were only granted for the Trial Pilot Study, and did not establish a precedent for full scale mining, which would still be subject to full WA environmental assessment and a federal EIS (EPA (WA), 1984).

The 1984 Total Group Annual Report stated that “continued activity in this area (uranium) is based on the commercial judgement by many companies that such an illogical policy cannot last” (Total, 1984), with reference to the Federal ALP government’s Three Named Uranium Mines Policy. This policy lasted for 13 years and was only changed when the Howard Coalition government came to power in 1996.

The ISL trial finally commenced in 1985, after construction of the pilot plant and the necessary approvals and permits were in place. The company claimed it was merely a test or evaluation, since no mining licence had been granted and certainly no uranium export permits were issued for the site (Moody, 1992). Confusion exists as to the amount of uranium that the trial was intended to produce, with original estimates ranging between 1,000 kg to 1,500 kg (1 to 1.5 tonnes) to be produced as an 18% peroxide slurry (EPA (WA), 1983). However, Senator Gareth Evans was later to claim less than 500 kg was actually extracted (Hansard, 1986).

The trial lasted a total 169 days on a 5-spot pattern 30 m in radius, involved total injection into the orebody of 40.5 million litres (Ml) of alkaline leaching solutions (Moody, 1992). The chemistry trialled was sodium bicarbonate as the leaching agent, and hydrogen peroxide and hypochlorite as oxidants (Moody, 1992), although there was one report of acid being trialled (Gascoyne, 1985).

There was no official release of information by the company or the government at the time to confirm the actual quantity of uranium produced or the operational and environmental performance of the ISL trial (Moody, 1992). It is also uncertain where the produced uranium was kept, although Senator Gareth Evans did state in May 1986 that the produced uranium was stored on site under the approvals of the Australian Safeguards Office (ASO) (Hansard, 1986). Allegations were made at the time that it had been flown to the Ranger mine in the North Territory (Moody, 1992).

Persistent enquiries to the company and different government departments concerning the location and nature of groundwater monitoring records and other pertinent information were met by a wall of hostility and bland assurances - when asked if the company had commenced Stage Two of its operations, Total replied "that is none of your business" (Moody 1992).

Concerned citizens who visited the mine at this time were able to photograph containers on site, and reported large piles of waste with virtually no protection for the public and wildlife (Moody, 1992). Birds and wildlife were observed to drink from the retention pond and dams (Gascoyne, 1985).

Technical problems with the pilot plant forced Total to abandon development of the site as a mine in December 1985 (Moody, 1992). By May 1986, the company admitted that they were "...not actively developing mining leases at Manyingee..." (Total, 1986). About the same time, rehabilitation works were claimed to be almost complete, although no assessment had been made available to the public (Hansard, 1986).

A total of $16 million was spent on the ISL trial and associated works until the project was abandoned (Armstrong, 1998).

According to investigators at Manyingee in 1986, assay workers for Minatome[4] in 1980/81 had been issued with wire brushes and instructed to erase any Aboriginal paintings in the area (Moody, 1992).

Ownership of the Manyingee deposit shifted to Cogema (Australia) in 1994 when all of Total's worldwide uranium interests were transferred to the French nuclear giant. However, in February 1998, Cogema announced they were placing both the Manyingee and Oobagooma deposits on the market, in order to raise capital to concentrate on the Koongarra uranium deposit in Kakadu National Park, in the Northern Territory (Poissonnet, 1998).

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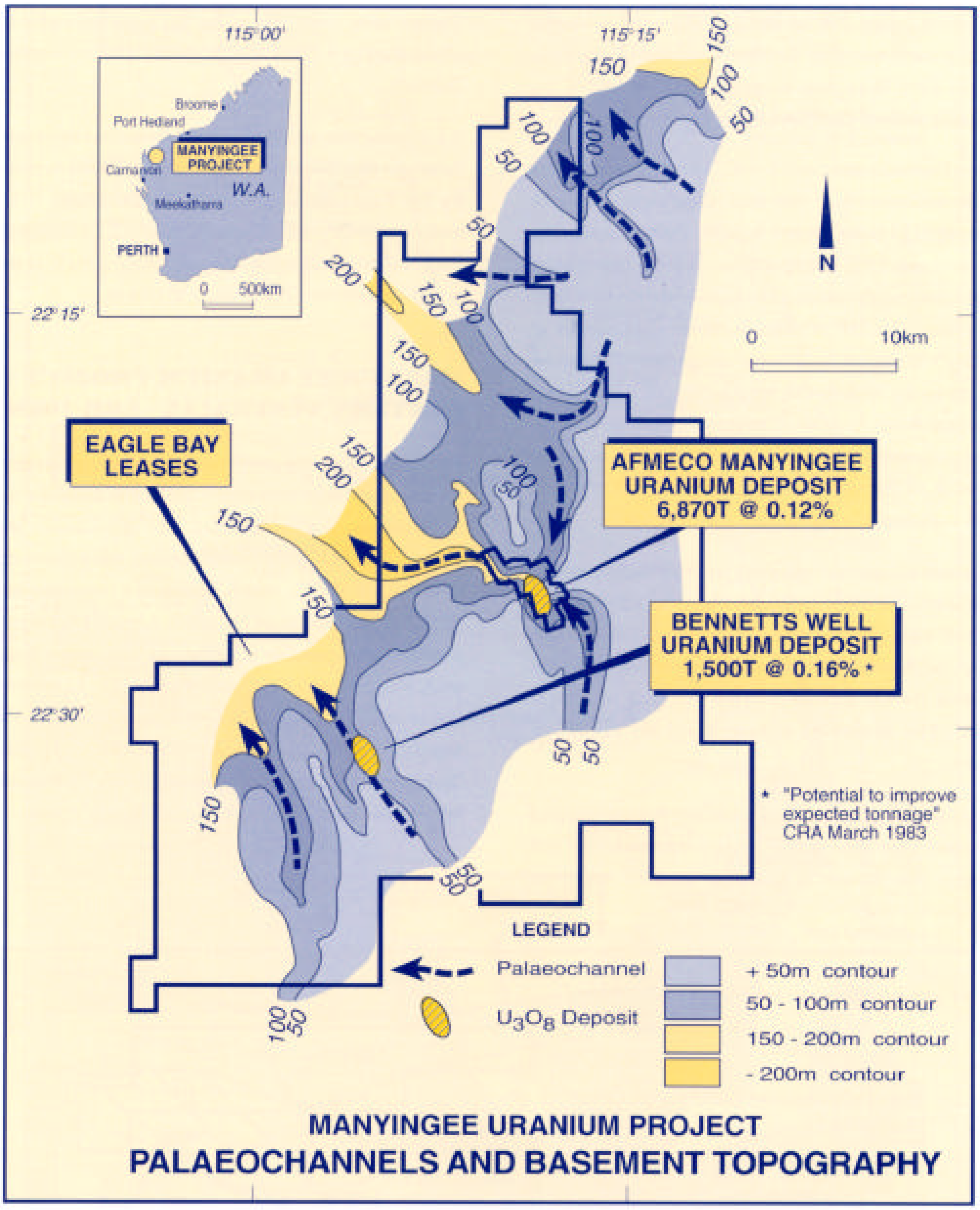
[4] - Minatome was the predecessor company to Total Mining, both French companies.

Both deposits were quickly bought by Perth-based company Paladin Resources in June 1998 (UIC, 1998a), with Manyingee being bought for $3.4 million and Oobagooma for a mere $750,000 (Armstrong, 1998). Paladin announced they hoped to have an operating ISL at Manyingee within two to three years (UIC, 1998a) and believed they could keep production costs below the crucial $10 per pound, given very optimistic predictions of $29 to $34 per pound for uranium by 2001 (Armstrong, 1998).

The area also contains the Bennett's Well uranium deposit, which is estimated to contain 1,500 tonnes of U_3O_8 at a grade of 0.16% (EBR, 1997). The exploratory work conducted by then CRA[5] in the early 1980's led to the conclusion that there was "potential to improve expected tonnage" with further exploration (EBR, 1997).

Figure 32 - Manyingee Uranium Deposit (EBR, 1997)



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[5] - CRA is now known as Rio Tinto.

7 Conclusions : The Future of ISL in Australia

Conclusions and Recommendations

The aim of this research report was to identify the major environmental management issues from the application of the In Situ Leach (ISL) uranium mining technique at sites around the world, and thereby developed the context for current Australian ISL proposals.

The following general conclusions seem reasonable to make :

- the use of alkaline solutions would appear to create lower potential for environmental problems in well managed operations;
- the level of heavy metals with acidic solutions can lead to significant environmental problems with high levels of metals such as zinc, copper, lead, nickel, cadmium, chromium, strontium and others;
- it is in a company's best interests to restore groundwater quality following ISL mining, this should not simply be a legal necessity but a good environmental policy requirement of the company as well as governments;
- old bores and drill holes need to be identified and properly sealed before ISL mining begins;
- evaporation of excess waste waters would appear the environmentally preferred method of disposal;
- radiation exposure from uranium dust, radium and radon daughters are potentially significant, especially in alkaline ISL mines;
- the two most active current Australian proposals at Beverley and Honeymoon in SA have established or continued trial ISL mines without the release of a modern EIS, and significant potential operational and environmental problems remain unresolved;
- significant concern over dealings with Aboriginal interests in the area remain.

Clearly, the technique of In Situ Leach mining of uranium (or any other metal) presents significant environmental problems. The experience overseas in the United States, and especially in Eastern Europe, has seen quite severe contamination at some sites, with some locals nearby ISL mines experiencing contamination of their private water supply wells with residual leaching solutions.

The environmental impacts are generally underground and therefore, on the surface, it would appear that such negative impacts are minimal. However, the quality of groundwater and the mined aquifer are permanently altered as a result of ISL mining. The natural processes which effectively minimised the migration of uranium and it’s associated radionuclides have been removed at many former ISL sites, such as the Nine Mile Lake sulphuric acid trial ISL site in Wyoming, USA, where there remains geochemical conditions for continued mobilisation of uranium and heavy metals at levels that are above the pre-mining concentrations.

The industry will continue to claim that the ISL technique is “environmentally benign”, but the reality of the depressed world uranium simply dictates that future uranium production will come from ISL merely due to it’s lower overall production costs, not because it is an environmentally preferred mining technique.

The current proposals certainly mirror the standards of projects that have seen considerable environmental problems in Eastern Europe - the use of sulphuric acid, the lack of groundwater restoration, and the lack of care concerning the potential for exploration bores to induce excursions. Certainly, the current proposals for Beverley and Honeymoon would need to undertake a substantial degree of work and investigation to meet regulatory requirements in the United States, and perhaps this is why foreign nuclear and mining companies are intending to try and establish an operation in Australia - there are less regulatory and economic impediments to unscrupulous mining operations.

The future of ISL in Australia will not only have to overcome the intense political issue of uranium and the broader nuclear debate, but also negative publicity and known problems at the early Honeymoon and Manyingee trials.

It is recommended that :

- all information and reports on the early and current trials at Honeymoon, Manyingee and Beverley be publicly released prior to pending EIS’s;
- all proposals make use of alkaline leaching chemistry to reduce the likely pollution load from leaching solutions; and
- all ISL proposals and trials be required to restore groundwater to it’s quality prior to mining, for all radionuclides and environmentally sensitive heavy metals.

Given the volatile nature of the uranium debate in Australia at the present time, especially the large international campaign directed at the Jabiluka proposal in Kakadu National Park in the Northern Territory, and the possible re-election of the Labour Party to federal government in late 1998, the future of In Situ Leach mining of uranium in Australia would appear uncertain.

8 Acronyms

ACF	Australian Conservation Foundation
AFR	Australian Financial Review
AIME	American Institute of Mining Engineering (USA)
AMDEL	Australian Mineral Development Laboratories
ANZECC	Australian and New Zealand Environment and Conservation Council
ASO	Australian Safeguards Office
AUNL	Acclaim Uranium NL (WA)
AWRC	Australian Water Resources Council
AWWA	Australian Water and Wastewater Association
CANE	Campaign Against Nuclear Energy (SA)
CCMV	Converse County Mining Venture (USA)
CCSA	Conservation Council of South Australia
CEC	Cation Exchange Capacity
CPM	Counts Per Minute (radiation)
CRA	Conzinc Riotinto Australia (now Rio Tinto)
DEF	Declaration of Environmental Factors
DEIS	Draft Environmental Impact Statement
DEQ	Department of Environmental Quality (Wyoming, USA)
DEST	Department of Environment, Sports and Territories
DoE	Department of Energy (USA)
EA	Environmental Assessment (USNRC)
EA	Environment Australia (Federal)
EBR	Eagle Bay Resources NL
EIA	Environmental Impact Assessment
EIA	Energy Information Administration (USDoE)
EIS	Environmental Impact Statement
ENDAUM	Eastern Navajo-Diné Against Uranium Mining (USA)
EPA	Environment Protection Authority
EPA	Environmental Protection Agency (USA)
ER	Environmental Report
ERDC	Environment, Resources and Development Committee (SA)
FEIS	Final (Supplement to the) Environmental Impact Statement
FoE	Friends of the Earth
FoEA	Friends of the Earth Australia
FRAHCC	Flinders Ranges Aboriginal Heritage Consultative Committee (SA)
GA	General Atomics (USA)
GAB	Great Artesian Basin
HDPE	High Density Polyethylene
HRI	Hydro Resources Inc. (subsidiary of URI) (USA)
IAEA	International Atomic Energy Agency
ISL	In Situ Leaching
JV	Joint Venture
LPM	Litres per minute
LQD	Land Quality Division (DEQ, Wyoming, USA)
MESA	Mines & Energy South Australia (now part of PIRSA)
MIM	Mt Isa Mines Ltd. (Qld)

MINAD	Mines Administration Pty Ltd (Honeymoon, SA)
NEPA	National Environmental Policy Act (USA)
NH&MRC	National Health and Medical Research Council
NML	Nine Mile Lake (USA)
NR&R	Noncoal Rules & Regulations (DEQ, Wyoming, USA)
QLD	Queensland
RME	Rocky Mountain Energy Co. (USA)
OTP	Oilmin - Transoil - Petromin group of companies (Qld)
PBJV	Paladin-Brightstar Joint Venture
PIRSA	Primary Industry and Resources South Australia
RO	Reverse Osmosis
RPCF	Radiation and Perpetual Care Fund (Texas, USA)
SA	South Australia
SAUC	South Australian Uranium Corporation Pty Ltd
SCR	Southern Cross Resources Pty Ltd (Can.)
SCRA	Southern Cross Resources Australia Pty Ltd (Aust. subsidiary)
SEA-US	Sustainable Energy & Anti-Uranium Service Inc.
SER	Safety and Evaluation Report (USNRC)
SRIC	Southwest Research and Information Center (New Mexico, USA)
SSCUMM	Senate Select Committee on Uranium Mining and Milling
TBRC	Texas Bureau of Radiation Control (USA)
TEA	Texas Energy Alliance (USA)
TWC	Texas Water Commission (USA)
UCL	Upper Control Limit
UIC	Uranium Information Centre
UMTRCA	Uranium Mill Tailings Radiation Control Act (USA)
URI	Uranium Resources Inc. (USA)
USBM	United States Bureau of Mines
USDoE	United States Department of Energy
USEPA	United States Environment Protection Agency
USX	U.S. Steel Corporation (USA)
WA	Western Australia
WEQA	Wyoming Environmental Quality Act (USA)
WISE	World Information Service on Energy (Netherlands)

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10 Glossary

Aquifer The place where one can find useful quantities of groundwater. Typically refers to a particular type of porous rock or soil, such as sandstone.

Barren Solution A solution in hydrometallurgical treatment from which all possible valuable constituents have been removed.

Bleed Solution Solution drawn to adjust production or to restore groundwater by pumping more fluids from the production zone than are injected, creating an inflow of fresh groundwater into the production area.

Brine Solution A concentrated solution containing dissolved minerals (usually greater than 100,000 mg/litre), especially chloride salts.

Elution Activities of removing "elutes" a material (uranium) adsorbed on ion exchange resin from the "eluant" solution.

Evaporation Pond A containment pond (that should have an impermeable lining of clay or synthetic material such as hypalon or high density polyethylene plastic, HDPE) to hold liquid wastes and to concentrate the waste through evaporation.

Extraction Well (Production) A well or a drill hole in an in situ leach operation through which the solutions (or groundwater) are extracted to the surface treatment plant. Typically surrounded by injection wells.

Groundwater Water beneath the surface in the saturated zone that is under atmospheric or artesian pressure.

Heavy Metals Metallic elements, including those required for plant and animal nutrition, in trace concentration but which become toxic at higher concentrations. Examples are mercury (Hg), selenium (Se), molybdenum (Mo), cadmium (Cd), and lead (Pb).

In Situ Leaching The in-place mining of a mineral without removing overburden or ore, by installing a well and mining directly from the natural deposit thereby exposed to the injection and recovery of a fluid that causes the leaching, dissolution, or extraction of the mineral.

Ion Exchange Reversible exchange of ions adsorbed on a mineral or synthetic polymer surface with ions in solution in contact with the surface. A chemical process used for recovery of uranium from solution by the interchange of ions between a solution and a solid, commonly a resin.

Injection Well A well or a drill hole in an in situ leach operation through which barren solutions are entered into an underground stratum or ore body by gravity or under pressure. Typically surrounded by monitoring wells.

Leachate The liquid that has percolated through the soil or other medium.

Lixiviant Leachate solution pumped underground to a uranium ore body; it may be alkaline or acidic in character.

Pachuca Tank A cylindrical tank with a conical bottom used in slime leaching.

Palaeochannel An old river bed formed at a time when the geology and climate of an area was different, with generally higher rainfall. Subsequent changes have seen the river bed, which would be mostly sand, gravels and clay lenses, buried by a further cover of sediment. The sands and clays (in minor amounts) are interlayered and are notorious for being highly variable and difficult to characterise.

Permeability The ease with which fluid flows through a porous medium.

Porous (Pore Space) The open spaces or voids within a soil or rock. It is a measure of the amount of liquid or gas that may be absorbed or yielded by a particular formation.

Pore Volume Volume equal to the open space in rock or soil.

Pregnant Solution A solution containing dissolved extractable mineral that was leached from the ore; uranium leach solution pumped up from the under-ground ore zone though a production hole.

Radon Chemically inert radioactive gaseous element formed from the decay of radium. A potential health hazard.

Reverse Osmosis The act of reversing a diffusion through a semipermeable membrane, typically separating a solvent and a solution, that tends to equalize their concentrations.

Restoration The returning of all affected groundwater to its premining quality for its premining use by employing the best available technology.

Roll Front A type of uranium deposition localized as a roll or interface separating an oxidized interior from a reduced exterior. The reduced side of this interface is significantly enriched in uranium.

Saturated Zone The zone of a soil or rock formation where the pore space is completely filled with water. This would be called an aquifer at depth or the water table if immediately below the surface sediments.

Solution Mining Another term used for In Situ Leaching.

Wellfield The area of an in situ leach operation that encompasses the array of injection and extraction wells and interconnected piping employed in the leaching process.

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Disclaimer

The views expressed in this report represent those of the primary author. In no way are they meant to convey the views of any other organisation, institution or company that may have contributed to the completion of this report.

Every attempt has been made to quote technical sources correctly and completely, but no liability can be assumed for actions arising out of the use of this report.

Appendix One - Chemical Symbols & Elements

Al	Aluminium	
Am	Americium	
Ag	Silver	
As	Arsenic	
Ba	Barium	
C	Carbon	- common forms include carbonate and bicarbonate (CO_3/HCO_3)
B	Boron	
Ca	Calcium	
C	Carbon	
Co	Cobalt	
Cu	Copper	
Cm	Curium	
H	Hydrogen	
Fe	Iron	
La	Lanthanum	
Pb	Lead	
Mg	Magnesium	
Mn	Manganese	
Hg	Mercury	
Mo	Molybdenum	
N	Nitrogen	
O	Oxygen	
P	Phosphorous	
K	Potassium	
Ra	Radium	
Rn	Radon	
Re	Rhenium	
Sc	Scandium	
Se	Selenium	
Si	Silicon	- most common form is silica (SiO_2)
Sr	Strontium	
S	Sulphur	- common forms include sulphate (SO_4) and sulphide (eg FeS_2)
Th	Thorium	
U	Uranium	
V	Vanadium	
W	Tungsten	
Y	Yttrium	
Zr	Zircon	
Zn	Zinc	

About the Author

Gavin Mudd has a B. Env. Eng. (Hons) *RMIT*, and is currently close to completing his PhD in Environmental Hydrogeology and Geomechanics at Victoria University of Technology (Footscray, VIC). Some major achievements are listed below.

Awards

1990 Dux, Year 12, Loyola College (Anderson Score - 374)

1991 - 1994 Best First, Second, Third and Fourth Year Student, RMIT Environmental Engineering

1994 Research Report for Env. Protection Authority on Environmental Management in Retail Petrol Facilities (fourth year Env. Eng. Investigation Project).

1994 Institution of Engineers Australia, Best Environmental Engineering Student

1995 Won an Aust. Postgraduate Award (Industry) PhD Scholarship at Victoria University of Technology (now nearing completion)

Work Experience

- 9 months consulting experience - including contaminated site field work and environmental assessment, preparation of client reports, advanced groundwater modelling, contaminated site assessment.
- PhD Research (March 1995 to present) - includes detailed analysis of groundwater geochemistry and patterns, solute transport modelling of reactive geochemistry, detailed field studies of coal ash leachability, computer modelling of leaching, unsaturated flow and evaporation processes, consulting reports on ash disposal sites.
- Semester One, 1998 - Lecturer in Earth Sciences/Geomechanics, VUT.

Papers to Date

Mudd, G M, J Kodikara & T McKinley, 1996, *Assessing the Environmental Impact of Coal Ash Disposal*, Paper presented at the Australian Institute of Energy 7TH Australian Coal Science Conference, Churchill, VIC, December 1996, 10 pages.

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More conference and journal papers currently under preparation.