Environmental Management and Optimization of In-situ-Leaching at Beverley

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Abstract. Heathgate Resources Pty. Ltd. operates the Beverley Uranium Mine in South Australia (SA) by utilizing a moderately acidic In-situ leaching (ISL) technology, which is best in terms of minimizing surface disturbance. The paper describes the optimization of ISL operation with regard to both leaching efficiency and minimization of environmental impacts in the framework of relevant approvals and regulations.

Introduction: Beverley ISL Mine

Heathgate Resources (Heathgate 2005) operates the Beverley Uranium Mine located on the arid plane between the Flinders Rangers and Lake Frome (Fig. 1), approximately 550 km North of Adelaide in South Australia (SA). After purchasing the mineral lease in 1990, Heathgate developed the mine utilizing a moderately acidic in-situ leach (ISL) technology including oxidant dosage to the mining solution (lixiviant) to increase uranium dissolution in the underground ore body. Initial field leach trials were performed in 1998. After obtaining all required permits, commercial mining commenced in November 2000. The Beverley project is licensed to produce 1,500 t of uranium oxide equivalent (U_3O_8) per annum. The 2004 production was 1,100 t U_3O_8.

Approvals and Regulation

The mine has been subjected to the scrutiny of a vigorous regulatory approval process and many subsequent inquiries; all have shown the Beverley mine to have no adverse impacts on the environment and by most considered to be world's best practice.

The major approvals required prior to commencing a commercial uranium mine in SA include:

a) Environmental Impact Statement - Commonwealth, SA (Heathgate 1998)
b) Mining Lease (Primary Industry and Resources SA - PIRSA)
c) Mining and milling license (SA EPA)
d) Uranium export permit (Commonwealth)
e) Permit to posses nuclear material (Commonwealth, Nuclear Non-proliferation Act)
f) License to store and handle dangerous goods (SA Workplace Services)

Heathgate reports to federal and state regulators quarterly and holds 6-months meetings with regulators. The Annual Environment Report to PIRSA is accessible on the website (Heathgate 2005).

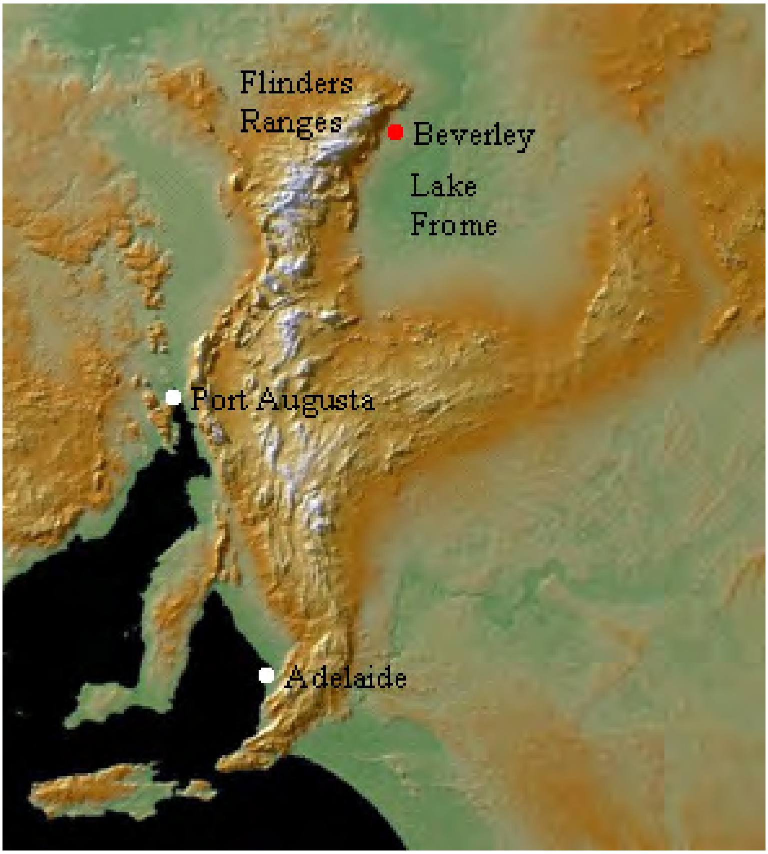

Fig. 1. Geographic map of part of South Australia showing the location of Beverley between Flinders Ranges (West) and Lake Frome (East).

ISL technology and environment

Of all the mining processes, ISL is the best technique in terms of minimizing surface disturbance and of all the ISL projects in the world, the Beverley Uranium Mine is the most technologically advanced. The ISL process requires minimal surface infrastructure in the form of a processing plant, more like a water treatment plant and has small wellfield areas that involve only the installation of water wells, some pipes and other utilities and a few small pumping huts called wellhouses. These wellfields are a rolling development that move along the (mineralized) paleochannels and can be progressively rehabilitated as completed. This ability to rehabilitate prior to the completion of mining at the area associated with a processing plant significantly reduces the observed surface impact for each mine.

An independent review of environmental impacts of acid ISL uranium mining has been published by CSIRO Land and Water (Taylor et al., 2004) for EPA SA, concluding that Beverley "has initiated and implemented world best practice methods" and that ISL mining of uranium is "more cost effective and environmentally responsible than any suggested alternative techniques".

Due to the Beverley deposit's location in the Frome Basin many of the wellfields are surrounded by environmentally sensitive areas and areas of cultural significance to the local Aboriginal people. With this in mind the Beverley wellfields have been designed in a way which minimizes the surface disturbance and minimizes the risk of other environmental impacts (Fig. 2). The installation of a state of the art digital control system has allowed total control of all wellfield operations from a central control room.

Continuous monitoring includes monitoring wells around the active ISL mining area, vegetation, fauna, soil and surface hydrology, meteorology, waste management, and environmental radiation.

Fig. 2. Wellfield within an environmentally sensitive area (creek), where environmental impacts (surface disturbance) were minimized to preserve vegetation.

Beverley hydrogeology and mineralogy

The Beverley deposit is located in Tertiary Age paleochannel sediments of the Eyre Basin in the Lake Frome region. The ore-bearing paleochannel sands (Beverley aquifer) are completely confined by clays above (Beverley clay) and below (Alpha Mudstone). The impermeable Poontana Fault Zone is an effective boundary of the Beverley aquifer to the West of the mineralized area. The Beverley sands grade into silts at the northern, southern and eastern boundaries. The undisturbed groundwater in the Beverley aquifer is quasi stagnant. The Great Artesian Basin (GAB) aquifer underlying the Alpha Mudstone has pressurized groundwater (Cadna-owie formation). Any contact of the Beverley aquifer to the GAB sediments is absolutely impossible because of the massive mudstone aquitard in between and due to the GAB pressurization. The Beverley uranium ore bodies are approximately 100-120 m below surface and about 10 m thick. The granite rocks of the Flinders Ranges probably served as the source for the uranium deposits.

The quartzose paleochannel sands of the Namba Formation (host rock) are fine to coarse grained. Uranium mineralization appears as extremely fine grained coffinite $U(SiO_4)_{1-x}(OH)_{4x}$ in voids and coatings of grains (Fig. 4). Kaolinite $Al_2Si_2O_5(OH)_4$ is the dominant clay phase. The underlying Alpha Mudstone consists of Smectite clays (Montmorillonite $(Na,Ca)(Al,Mg)_6(Si_4O_{10})_3(OH)_6 \cdot nH_2O$ mainly). Pyrite and other sulfides are less abundant. The U ore typically contains 0.1 to 0.5 % U_3O_8.

The initial Beverley resources in the North, Central, and South deposits were 3,900 t, 6,200 t, 3,900 t U_3O_8, respectively (14,000 t in total). Exploration activities around Beverley are in progress. Present exploration data are promising to increase the reserves considerably in the near future.

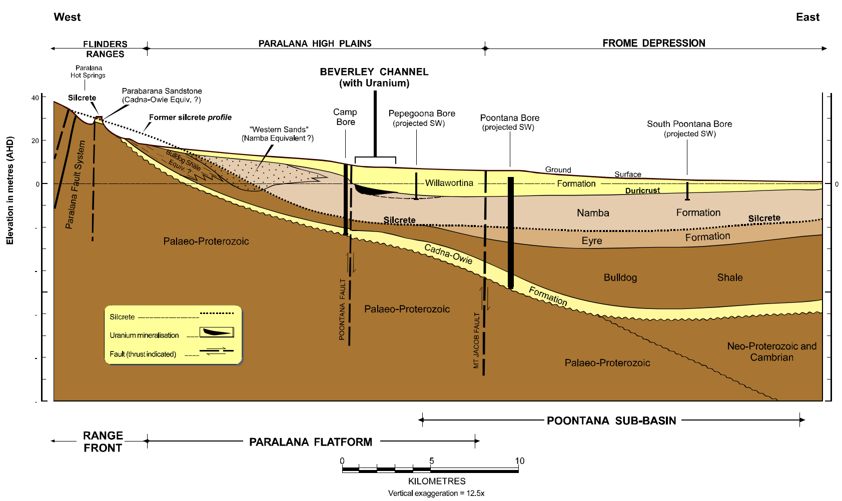

Fig. 3. Stratigraphic profile of the Willawortina-Namba-Cadna-Owie formations

Uranium ISL and processing (overview)

ISL mining and U processing include the following major operational areas (cf. Fig. 5): (i) lixiviant (closed-loop) cycle through several wellfields in parallel, each consisting of about 14 extraction wells and about twice as much of injection wells, (ii) barren lixiviant acidification and oxidant dosage point, (iii) U capture from the pregnant lixiviant by applying an anionic ion exchange (IX) resin in sequences of two columns (head and tail), (iv) in-place elution in a two-stage operation, (v) uranium precipitation with hydrogen peroxide, (vi) thickening and washing (for removal of dissolved impurities), de-watering, drying, packaging.

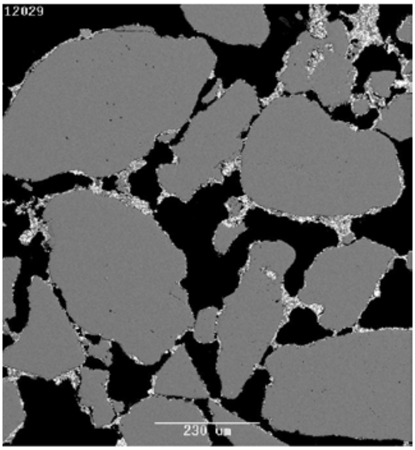

Fig. 4. Backscattered electron micrograph of the mineralized sand: quartz grains (grey) with coffinite+kaolinite minerals against open porosity (black).

Optimizing leaching hydrology

Efficient leaching requires a water exchange rate within the ore body fast enough for optimum contact between the oxidizing lixiviant and the uranium mineral, whereas dissolution rates were found to be remarkably higher. The design of wellfields (pattern and spacing) varies greatly depending on the local conditions such as permeability, sand thickness, grade and distribution. In order to obtain more than 70 % recovery within 1 year or less (economic criterion), a minimum pore volume exchange rate (PVE) of more than 70 is generally required. .The optimum drilling density for production bores can then be balanced against surface limitations, grade distribution and budgetary considerations to give a final design.

The types of patterns (cf. Fig. 6) employed at Beverley so far include (i) 5-Spot pattern (usually 20 to 25 m spacing), (ii) 7-Spot pattern with distances between wells varying between 13.5 and 20 m, (iii) “line drive” generally only used if the ore is confined to skinny channels where no other pattern design is possible, (iv) “wall”, i.e. a sequence of rows each consisting of extractors and injectors (concept for low grade, average thickness zones). Real (optimized) patterns are usually more sophisticated as shown in Fig. 6 (bottom).

The primary wellfield design is based on a standard delineation drilling program. Usually, wellfield design and performance is adjusted (optimized) during operation for maximizing recovery rates.

The sequence of a wellfield operation is roughly as follows:

- Phase 1: leaching according to primary wellfield design
- Phase 2: additional measures to increase recovery (infill wells, role reversals) based on the evaluation of wellfield performance in phase 1
- Phase 3: wellfield flushing (combined with U capture) and restoration

Optimizing leaching geochemistry

Barren lixiviant pH and ORP have been adjusted for optimum leaching of the ore. The pH is kept at moderately acidic conditions (injection pH in the range from 1.6

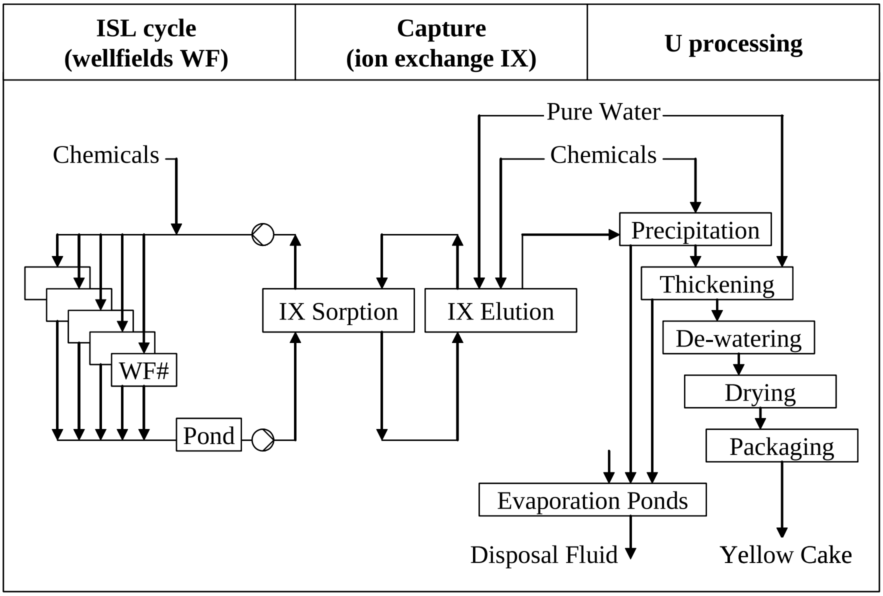

Fig. 5. Schematic of ISL cycle, capture and uranium processing.

to 2.3). It must be controlled such that it is low enough to ensure a stable lixiviant (both in ensuring uranium stays mobile and limiting the precipitation of secondary phases such as gypsum and iron phases) and high enough to limit the dissolution of host minerals (such as silicates). The ORP of the barren lixiviant is adjusted by the dosage of oxidant so that most of the majority of the iron is oxidized to ferric (conditional dosage).

Uranium recovery and processing

The typical average head grade at Beverley is about 180 ppm (2004 average). The uranium species formed in the acidic lixiviant, $UO_2(SO_4)_2^{2-}$ and higher order complexes, are captured via anionic ion exchange (IX) resins. The efficiency of resin loading is heavily dependant on the concentrations of competing anions and total dissolved solids (TDS). The Beverley ore bodies are located in highly saline aquifers with TDS between 6 and 14 g/L naturally with interfering leaching effects, the TDS in the lixiviant is even higher. In particular the presence of chlorides in the lixiviant, up to 5.5 g/L, limits the capture efficiency considerably. However, IX operation has been optimized to enable an economic U production under these chemical constraints. The ion exchange process consists of three “trains” each with five IX columns, capable of treating in excess of 300 L/s. Four of the columns are used for capture usually configured as two lead columns and two tail

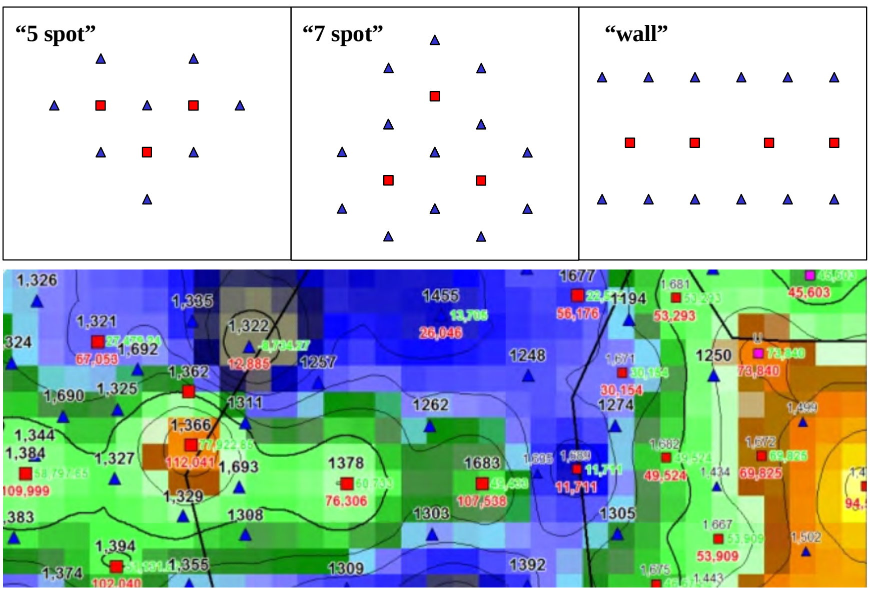

Fig. 6. Wellfield pattern types (top, triangles – injectors, squares – extractors) and cut of a real wellfield pattern with an underlying map showing the spatial distribution of left uranium reserves (tool for leaching performance control).

columns. The fifth column is either being eluted or is idle. The IX columns can be configured in any arrangement of lead, tails, elution or idle which allows for continuous loading and elution of ion exchange resin.

Loaded resin is eluted in-place using a two stage process: (i) main elution by 1.5 bed volumes (BV) of ~1M NaCl eluant followed by (ii) conversion by 1.5 BV of ~0.1M H_2SO_4). This elution regime is a balance between elution efficiency, time and reagent consumption to produce a pregnant solution in excess of 10 g/L U_3O_8. Uranyl peroxide is precipitated by the addition of hydrogen peroxide combined with caustic soda dosage for pH adjustment, followed by thickening, washing, de-watering and finally drying of the precipitate to produce a final pure Yellow Cake product.

Water balance and control

The lack of available water at suitable quality makes water balance one of the major challenges in operating the Beverley Mine. Beverley is located in an arid region, where the temperature from November to March regularly exceeds 40oC, with an average mean maximum temperature of over 30°C in the summer months and 15oC in the winter. The average annual evaporation rate is around 3,000 mm against an average yearly rainfall of only 192 mm. Consequently, there is no access to surface water for the mining operation. The water used for mining operation and uranium processing is drawn from two main sources: the Namba aquifer (outside of the mining zone) and the GAB.

Fig.7. View of the U processing plant showing part of the IX columns for U capture.

Despite the poor quality of water form the Namba aquifer (annual usage around 200 ML) it is still acceptable for (i) make-up of eluant solutions, (ii) plant wash down water, and (iii) first wash of the precipitated product. The use of the better-quality GAB water is highly regulated (limited to 57 ML/y). GAB water is used for (i) final washing of the product, (ii) feed to the potable water RO plants, (ii) dust suppression on roads, (iii) periodic dilution of the lixiviant, and (iv) drilling mud make-up water.

To meet a total neutral water balance as a precondition for avoiding pollutants migration in the underground, the disposal fluid volume is considerably reduced by evaporation in ponds. The mining aquifer at the Beverley Mine was proven to be confined during the EIS (Environmental Impact Statement) process. Control must be maintained of mining fluids within the Beverley mining aquifer to ensure no excursions occur laterally outside of the mining area. Flows in and out of the wellfield are constantly recorded and regularly analyzed to ensure a neutral water balance is maintained. To monitor the effectiveness of the flow control program, monitor wells have been installed surrounding the mining zones.

A rigorous monitoring program demonstrates that the mining and disposal fluids remain under control. To better enable the tracking of fluid movements Heathgate has developed a hydro-geological model of the Beverley sands. This is the latest in advanced technology and provides a diagrammatic map of the current

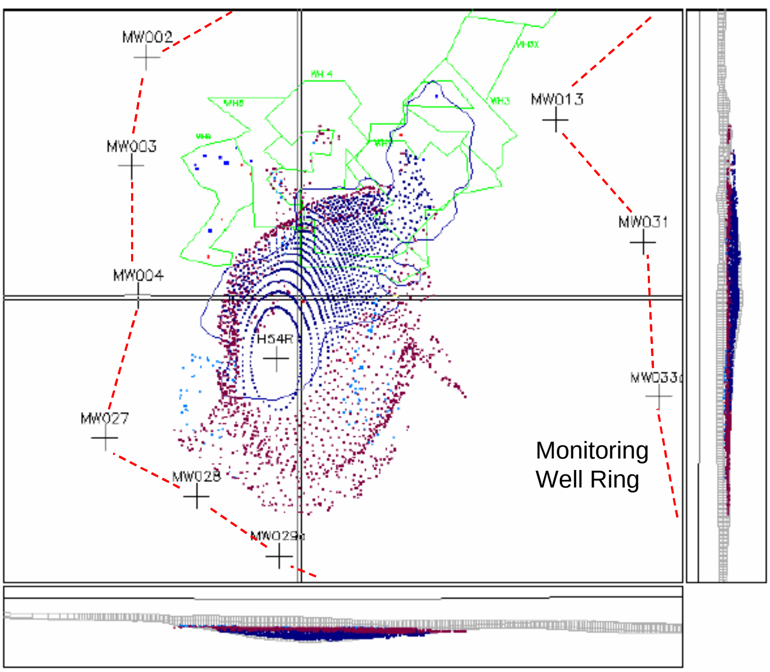

Fig. 8. Disposal flow pattern (hydrological model forecast based on a model calibration by monitoring data) within the monitoring well ring.

flow paths and in addition serves as a prediction tool. This tool assists Heathgate in demonstrating the sustainability of current and future operations at Beverley.

Summary and Outlook

Heathgate Resources Pty. Ltd. continues to operate and develop the Beverley mine to meet both conditions: technological and economic optimization based on world's best practice on the one side and minimization of environmental impacts on the other side.

An extensive exploration program in the area is continued to increase the potential uranium reserves.

Further initiatives for developing and improving ISL operation, uranium processing, overall water management, and rehabilitation include:

- Introduction of a water recycling program to treat disposal fluid by membrane technology to minimize water consumption
- Desalination technology to remove unwanted ions, specifically chloride ions, in the lixiviant and to limit TDS in long term for better leaching and improved capture efficiency
- Implementation of a wellfield restoration program after the abundance of first wellfields, i.e. phase 3 operation by flushing the leached ore bodies in conjunction with uranium capture and conditioning of rest groundwater for enhanced natural attenuation

Acknowledgement

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