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REMEDIATION OF THE SIERRA PINTADA MINE DURING OPERATION

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1. INTRODUCTION

Argentina has two nuclear power plants (NPPs) working with natural and low-enriched uranium, consuming nearly 120 t U/year. In the past, CNEA exploited several uranium ore deposits in Argentina; however, currently, Sierra Pintada mine is the only one that remains open. From 1979 to 1995, the Sierra Pintada plant produced, by heap leaching, 1000 t U in yellow cake form, to supply the fuel to Argentine NPPs.

The uranium mines and yellow cake production plants were shut down during the 1990s due to the lower price in the spot market and an overvaluation of our currency. The changes in both conditions made our country decide to re-start the Sierra Pintada mine operation within the next year. To obtain the approval of the Mendoza Province, we need to remediate the old wastes during the new operation.

2. ENVIRONMENTAL SITUATION

Sierra Pintada mine remediation work that needs to be completed:

Solid waste:

The solid waste includes 13 400 000 m^3 of waste rock, 1 000 000 m^3 of treatment tailings, ~250 000 m^3 of precipitated mud and 240 000 m^3 of low-grade mineral. There are 200 000 m^2 of old dumps with open pit water and neutralized muds

Liquid waste:

There are 800 000 m^3 of open-pit water and neutralized effluents distributed in open pits and old dumps. Our proposal is to remediate the site during new exploitation.

Characteristics of the wastes:

We need to remediate the following wastes:

Neutralized effluents:

pH:7, Hardness (mg CO_3Ca/l): 3000, Sulfate (mg SO4=/l): 3000–4000, Nitrate (mg NO_3^-/l): 1740, Ca (mg Ca/l): 240, Mg (mg Mg/l): 570, Amonium (mg NH4-/l): 468, Na (mg Na+/l): 474, U(mg K+/l): 61, Ra (pCi/g): 5,6

Open pit water

pH.: 8, Carbonate: 5 mq/l, Bicarbonate: 166 mg/l, Sulfate: 344 mg/l, U: 5–30 ppm, Ra; 10 pCi/l. As: 50–160 µg/l. We need to point out that As is variable and abnormally high because of the residence time of the water in the open pit. There are no problems with As when the water is removed as it is produced.

Leaching tailings

Basically, the tailings are acid sands with the following composition: SiO_2 (g/100 g): 57,49, Al_2O_3 (g/100 g): 20,15, Fe_2O_3 (g/100 g): 1,46, U (ppm):100, Ra (pCi/g): 150, Humidity: 10–15%, Size: < 5 mm

Precipitated muds

When the liquid effluents from IX are neutralized, the decant in the dumps precipitated with the following composition: SiO_2 (g/100 g): 4,07, Al_2O_3 (g/100 g): 5,72, Fe_2O_3 (g/100 g): 5,22, CaO (g/100 g): 31,48, U (ppm):184, a (pCi/g): 5,6

3. METHODOLOGY OF TREATMENT

Areas to use

To restore the solid waste and liquid effluents, it is planned to use the same areas previously impacted, trying not to touch clean areas.

Mineral tailings:

The old mineral tailings (1 000 000 m^3) are distributed in different locations within the mine.

The technique used includes diminishing the height and also lowering the angle of the side slope from the current 30° to 11°. After correcting the height and side slope, the surface will be compacted and then a multi-layer cover will be applied. The humidity of the tailings is about 9% (near retention capacity of this material) and after the multi-layer cover is on, this humidity will be maintained. The multi-layer will be arranged as you can see in Fig. 9 and consists of: (1) 0.5 m clay high plasticity, (2) 0.2 m protection gravel, and (3) 0.7 m waste rocks. After exploitation re-starts, the new tailings will be immediately neutralized with clay, and then the same treatment will proceed as it did before.

4. PRECIPITATED MUDS

There are 215 000 m^3 of precipitated muds accumulated in the dumps. There are two types of dumps. The dumps numbered DN-1 to DN-3 (see Fig. 3) have slurries without a bituminous membrane below. It will be necessary to modify the old dumps to achieve remediation. The dumps are in the area of a water divide.

The old slurries will be stabilized by adding low-grade rocks. Then the tailings will be extended over the rocks and isolated with a multi-layer covering (see Fig. 6).

The other type of dumps (4 to 10) were normally processed with a liquid evaporation method; they have a bituminous membrane below. Over these dumps, the new precipitates will be managed. In this case, after stabilizing the muds and leveling the surface, a 0.3 m layer of gravel will be applied, followed by 0.5 m of compressed clay and 0,4 m of gravel, wherein pipes will be placed to detect possible water leaks. A high-density, 1 mm-thick polyethylene membrane will be the last layer. Over the membrane, there will be 0.3 m of sand as support for the pipes that will collect the water from the precipitates; the density of the precipitate will increase. A geotextile membrane will be placed over the pipe within the sand. This last filter layer below the precipitate will allow the water to drain and recycle to the dumps. This draining of the water during operation will make the consolidation of these precipitates much easier, diminishing the cost as it will no longer be necessary to stabilize with rocks as we did previously.

At the final closure, when the old liquids are eliminated, a layer of rocks will be applied, followed by a multi-layer cover like the one shown in Fig. 8. The multi-layer cover will be constructed over 0.3 m of gravel to normalize the surface. The first layer will be a mixture of 35% clay and 65% gravel (0.5 m) compacted to 95% of Proctor density, in order to avoid penetration of rain and escape of radon. The second layer will have 0.2 m of gravel compacted to protect the first layer. The last layer will be 0.7 m of sterile rock to protect against erosion.

Low-grade rocks

These minerals will be managed in order to stabilize the old precipitates and to prepare the surface below the new precipitates for the final closure

Open pit water

This water will be utilized in the leaching process. When, after some years of exploitation, the water flow exceeds the needs of the plant, it will be treated by ion exchange in anionic resin, and $(SO_4)_3Fe_2$, $(OH)_2Ca$ and Cl_2Ba will be added to eliminate U, Ra and As. After that, the processed water will be sent to evaporate as an infiltrate in the clean area. The aim is not to discharge this water to the river, because it may create a negative perception of the mine among the local people. There are many vineyards downstream from the mine, and the owners are afraid that the mine waters may affect their wine.

Liquid effluents treatment

The liquid effluents coming from the IX will be neutralized with lime to pH12 and sent to evaporation dumps where, at that pH, the precipitated calcium will be decanted and the ammonium evaporated. The overflow will evaporate.

5. CONCLUSION

Using the same areas impacted before, our objective is to fulfill the important premise: to impact as little area as possible. In this scenario, the project does not need any new areas to manage the wastes.

The chemical treatment to reduce U, Ra and As of the liquid effluents diminishes the environmental impact using marginal minerals to stabilize the dumps, helping to manage the waste.

During waste management, the neutralization of the new tailings will improve the final closure.

FIG. 1. Plant view.

FIG. 2. Open pit water.

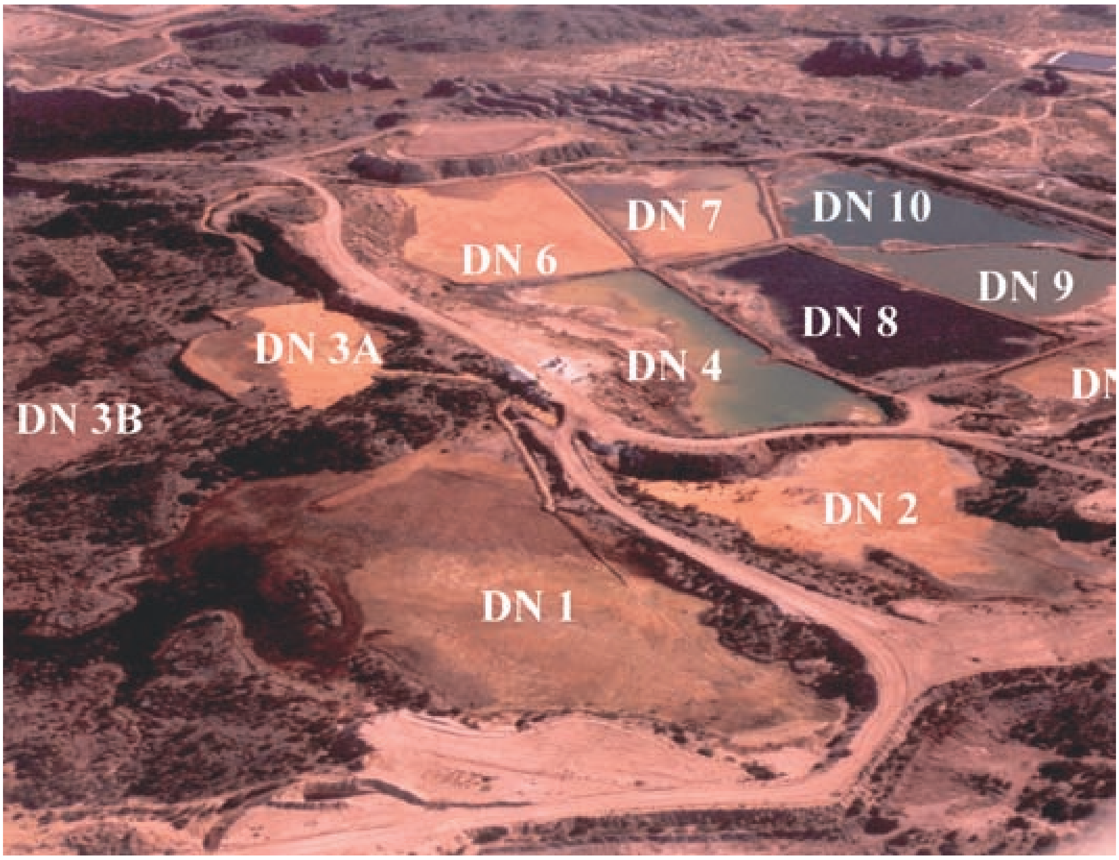

FIG. 3. Evaporation-precipitation dumps.

FIG. 4. Treatment of tailings.

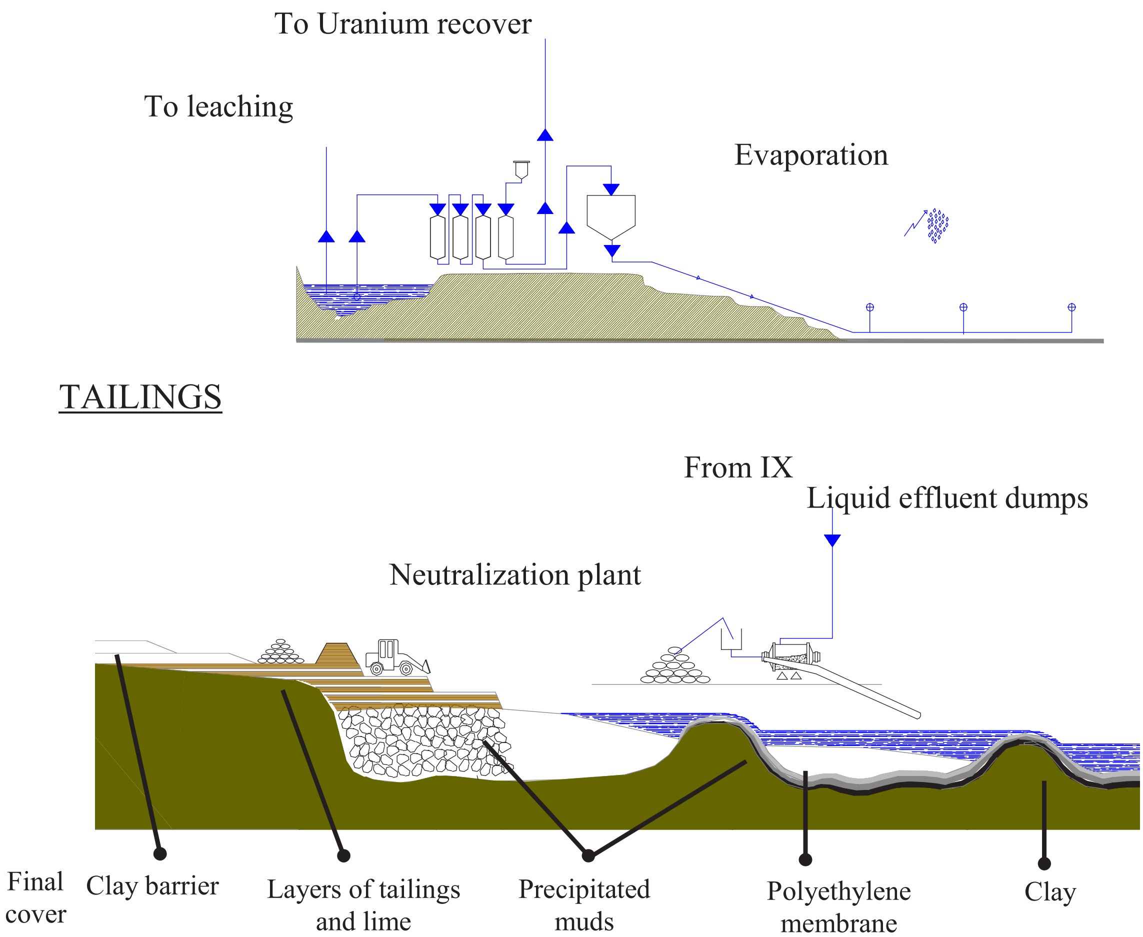

FIG. 5. Scheme of liquid treatment: Open pit treatment.

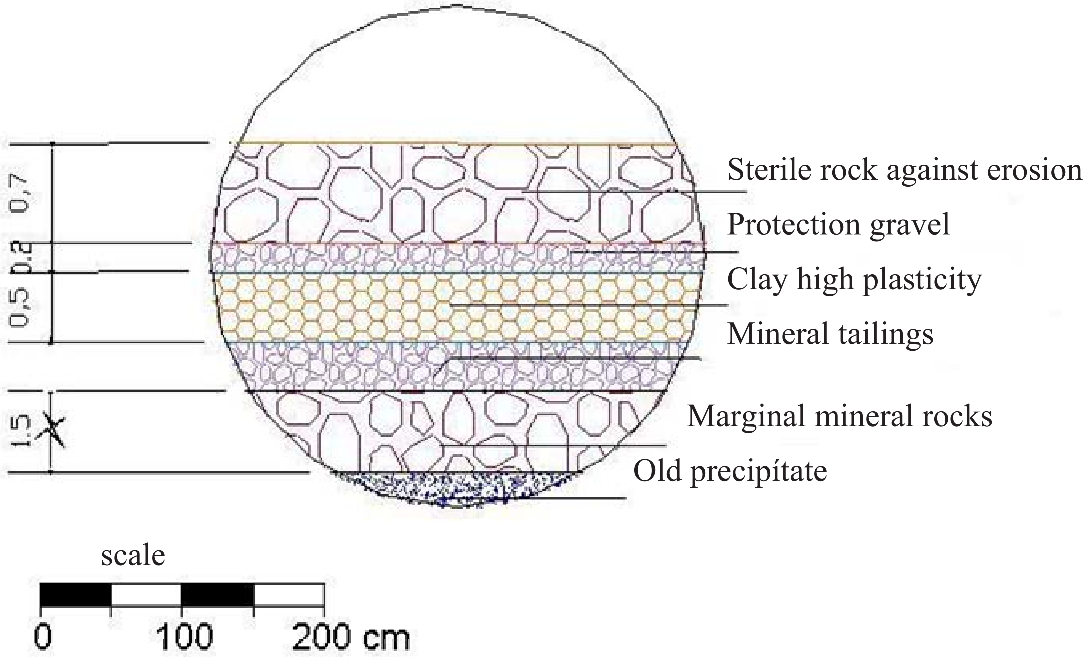

FIG. 6. Cover for dumps 1 to 3.

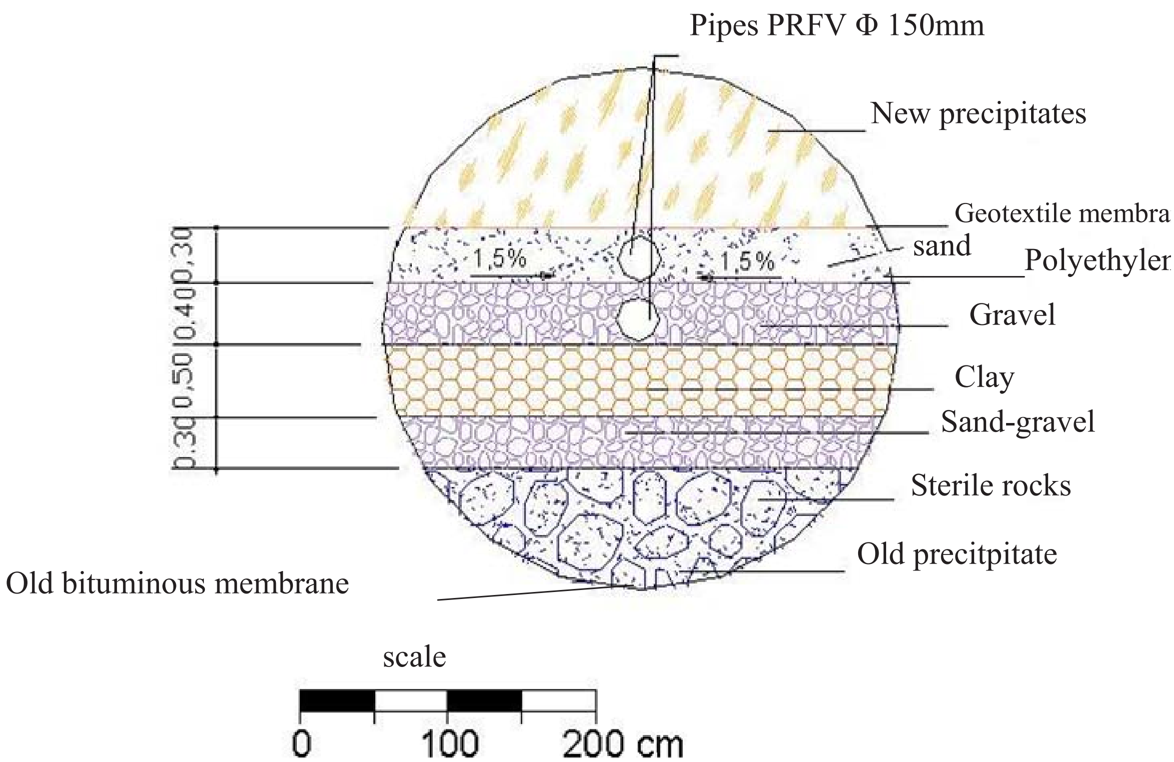

FIG. 7. Impermeabilization dumps 4 to 10.

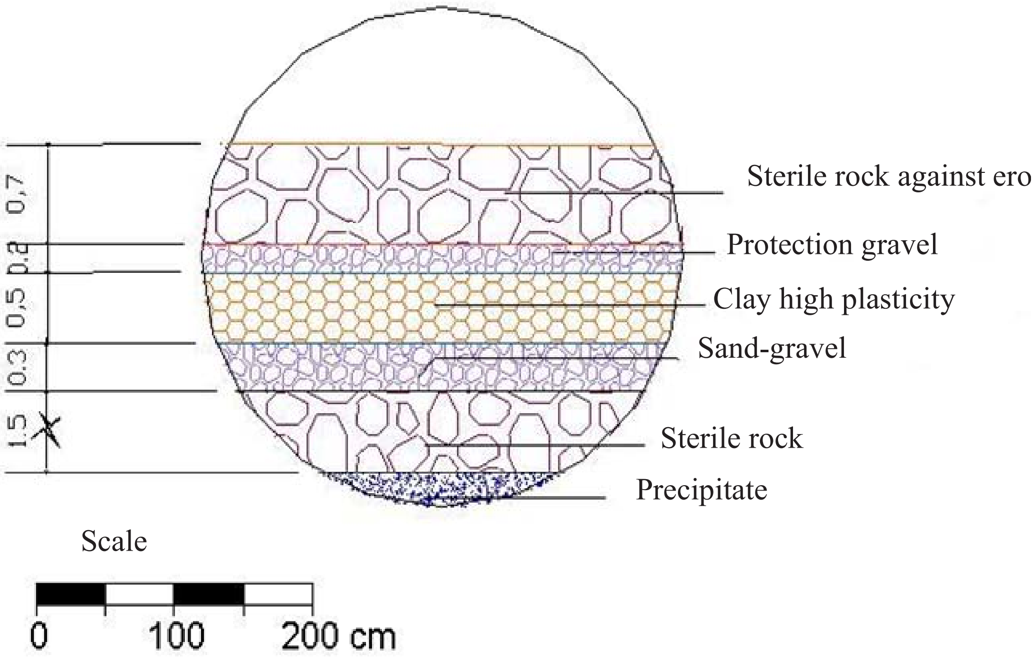

FIG. 8. New precipitated cover.

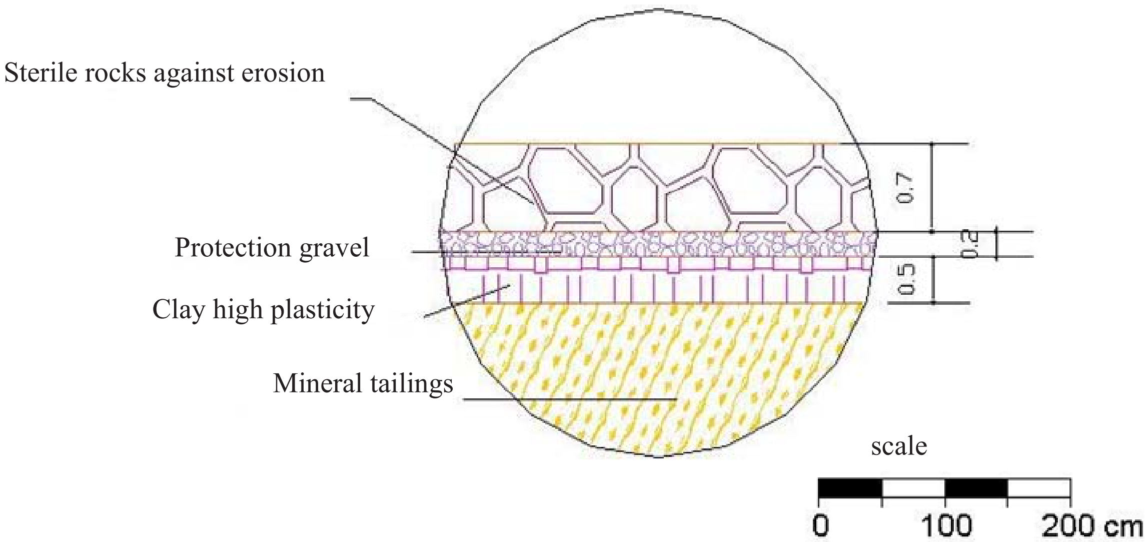

FIG. 9. Tailings cover.

RADIOMETRIC BASELINES IN URANIUM EXPLORATION PRODUCTION AREAS OF CHUBUT PROVINCE, ARGENTINA

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This paper presents results of work done to establish radiation baselines in the uranium exploration — production areas that belong to the Golfo de San Jorge basin in the Chubut province, Argentina (Figs 1 and 2). This was accomplished through a number of National Atomic Energy Commission (CNEA) and International Atomic Energy Agency (IAEA) supported activities (TC ARG 3/007 and TC ARG 3/008), including total and spectrometric gamma ray airborne surveys, reprocessing and back-calibration of spectrometry data and acquisition of new ground gamma ray spectrometry data.

In 1956, the CNEA started the uranium exploration activities in the Patagonia Region, considering the presence of radioactive anomalies detected in boreholes drilled for oil exploration. The uranium potential of the fluvial and pyroclastic sediments of the Chubut Group of Cretaceous age was evaluated. Subsequently, extended areas where this Group outcrops were investigated, looking for uranium using gamma ray airborne surveys and other geological and geophysical exploration methods. This resulted in the discovery of several uranium deposits and the identification of hundreds of clusters of uranium anomalies.

Specifically, in the 1960–1961 period, 20 000 square kilometers of the study area were covered by an airborne radiometric survey that discovered Los Adobes U deposit (Latitude: 43º21´ S, Longitude: 68º45´ W); while in 1971, another airborne survey conducted to the discovery of Cerro Condor U deposit (Latitude: 43º24´ W, Longitude: 69º05´ S), located in the western part of Los Pichiñanes Range. These gamma ray surveys, flown at a 250–1000 m spacing with a NaI volume detector of 5 liters, constitute the background radiation data of these sandstone-type deposits related to paleochannel structures. Figure 3 shows the original radiation map for the Los Adobes site, and Figure 4 shows the available pre-mining radiometric map for the Cerro Condor site, included at 1.45 times the background zone.

In 1971, in consideration of the geological and structural evidence, a drilling programme, which was executed in the vicinity of the Los Adobes deposit, found U mineralized levels at the Cerro Solo location (Latitude: 43º20´ S, Longitude: 68º45´ W). In 1976, the Los Adobes U deposit was mined by open pit, obtaining 108 tonnes of U at an average grade of 0.12% U (Fig. 5). The mineral extracted from this deposit was treated in a milling facility located beside the Chubut River at latitude 43º38' south and longitude 68º56' west. This heap leaching plant (Fig. 6), operated from 1977 to 1981, also processed the mineral extracted from Cerro Condor in 1979 by an open pit — 45 tonnes of U at an average grade of 0.078% (Fig. 7).

From 1978 to 1979, the first airborne gamma ray spectrometry survey in Argentina was carried out, covering 100 000 square kilometers of the Golfo de San Jorge basin. Recently, this survey was reprocessed, back-calibrated, leveled and applied both to establish the radioactive element characteristics of the main lithologies present in the study region and to determine the current situation at the U exploration production sites. At the regional scale, the exposure rate levels range from 2 μR/h over soil to 16 μR/h associated with rhyolites of the Marifil formation from the Jurassic basement, while considering the 100 000 square kilometer area, the average exposure rate value computed from the archived flight line data is 6.2 ± 1.5 μR/h. On the other side, in Figure 8, the after mining radiometric situation of Los Adobes site is shown.

During the late 1980s, the milling facility was reclaimed. The entire infrastructure was removed, and the heap leaching piles and solid effluent dikes, located on a polyethylene impermeable basement, were covered with arid material to avoid the effects of aeolian erosion (Fig. 9). At this site, the current exposure values are very close to the background of the surrounding soils (4.5 μR/h), and the average radon emanation rate is 4,0 Bq/m^2 s.

From 1990 to 1997, with the purpose of improving uranium resources, the CNEA selected the Cerro Solo sandstone-type uranium deposit to perform an assessment project based on the deposit promising grade. Mineralized layers are distributed in fluvial sandstones and conglomerates, lying 50 to 130 m deep. The thickness of mineralized levels ranges from 0.5 to 6 meters, the average grade is 0.4% U and the uranium resources (RAR + EAR I) are calculated in 4 600 tonnes of recoverable uranium.

Considering a 4 km by 4 km area around the Cerro Solo deposit, the average exposure rate value computed from the archived flight line data is 7.41 μR/h. The concentrations of radioactive elements derived by ground gamma ray spectrometry compare closely with the corresponding airborne levels. For example, cover material around the deposit has an average ground exposure rate of 7.12 μR/h. Figure 10 shows the background radiation map of this sector.

In 1997 and 1998, the restoration of the Los Adobes open pit, involving an area of about 4 square kilometers, was done. First, the barren material, which was spread in the surrounding area, was disposed of in the open pit. Then, the slopes of the quarry were smoothed by covering them with soil of the site, which also facilitates the growth of vegetation. Figure 11 shows the post-restoration landscape of the site, where the current values of radon emanation range from 0.04 to 1.68 Bq/m^2 s.

Finally, some ground spectrometry was performed in the Los Adobes reclaimed mine and surrounding areas to monitor the current radioelement behaviour and radiation levels. Near the Los Adobes deposit, the emanation values are between 0.001 and 0.27 Bq/m^2 s.

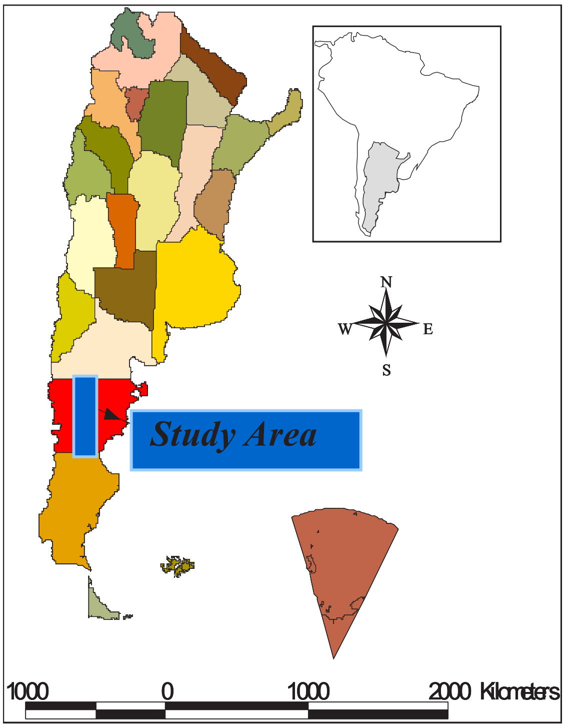

FIG. 10. General location of the study area.

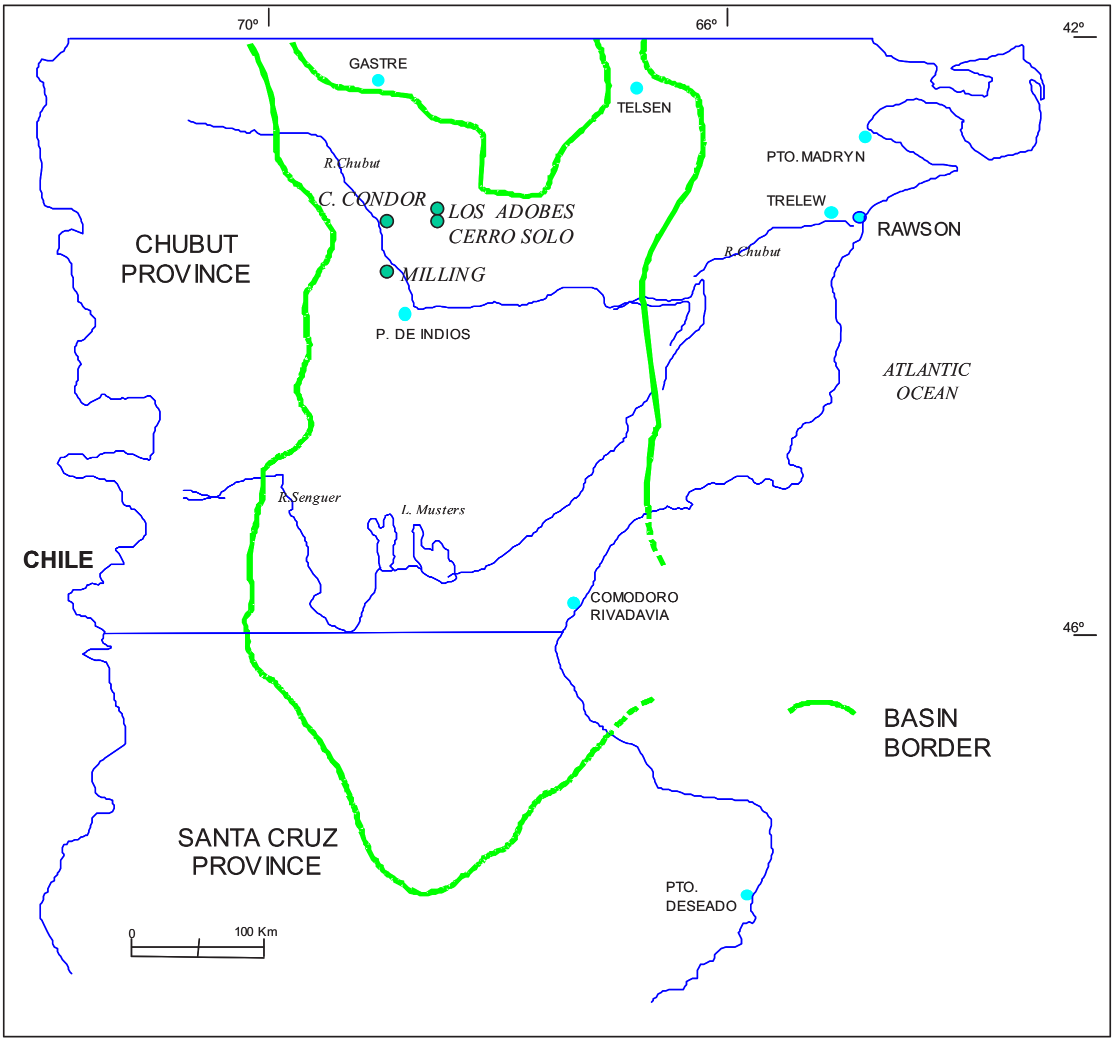

FIG. 11. Golfo de San Jorge Basin.

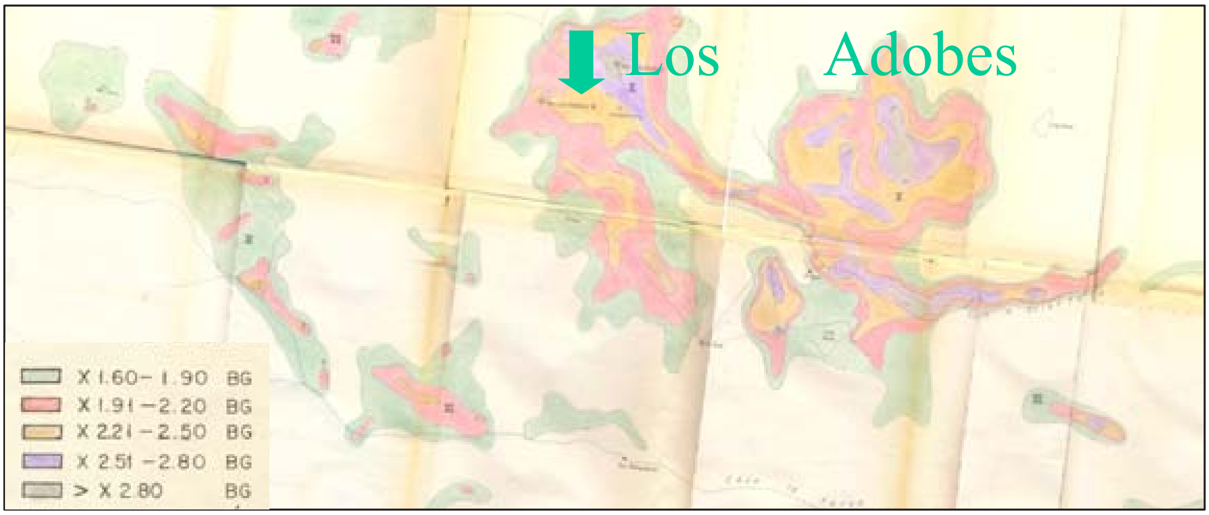

FIG. 12. Airborne radiation map of the Los Adobes site.

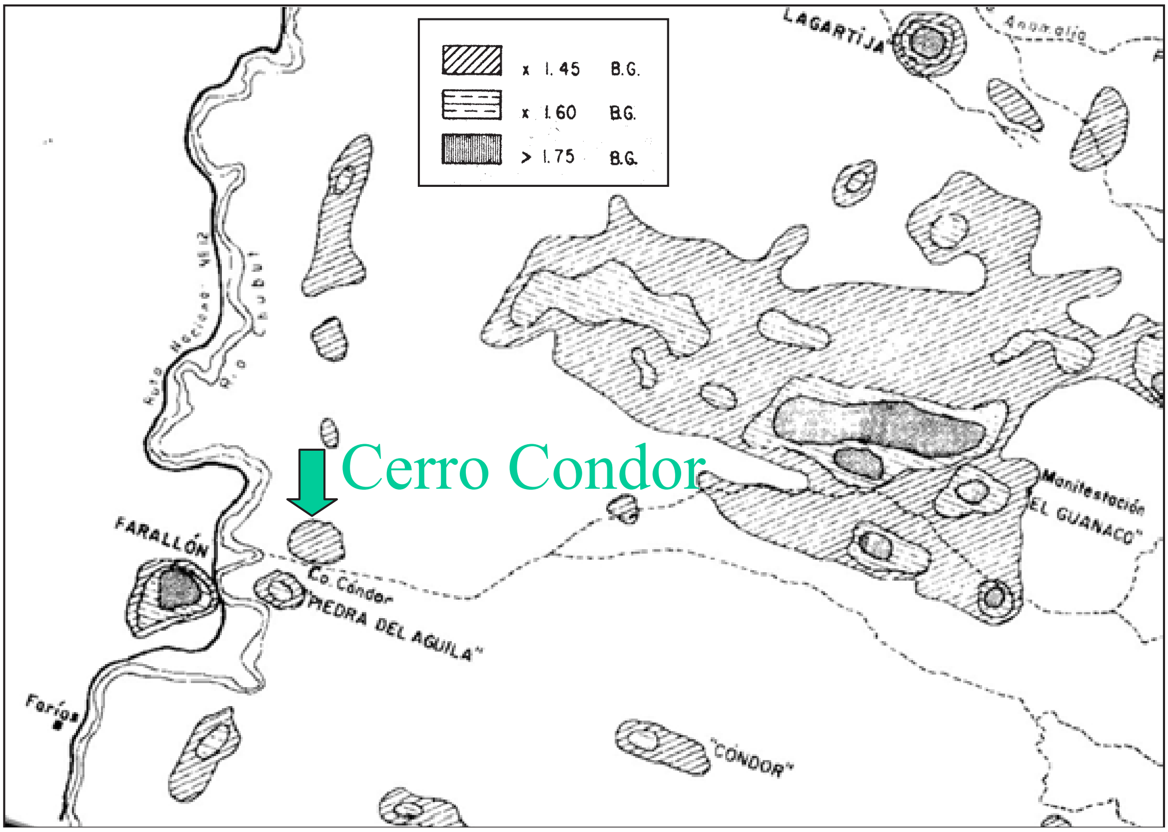

FIG. 13. Airborne gamma total count map at the Cerro Condor site.

FIG. 14. Los Adobes U deposit.

FIG. 15. View of milling operation.

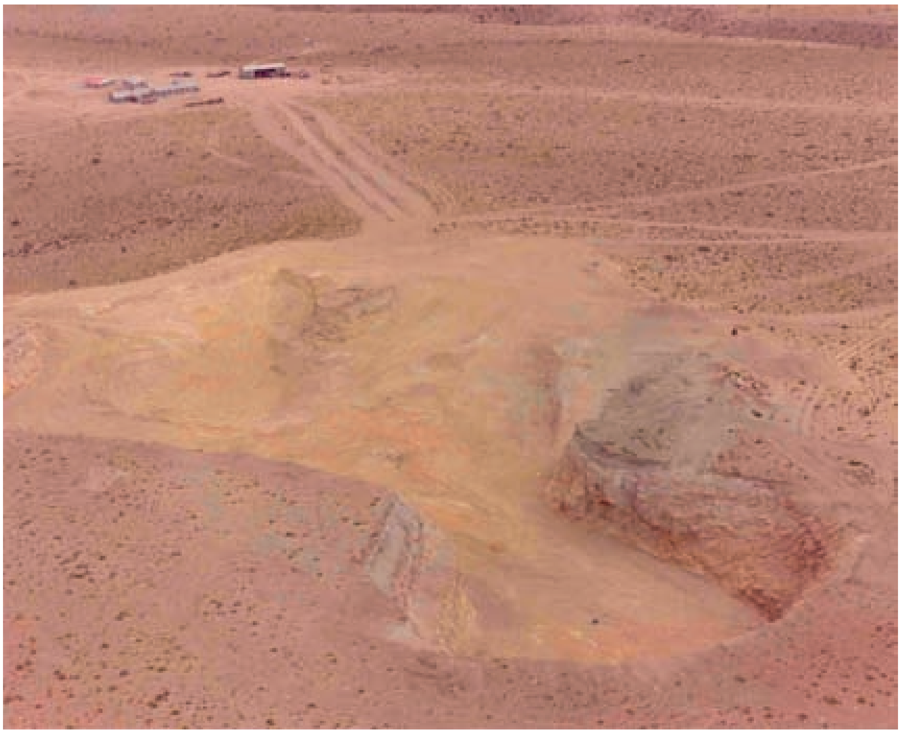

FIG. 16. Cerro Condor U deposit.

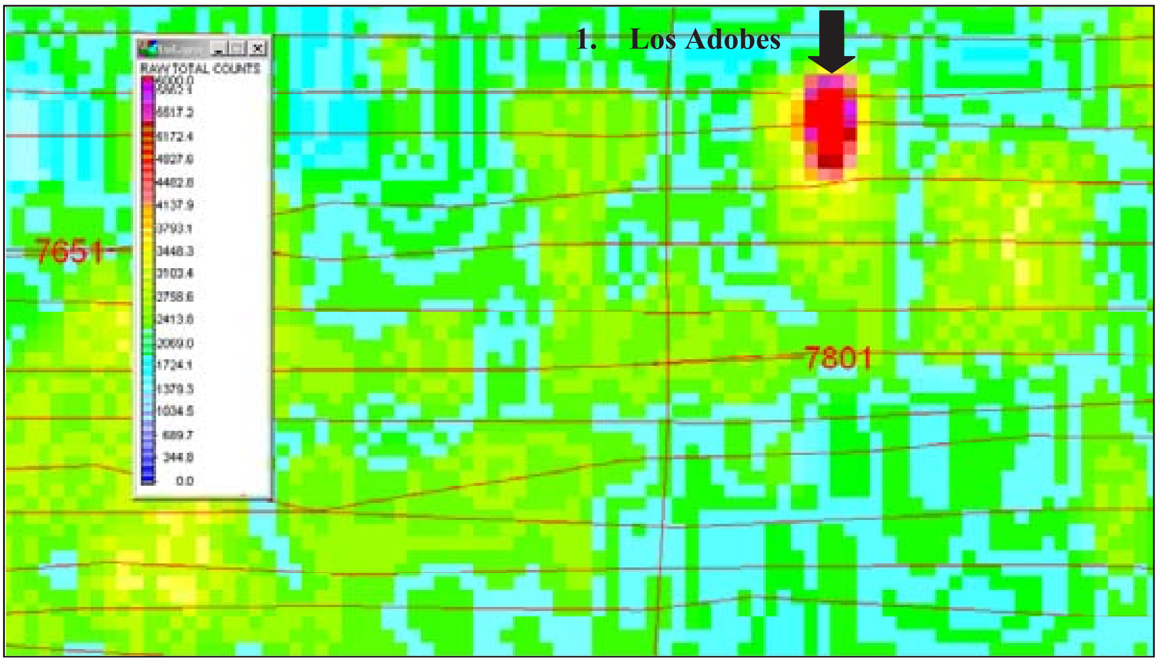

FIG. 17. Total count gamma ray map of Los Adobes U deposit.

FIG. 18. Reclaimed milling operation.

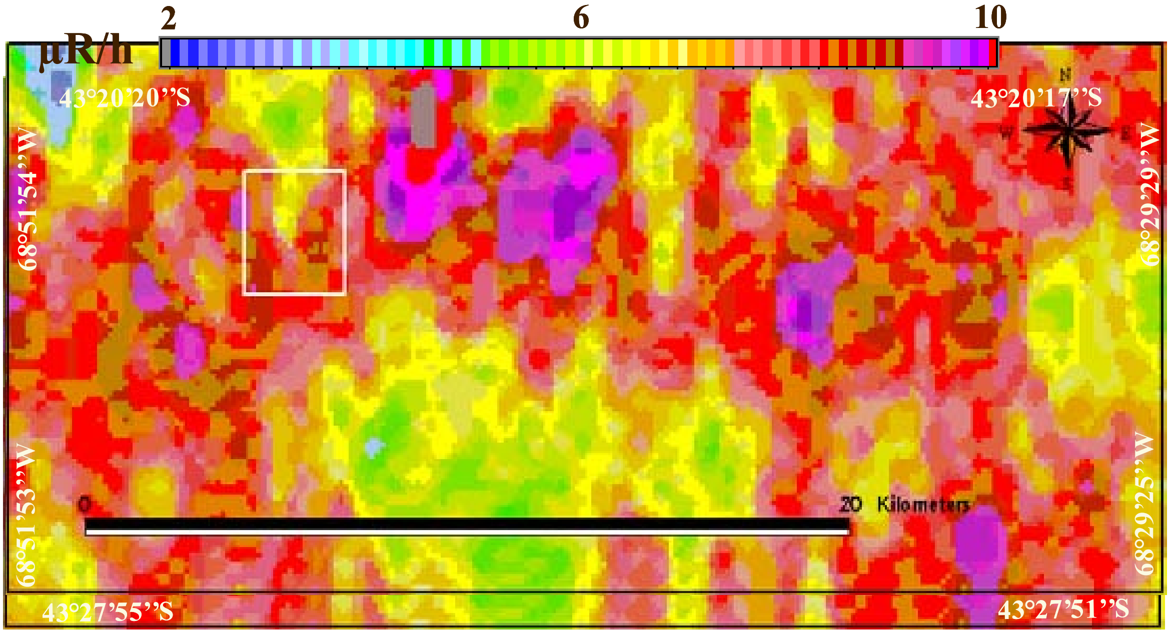

FIG. 19. Background radiation map of Cerro Solo area.

FIG. 20. Los Adobes open pit after restoration.

WATER QUALITY MONITORING IN THE CERRO SOLO U DISTRICT CHUBUT, ARGENTINA

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This work was carried out on behalf of the European Union INCO DC project called Water Quality in Mining Areas of Latin America. The Cerro Solo U district is located in Chubut province in the southern Patagonia region of Argentina at 43º20' south latitude and 68º45' west longitude, at 630 metres above sea level and covering an area of 420 square kilometers (Figs. 1 and 2).

The main deposit occurs as conformable layers and lenses within Cretaceous sandstones and conglomerates of the Los Adobes formation (Chubut Group). These units represent a high-energy fluvial system. The mineralized horizons occur between 60 and 120 metres below the surface. The average grade is 0.4% U, and the uranium resources (RAR + EAR I) are calculated in 4 600 tonnes of recoverable uranium. Cretaceous tuffs of the Cerro Barcino formation (Chubut Group) and Jurassic andesitic rocks of the Lonco Trapial formation complement the main local geology.

In this area, a water quality monitoring network was established in order to evaluate the pre-mining hydro-geochemistry baseline of the district (Fig. 3). The sampling stations include: exploration boreholes (8), springs and wells (5), streams (2) and an artesian well (1). The boreholes belong to the Cerro Solo deposit and represent the groundwater in contact with the mineralized bodies (Fig. 4). The spring and well stations are located close to the deposit area and provide a source of water for human and animal consumption in the surrounding farms (Fig. 5). The stream stations are located in the Chubut River, which is the only perennial stream in the region and represents the background for surface water quality (Fig. 6). Finally, the artesian well represents a mineralized water source in the study area (Fig. 7).

In order to evaluate the seasonal variations in the water composition, the samples were collected both in the wet and dry periods of the year. Water samples were filtered (0.4 µm), and collected in pre-cleaned, high-density polyethylene bottles. Temperature, pH, Eh, dissolved oxygen, conductivity and alkalinity were measured on the site. Major, minor and trace elements were determined at different laboratories using different methods.

The water in the area shows a prevalent $Na\text{-}HCO_3\text{-}SO_4$ character with a general increase in sulfate-dissolved content at the deposit. The pH is near neutral or slightly alkaline, except for the Pozo Soplador, where its value is 6.5. Eh values are typical of water in equilibrium with the atmosphere, except for some boreholes and the Pozo Soplador, where the Eh is lower but still positive. TDS ranges from 0.3 to 5.9 g/l, and its increase is mainly related to an increase of sulfate, bicarbonate and sodium.

The uranium content of the water is related to the rates of uraninite and coffinite dissolution, which is facilitated by the pyrite oxidation. The trend observed in Fig. 6 reflects the contemporary mobilization of U and S. Figure 8 shows a plot with U/Pb and Mo/Pb dissolved contents, which marks a clear distinction between Pb content in the borehole waters and that in all the other sample points. Since U appears not to be controlled, lead is supposed to be fixed by carbonate species in shallower waters or more probably made available only by mineralization.

The present anomalous content of some elements (As and F) in wells and springs providing water to the farms not far from the deposit is related to the natural characteristics of groundwater from the Pichiñanes Range. As and F show amounts above the admitted limits for drinking water established by Argentinean law. There are no levels of uranium above the admitted limits for drinking water, which for Argentinean law is relatively high (100 µg/l), except at one borehole in the ore deposit and at Pozo Soplador, whose waters exceed the limits for many other chemical parameters. Outside of the ore deposit, on the surrounding farms, the uranium average dissolved content is 25 µg/l. This figure may be considered relatively high for drinkable waters, but usual in uranium-enriched areas.

The potential future risks during the mining works are related to the possible impact on the water resources of the acid leachate employed to recover uranium, and the use in the exploitation activity of groundwater rich in U, Pb, Fe, Al and Mn from boreholes, with the consequent possible dispersion at the surface.

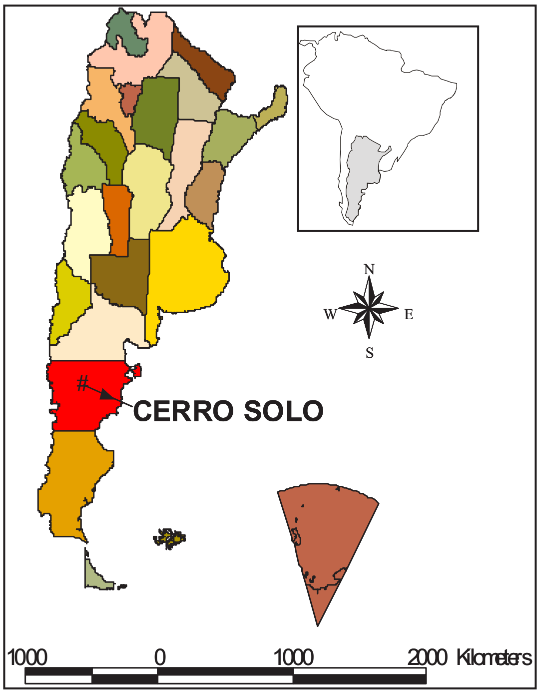

FIG. 21. Location map.

FIG. 22. View of the U Cerro Solo deposit.

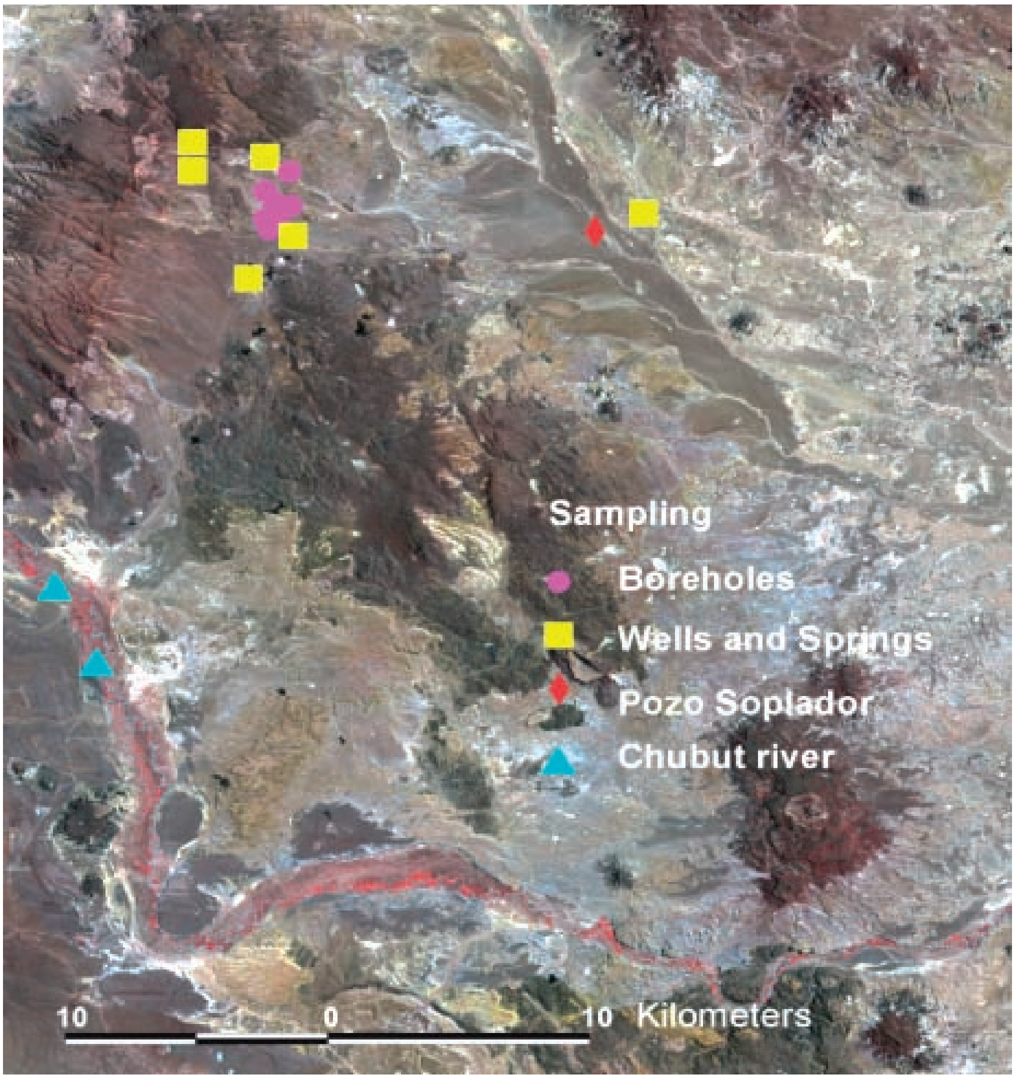

FIG. 23. Sampling stations.

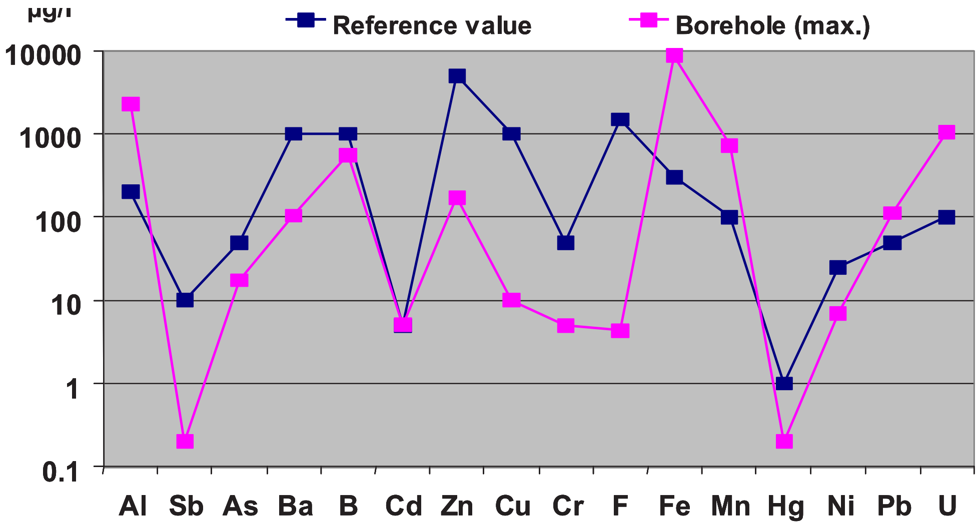

FIG. 24. Water quality in boreholes.

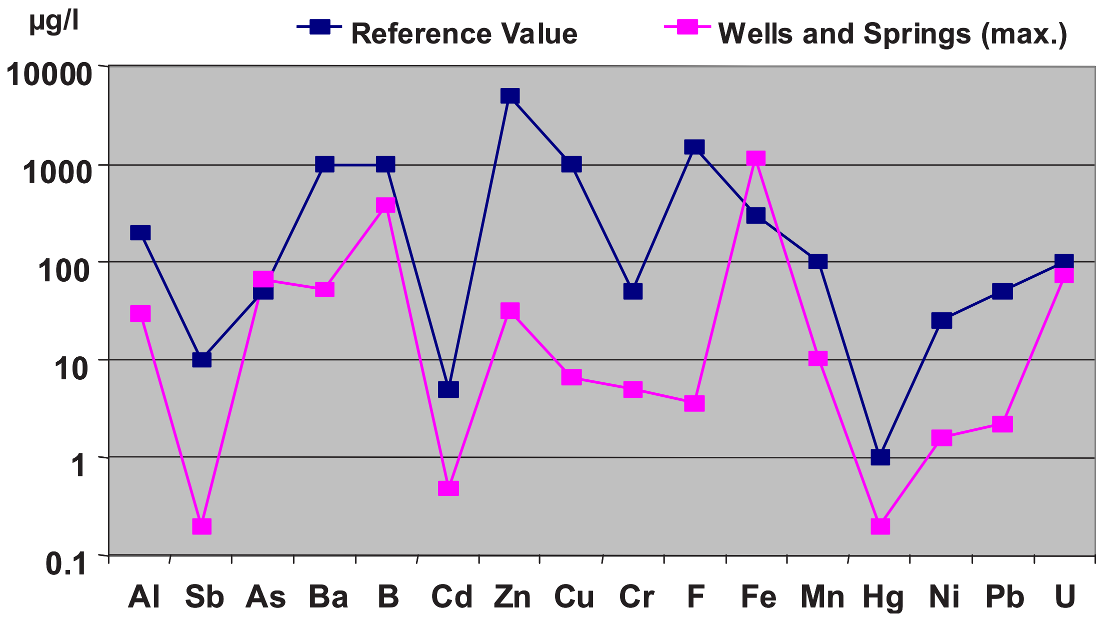

FIG. 25. Water quality in wells and springs.

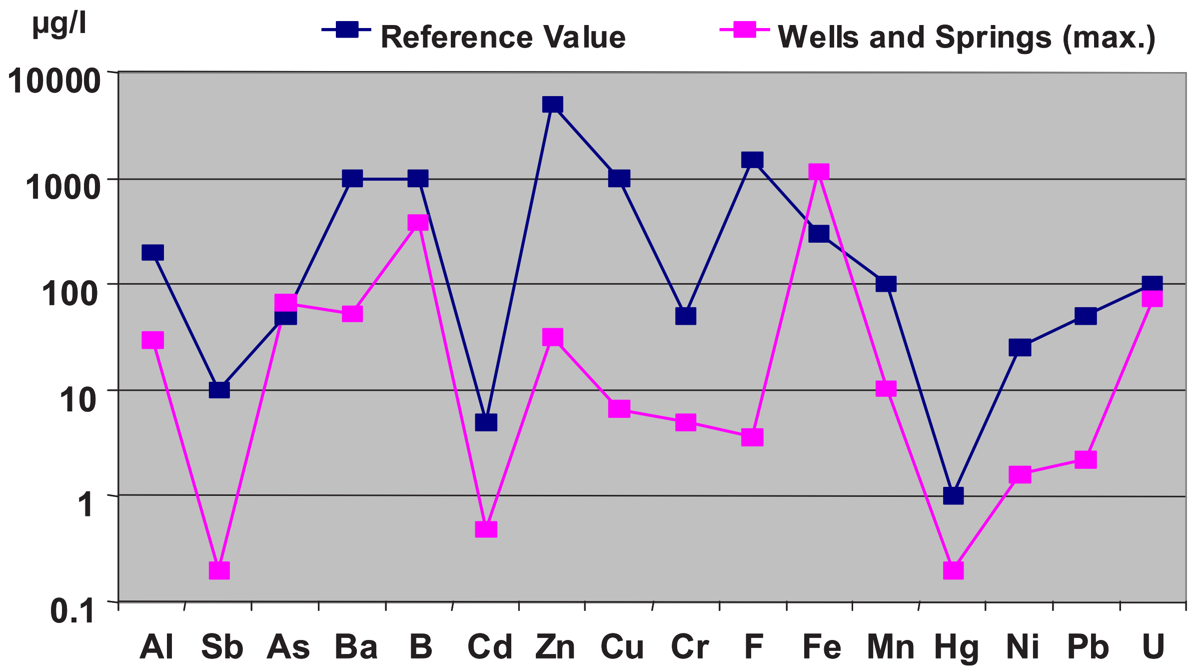

FIG. 26. Water quality in the Chubut River.

FIG. 27. Pozo Soplador.

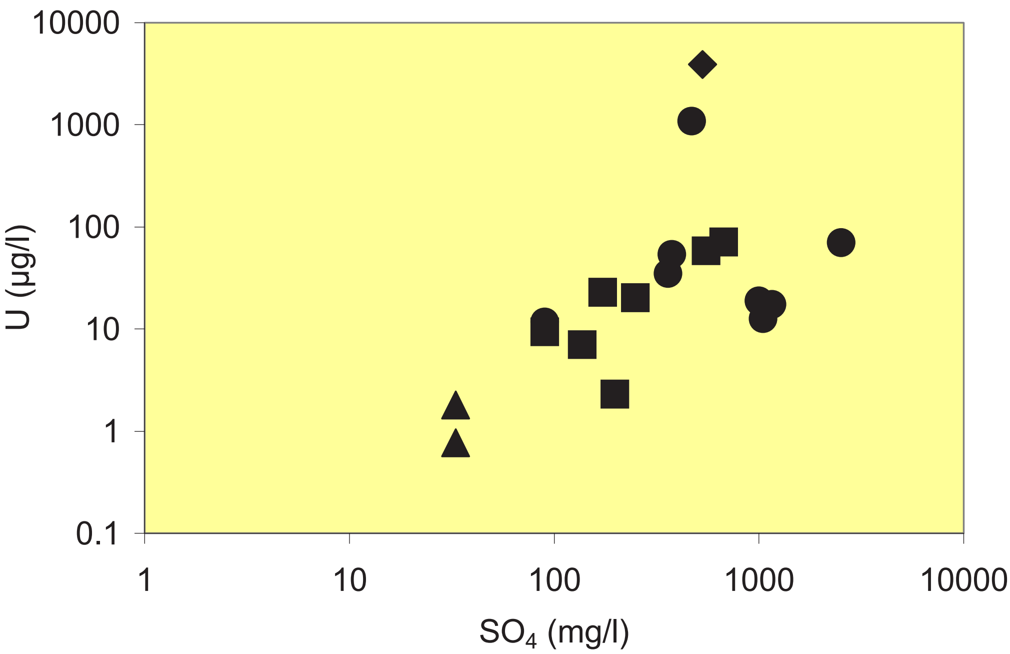

FIG. 28. Dissolved uranium and sulphate contents. Boreholes (circles); wells and springs (squares); Chubut river (triangles); Pozo Soplador (rhombus).

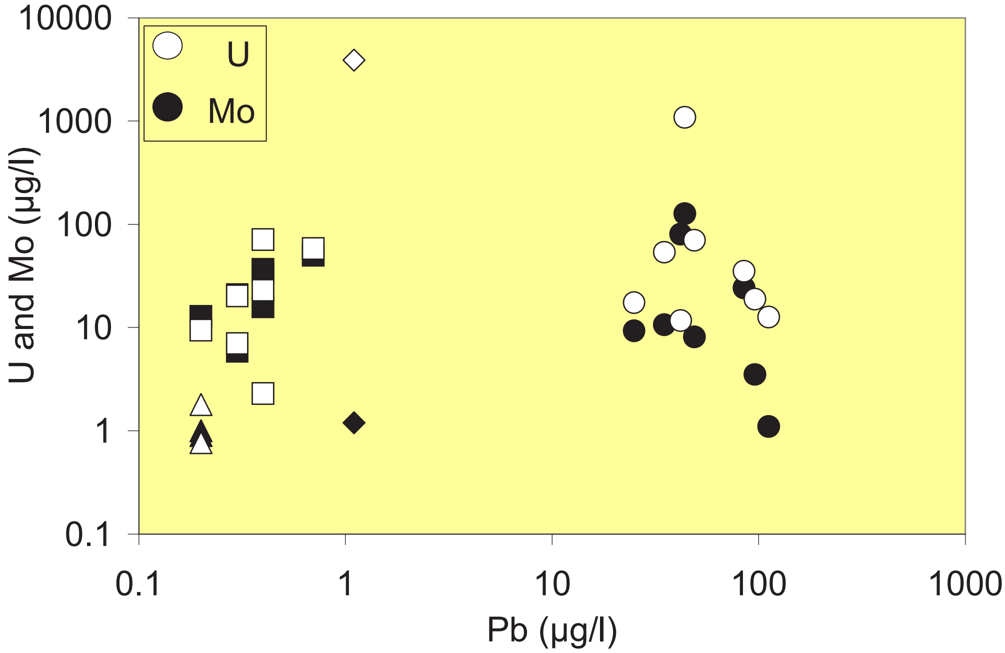

FIG. 29. Dissolved uranium and molybdenum contents vs. lead (symbols as in Fig. 7).

ENVIRONMENTAL MANAGEMENT AND REGULATION AT AN AUSTRALIAN IN SITU ACID LEACH URANIUM MINE: BEVERLEY

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Abstract

The Beverley Uranium Mine is situated approximately 600 km north of Adelaide in South Australia. The mine utilises a moder-tely acidic In Situ Leach (ISL) technology in contrast to the more aggressive strong acid leach ISL mines developed in many eastern European countries.

Of all the mining processes, ISL is the best technique in terms of minimising surface disturbance, and of all the ISL projects in the world, the Beverley Uranium Mine is unquestionably the most technologically advanced.

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 the mine is by most considered to have the world's best practice.

1. INTRODUCTION

Heathgate Resources Pty Ltd (Heathgate) operates the Beverley Uranium Mine (Beverley) situated on the arid planes between the Flinders Rangers and Lake Frome, approximately 600 km north of Adelaide.

After purchasing the mineral lease in 1990, Heathgate developed the mine utilizing a moderately acidic ISL technology. Initial leach trials commenced in 1998. After obtaining all required permits, commercial mining utilizing the ISL technology commenced in November 2000.

The chosen technique utilizes an oxidant to assist with uranium dissolutions and is vastly different from the more aggressive strong acid leach ISL mines developed in many eastern European countries.

2. APPROVAL PROCESS AND REGULATION

In order to obtain approval for the development and operation of a uranium mine in South Australia, various processes must be completed and subsequent permits/licenses obtained. Table 1 details each of these processes and the relevant legislation.

Initial mine approval

The Environmental Impact Assessment (EIS) process undertaken for approval of the Beverley Mine was a thorough assessment involving:

- Assessment and description of the existing environment;
- Details of the various possible alternatives and reasons for final choice;
- Description of the proposed development;
- Undertaking an assessment of Aboriginal culture and heritage at the proposed site;
- Assessment of the socioeconomic impacts (positive and negative);
- Assessment of all possible environmental impacts and proposed mitigation and management process to be implemented;
- Prediction of radiation exposures and emissions, and details of control measures.

TABLE 1. APPROVALS REQUIRED PRIOR TO COMMENCING C OMMERCIAL URANIUM MINING IN SOUTH AUSTRALIA

Approval	Legislation
Environmental Impact Statement • Prepare document for public comment • Prepare supplement addressing comments • Provide further information as requested from governments • Obtain approval with list of conditions	Commonwealth Environment Protection (Impact of Proposals) Act 1974 South Australian Development Act 1993
Application for Mining Lease Condition requires preparation and approval of: • Mining and Rehabilitation Plan • Environmental Monitoring and Management Plan • Transport Management Plan (Uranium and other dangerous goods) • Waste Management Plan (Radioactive and non-radioactive)	State Primary Industry and Resources South Australia
Application for License to Mine and Mill Condition requires preparation and approval of: • Radiation Management Plan • Demonstration of compliance with both codes of practice	South Australian Environmental Protection Agency
Application for permit to export uranium product	Commonwealth Department of Industry, Tourism and Resources
Application for permit to possess nuclear material (Nuclear Non-Proliferation Act)	Commonwealth Australian Safeguards and Non-Proliferation Organisation
Application of license to store and handle dangerous goods	South Australian Workplace Services
Various other minor licenses as required under state legislation.	

The prepared EIS was sent out for public comment, and a second document was prepared responding to these comments. This supplement contained further explanation and mitigation measures as required.

Both the federal and state governments were satisfied that the environment would be satisfactorily protected and approved development of the mine in 1999.

Government inquiries

Since mining began at Beverley, the state and federal governments have conducted further inquiries into aspects of the Beverley Mine:

- South Australian EPA Task Force investigation into the activities and operations at the Beverley ISL, May 2002;
- Hedley Bachmann independent review of reporting procedures for the SA uranium mining industry, August 2002;
- Senate inquiry into regulating the Ranger, Jabiluka, Beverly and Honeymoon uranium mines, 2002/03;
- South Australian government review of environmental impacts of the acid ISL uranium mining process, EPA 2003/04.

Summaries of the findings of these inquiries have been presented in the following sections. No inquiry found that operations conducted at the mine were having adverse impacts on the environment.

South Australian government investigation into the activities and operations at the Beverley ISL

Following a number of incidents at Beverley, the South Australian government formed a task force of key senior regulators. The purpose of the task group was to assess the operating procedures at the mine with particular focus on worker safety and the potential for actual environmental harm.

The group found no evidence that licence conditions have been breached or workers exposed to unacceptable risks.

The final task group report made the following statement in its conclusion.

> *Heathgate believes its ISL practices are the most advanced in the world and is looking to achieve continuous improvement. It accepts that the number of spills to date is not acceptable and continues to investigate ways to improve its performance. Senior personnel claim that the company sees itself operating on this site for at least 20 years and is prepared to continue investing in best practice technology to meet the requirements of its existing licence and any other reasonable requirements placed on it.*

Hedley Bachmann independent review of reporting procedures for the SA Uranium Mining Industry

Mr. Hedley Bachmann was employed by the South Australian Government in July 2002 to conduct an independent review into the reporting procedures for the uranium mining industry in South Australia.

The review found that the reporting requirements for radioactive spills and similar incidents that currently apply to ISL uranium mines in South Australia were more stringent than those used elsewhere in the world. It concluded that these procedures were not appropriate for commercial mining operations and will be among the best practice reporting requirements.

Senate inquiry into regulating the Ranger, Jabiluka, Beverly and Honeymoon uranium mines

This inquiry was initiated as a minority report by the Australian Democrats/Greens as a federal government response to numerous incidents that had occurred at the four uranium mines in question but did not include the Olympic Dam operation for some reason. Its terms of reference required the senate committee to assess the adequacy and effectiveness of the current system of environmental regulation at uranium mines.

The committee was headed by a long term anti-nuclear campaigner and as such the final report came across as tainted by these opinions. Full agreement was not obtained by all on the committee and as such a dissenting report was prepared by some on the committee. In this dissenting report, the government senators made the comment that:

> *Government senators believe Beverley and Honeymoon mines to be the most environmentally friendly mine sites that they have ever seen. Parliament, indeed all Australians, should be encouraging such passive means of mining rather than promoting old-fashioned and intrusive technologies.*

South Australian government review of environmental impacts of the acid in situ Leach uranium mining process

In November 2003, the South Australian Government announced that the Environment Protection Authority (EPA) would conduct an independent review of the environmental impact of the acid ISL uranium mining process.

A draft of the report for this review has been prepared, however has not yet been made public. This draft report indicates that the ISL process at Beverley has not had an adverse impact on the local environment. In addition, when compared to alternative mining techniques, the ISL method is a proven method to minimize impact.

3. BEST PRACTICE ENVIRONMENTAL MANAGEMENT FOR IN SITU LEACH

Of all the mining processes, In situ Leach (ISL) is the best in terms of minimizing surface disturbance. 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 as well as a few small pumping huts called wellhouses. These wellfields are a rolling development that move along the 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.

The Beverley Uranium Mine is unquestionably the most technologically advanced ISL mine in the world. Instrumentation and automated process control have been implemented throughout the operation that provides the capability to sense and automatically shut down or provide warnings for a number of circumstances.

Much of the technology implemented at the mine has been borrowed from similar Australian and international industries, however a significant portion has been developed or adapted by Heathgate specifically for the Beverley Mine. A summary of these processes is provided in the following sections.

Control of mining fluids

The mining aquifer at the Beverley Mine was proven to be confined during the EIS process. It is bounded above and below by impermeable clay layers. These clay layers ensure mining fluids do not migrate above into the Willawortina Formation, utilized for stock watering purposes by local pastoralists, and/or below into the Great Artesian Basin (GAB). The GAB is utilized across Australia for a variety of purposes and at the mine for drinking water following treatment (Figs 2 and 3).

Control must also 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 analysed to ensure a neutral water balance is maintained. Balances within each individual wellfield are adjusted on a daily basis, a full plant and wellfield water balance is calculated monthly and then reported to the state and federal regulators quarterly.

To monitor the effectiveness of the flow control programme, monitor wells have been installed surrounding the mining zones (Fig. 4). A rigorous monitoring programme demonstrates that the mining fluids remain under control.

To better enable the tracking of fluid movements, Heathgate has developed a hydrogeological model of the Beverley sands, which has proved to be a valuable tool. This is the latest in advanced technology and provides a diagrammatic map of the current flow paths and in addition serves as a prediction tool. This enables Heathgate to predict future flow paths and demonstrate the sustainability of current and future operations at Beverley. Figure 5 illustrates the model of disposal fluid as of March 2004.

Hazard and Operability Study

In January 2002, a full Hazard and Operability Study (HazOp) was conducted on the process at Beverley. This technique was seen as a very efficient method of identifying potential hazards at the design stage and has now been implemented as a site standard for all new installations and changes to the process.

The HazOp process is a technique that identifies the potential hazards and operating issues with the design and construction of equipment and plant, and involves the interaction of a multi-disciplinary team. The identification is carried out using a series of keywords to examine deviations in the process and their subsequent effects on the process as a whole.

Automatic shutdown

All processes in the plant and wellfield are monitored from a central control room via the use of a Distributed Control System (DCS) and flow, pressure, temperature etc. indicators. This enables the setting of alarm limits and automatic shutoff values (both software and hardwired).

Wellhouse

Within the wellhouse, signals are constantly sent to and from the DCS for both extraction and injection flows. The following automatic shutdowns have been programmed to minimise the potential for spills and other operational issues:

(1) Injection pressures must remain below the calculated fracture pressure of the orebody, thus minimizing the potential for fluid migration into the overlying aquifer;
(2) Extraction pressures must remain below the pipe pressure ratings;
(3) Extraction pressures give an alarm when nearing high set point, and they also have a low-pressure set point that may indicate a pipe failure;
(4) Injection and extraction flow rates are individually monitored and set points entered within the control rooms based on their current flows; any sudden increase in flow rate indicates a pipe failure and results in pump shutdown;
(5) All pressure and flow alarms are linked to the plant booster pumps; critical shutdowns also stop these pumps;
(6) Every individual well flow meter is constantly tallied and compared with the overall wellhouse totalizer. Discrepancies may indicate a pipe failure, which results in an alarm.

Plant and trunk lines

(1) The main injection trunk line is fitted with a mechanical valve that can be operated for a major incident from the control room — this valve is set to fail closed;
(2) Rupture discs have been installed as the trunk line enters the plant – these ensure pipe integrity in the case of overpressure or water hammer;
(3) Certain valves with the plant area have been set to fail open, so as to ensure wellfield pumps will never be subject to dead head conditions;
(4) In the case of power failure or loss of DCS communication, all wellfield pumps will be shut down, minimising the potential for dead heading in the plant.

Drip trays

Following concerns from the local Aboriginal people that drips and vent valve spray from individual wellheads would over time contaminate the local soil, Heathgate resources designed and had manufactured individual drip trays for each wellhead.

Over time, the vent valves were found to occasionally spray past the tray or block and allow fluid to pass quickly into the drip tray and eventually overflow. All vent valves are now plumbed with small elbow and tubing such that fluids can be directed into the trays or, as needed, into larger containers.

Spill sensors

To ensure the early detection of any fluids from spills within the wellhouses conductivity sensors were placed in each hut. These are mounted in small sections of PVC casing on the floor at three sides of the wellhouse. When moisture is detected a blue flashing light is triggered at the top of the wellhouse and an alarm signal is sent to the central control room to alert the operators.

Due to the nature of the mining process at the Beverley mine, over time the wellfield have become spread out, being now kilometres from one end to the other. The wellfield operator was having difficulty maintaining a vigilant watch on each individual well, resulting in drip trays filling or overflowing prior to them returning on their routine checks. To assist the operator in the minimising of spills the Beverley team developed and installed individual conductivity sensors on each drip tray, each sensor when activated sends a signal to the wellhouse where the well number can be identified, the alarm is then also sent back to the central control room and the blue alarm light activated.

Great Artesian Basin

The GAB is one of the largest artesian groundwater basins in the world. It underlies approximately one-fifth of Australia and extends beneath arid and semi-arid regions of Queensland, New South Wales, South Australia and the Northern Territory, stretching from the Great Dividing Range to the Lake Eyre depression. Subsequently it provides a valuable water resource to the majority of Australia's arid regions and hence is considered one of Australia's most important natural resources.

The GAB is located approximately 300 m below the surface of the Beverley Mine. Mining operations are conducted at approximately 100 m below the surface. Both 200 m of alpha mud stone and the pressure of the GAB ensure that no mining solutions from the Beverley Mine can enter this valuable resource.

In arid regions such as this, Heathgate depends heavily on the GAB for both potable water and to a lesser extent water for mining processes.

Historically, many of the GAB bores installed for pastoral purposes early in the 20th century were allowed to free flow. This resulted in the formation of miniature wetlands and proved to be a very inefficient method of water use. After some time, these free flowing bores were showing negative effects on the GAB. To ensure the sustainability of this valuable resource, a GAB consultative committee was formed who in turn developed a Strategic Management Plan and implemented licensing and capping programmes.

Heathgate is fully committed to the guidelines of the GAB Strategic Management Plan and ensures that draw down of the GAB is minimized through constant flow and volume monitoring; a careful watch on GAB use is maintained at all times.

Additional to their mine site requirements, Heathgate undertook a programme of GAB water use reduction during 2002. This was a two-phased programme:

- Reduction of GAB use in the mining process;
- Capping of free flowing pastoral bore.

Reduction of GAB in process

After obtaining the appropriate state government approvals, Heathgate implemented a programme of sourcing and utilizing water from within the mining aquifer (know as the Namba Formation Aquifer). This water would be obtained from a part of the aquifer that had not been previously contacted with mining solutions. Being from the Namba Formation, this water has elevated radionuclide levels and a high total dissolved solid content, hence making it unsuitable for any current or future use. Utilising this otherwise unusable water source in the place of valuable GAB water was a site-based initiative and one of which Heathgate is very proud. Currently the mine utilizes 200 mega litres (ML) of Namba water per year, water that would otherwise need to be extracted from the GAB. This has helped ensure the sustainability of the GAB for future generations.

Capping of old bore

One of the GAB pastoral bores that now services the mine had historically been free flowing for stock purposes at approximately 16 ML per year. This bore was capped during 2002 as part of Heathgate's contribution to the national programme. This well had been allowed to free flow in the area for many years and as such had caused the formation of a small wetland. To ensure the preservation of this wetland in line with requests from local Aboriginal groups, Heathgate obtained approval from state regulators to direct reverse osmosis reject water to help sustain this wetland. This water had previously been a waste product, formed during the production of potable water for the Beverley Mine camp and office areas, from the reverse osmosis of GAB water.

Minimization of vegetation clearance

One of Heathgate’s primary objectives is the minimization of surface disturbance and vegetation clearance. Prior to any future development or delineation drilling, an environmental clearance certificate is required. This process involves:

- Justification for the disturbance;
- Documentation and photographing of pre-disturbance vegetation etc.;
- Flagging off of environmentally sensitive areas;
- Determination of road network;
- Ensuring minimal disturbance to vegetation and surface.

During 2003, mining operations moved to the northern extremes of the Beverley Deposit, and ore was located underneath a small creek. The environmental certificate system ensured that operations within this area minimized surface and vegetation clearance with the result being shown on the 2003 Annual Environment Report, where the operational well can be seen amongst dense vegetation with the protected Sturt Desert Pea in the foreground.

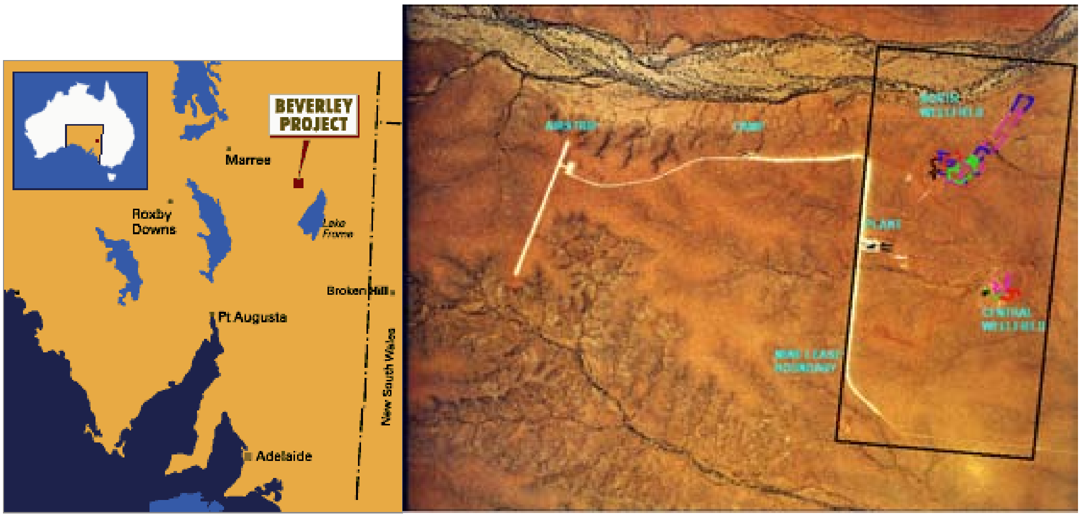

FIG. 30.

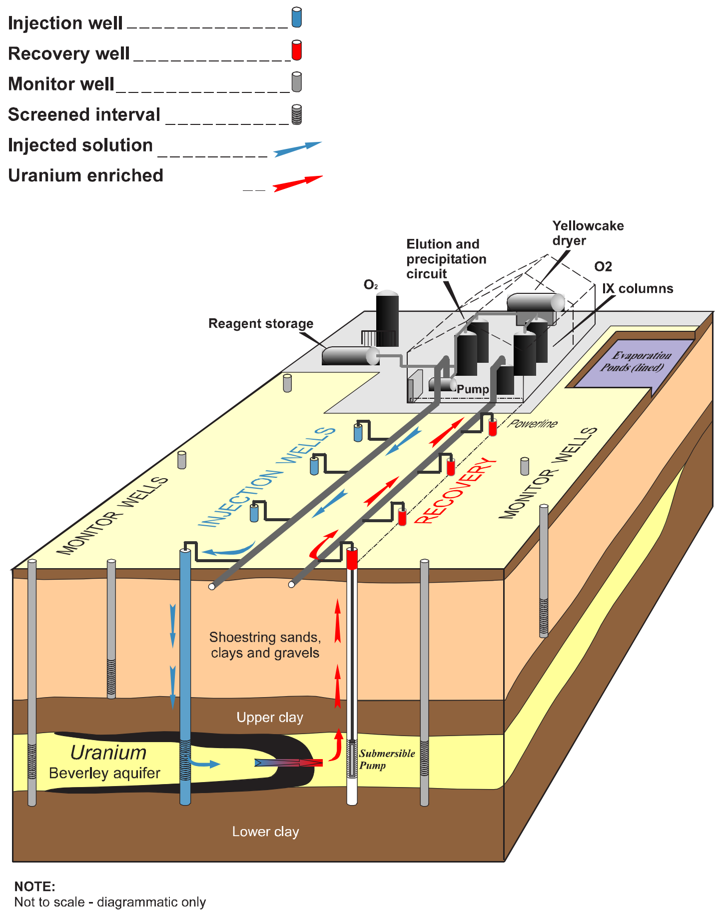

FIG. 31. ISL process at the Beverley Mine, demonstrating aquifer confinement and monitor wells.

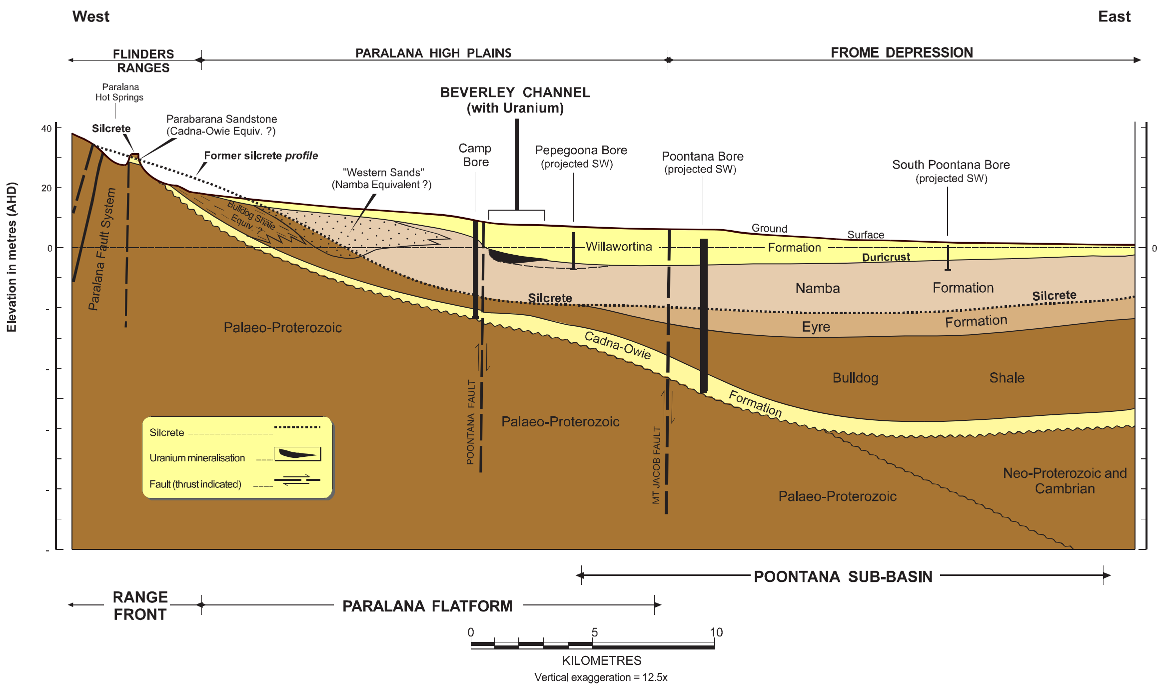

FIG. 32. Regional geological section demonstrating separation of Beverley Channel from GAB.

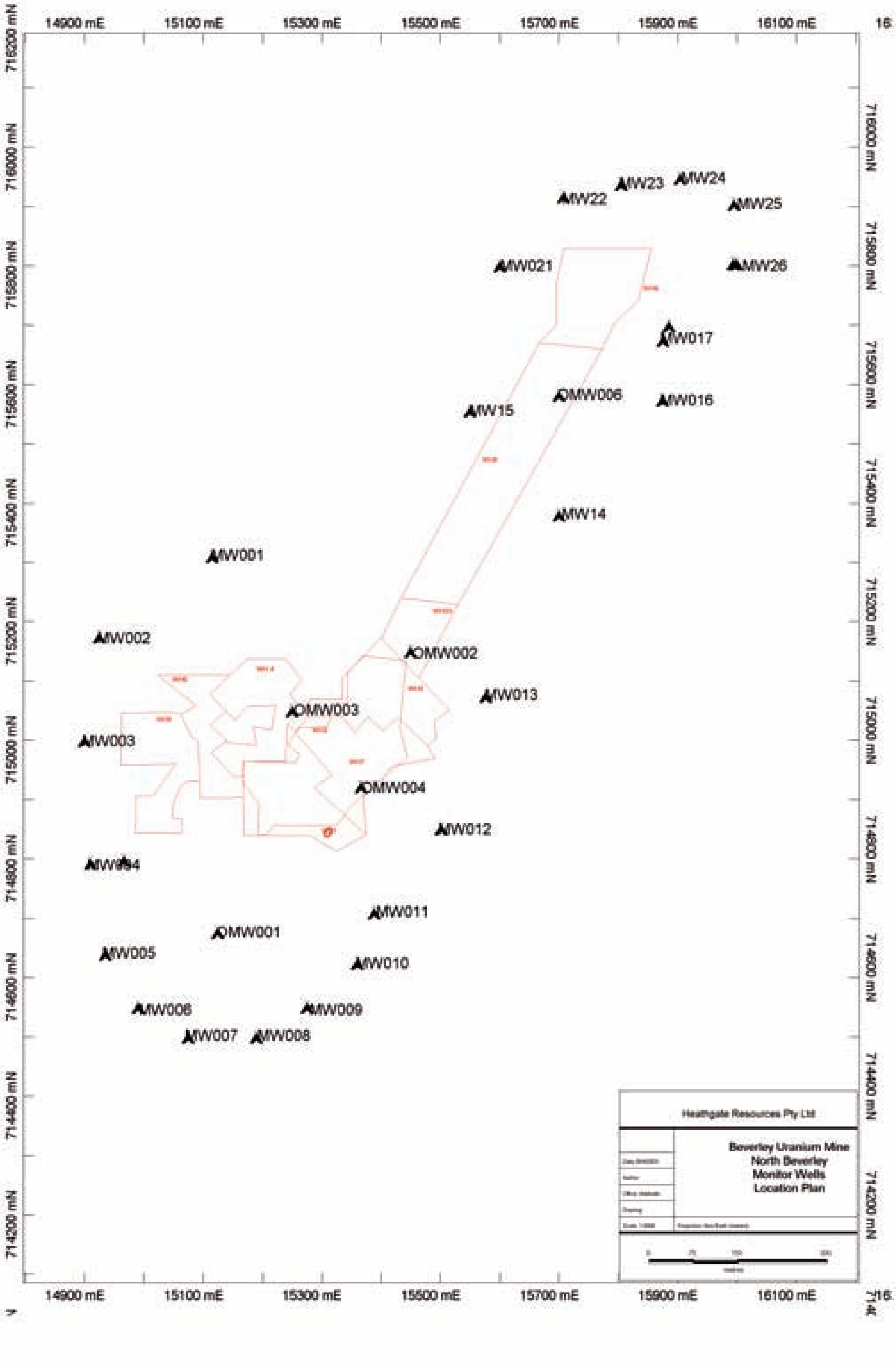

FIG. 33. Monitor wells in the North Beverley wellfield area.

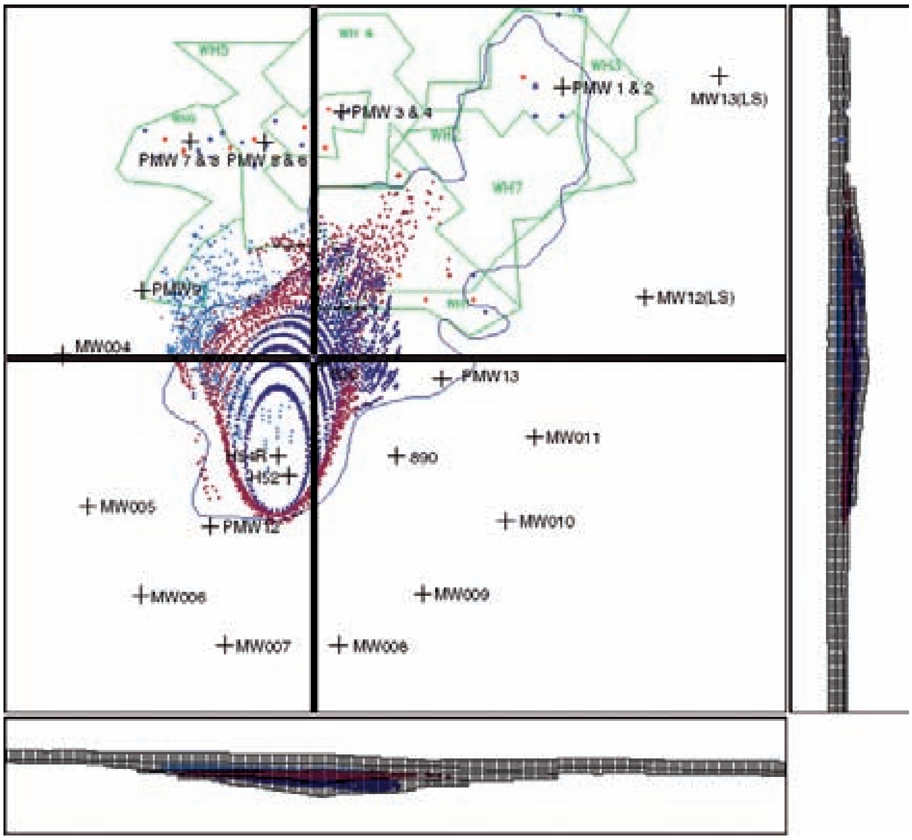

FIG. 34. Liquid waste disposal flow plume for life of mine (March 2004), demonstrating fluid control within monitor well ring.

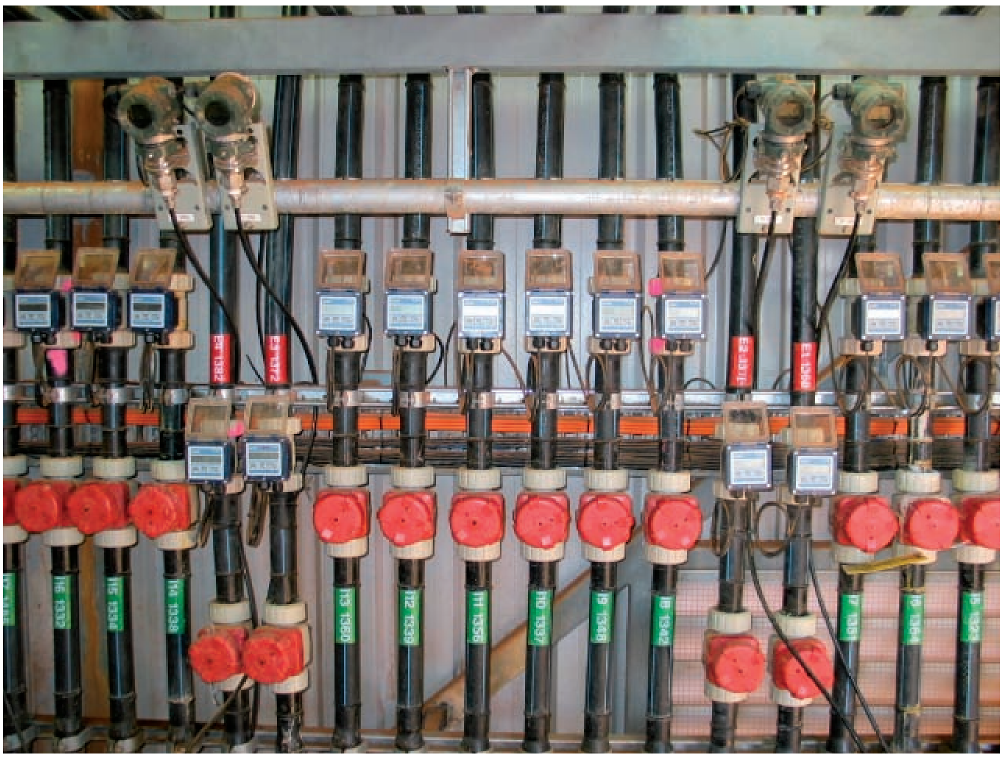

FIG. 35. Automatic sensing, control and shutdown installed within each wellhouse.

FIG. 36. Drip tray installed at each wellhead with vent valve modification and spill sensor.

FIG. 37. Capping free flow from four mile GAB bore and commencement of RO reject flow to wetland.

FIG. 38. Mining operations being conducted with creeklet and minimal surface disturbance.

WATER MANAGEMENT AT AUSTRALIAN URANIUM MINES

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Abstract

The Australian uranium operations are located in widely different climates, ranging from monsoonal conditions at the Ranger uranium mine in the Alligator Rivers region of the Northern Territory to semi-arid conditions in inland South Australia, where the Olympic Dam and Beverley operations are located.

This paper describes the range of water management strategies that are in place or planned to deal with the varying issues facing Australia's three operations. For Olympic Dam, the strategies are focused on water conservation and reuse, and evaporation of the acidic liquor arising from the leach process.

Net water usage at an in situ operation such as Beverley is considerably less than comparable underground or open pit mines as acidic leach liquor is recycled in the wellfields, and there is no water loss with tailings. However, bleeds are required to maintain control of wellfield balance and to limit the buildup of impurities. The disposal of the bleed stream into the mining aquifer via wells must be balanced carefully to ensure that it does not impact on mining or wellfield management.

Water management at Ranger has evolved considerably during its almost 25-year operating life. This is particularly the case over the last 8 years with the development of pit #3 and the deposition of tailings into the mined out pit #1. These changes, which have significantly increased the catchment area from which runoff water must be collected and managed, and the recent higher-than-average rainfall combined with the further expansion of pit #3 now have the potential to move the site water balances into significant surplus.

To address this risk, ERA has successfully investigated processes at the pilot plant scale that would complement the capacity of existing passive pond water treatment systems by allowing the treatment and release of pond and/or process waters. These processes, which are part of a number of strategies currently being considered for implementation at the Ranger site, are outlined.

1. INTRODUCTION

The Australian uranium operations are located in widely different climates, ranging from monsoonal conditions in the Alligator Rivers region to semi-arid conditions in the inland.

The Ranger uranium mine is in the Alligator Rivers region of the tropical "Top End" of the Northern Territory. This region lies partly within Kakadu National Park, a world heritage area of great natural beauty. The annual rainfall averages 1 500 mm, while evaporation is about 1 800 mm. The Olympic Dam copper/uranium and Beverley in situ uranium operations are located in the semi-arid inland of South Australia, with both sites only receiving around 190 mm per annum of rainfall and 3 000 mm per annum of evaporation.

Good quality groundwater is in abundant supply at Ranger, whereas the larger discrepancy between the rainfall and evaporation rates at Olympic Dam (ODO) and Beverley, require water to be drawn from underground aquifers, with ODO drawing from the Great Artesian Basin (GAB), and Beverley from a combination of the mining aquifer and the GAB. GAB water is slightly brackish and requires desalination for potable, and some process, uses. Both sites are restricted in their yearly use of GAB water.

These extremes in quality and availability of water have necessitated the development of total water management strategies at all the Australian sites. These strategies are continually evolving to take account of operating experience and changes to operating plans. The treatment and release and/or recycling of water are now being considered as part of these strategies. This paper describes the range of water management strategies that are in place or planned to deal with the varying issues facing Australia's three uranium operations.

WATER MANAGEMENT IN A TROPICAL MONSOONAL CLIMATE ZONE

2. WATER TREATMENT AT THE RANGER URANIUM MINE

Energy Resources of Australia Ltd (ERA), a subsidiary of Rio Tinto, operates the Ranger uranium mine, which has been producing since 1981 and is located in the Ranger Project Area approximately 250 km east of Darwin. Since the Project Area has been progressively surrounded by, but remains separate from, the World Heritage-listed Kakadu National Park, protection of the environment is a key operational concern.

The Ranger operation is a conventional milling, leaching, SX circuit that treats around 2 000 000 tonnes of ore per annum from an open cut pit to produce 5000 tpa of U_3O_8.

2.1. Current water management strategy

At ERA, water management is a key part of the overall site operational management and of key interest to stakeholders. Water management at Ranger has evolved considerably during its almost 25-year operating life. This is particularly the case over the last 8 years, with the development of mining pit #3 and the change from deposition of tailings in the dedicated tailings storage facility (TSF) into the mined out pit #1.

Water is characterized by quality into three (3) broad systems:

- Process water;
- Pond water (actively managed water); and
- Sediment control water (passively managed water).

The systems are shown in Figure 1.

The low-quality process water circuit comprises the processing plant, tailings disposal areas (a dedicated tailings storage facility and an exhausted open pit) and pipeline corridors. Process water reports to the pit #1 TSF, as part of the leach tailings slurry stream (tailings), for final storage of solids and decantation of liquor. Some liquor is returned to the plant as make-up process water with the remainder being stored or evaporated in situ or from the dedicated tailings storage facility to the south-west.

The pond water circuit comprises waters that have the potential to become contaminated by contact with mineralized material, such as the current open pit mine, ore stockpiles, and roadways. Pond waters at Ranger are captured via a network of drains and sumps before being pumped to Retention Pond 2 (RP2) or pit #3 for storage during the wet season. A significant volume of pond water enters the process water circuit via pit #1, and overflow from Retention Pond 3 (RP3). Pond waters are disposed of during the dry season via a passive treatment system. This system comprises a network of constructed wetland filters that strip out much of the dissolved uranium before dry-land irrigation.

Sediment control water is runoff from clean stockpiles and natural woodland areas and is collected in Retention Pond 1 (RP1), the Djalkmara Billabong and in the Corridor Wetland System (located to the west of the MBL bund). RP1 and the Corridor Wetland System overflow during the wet season, whereas Djalkmara Billabong is pumped to Magela Creek in accordance with strict release criteria.

2.1.1. *Quality approach to water management*

Between 1999 and 2002, a series of investigations were undertaken to refine the way water was managed at Ranger. Traditionally all waters coming into contact with mineralized material were captured and treated via the pond water management process, regardless of water quality. The current approach adopted allows the volume of water reporting to the pond water system to be reduced by diverting surface water runoff directly to the wetland filters. This involves preparing the top surfaces of low-grade stockpiles to retard infiltration and maximize rapid runoff. This water is conveyed to wetland filters for polishing before being released to controlled impoundments. A Whole of Mine Release model was developed to ensure that managed releases do not impact upon water quality at the downstream compliance point. The model considers water quality in the impoundments as well as flow in Magela Creek (the receiving environment). Flow from the impoundments is regulated to maintain compliance at all times.

2.2. Emerging water management challenges

Despite recent changes to reduce the volume of water requiring management, a number of scheduled and unplanned events now have the potential to move the site water balances into significant surplus. These "events" include:

- An increase in the area of ore and waste rock stockpiles, which have significantly increased the catchment area from which runoff water must be collected and managed;
- A series of five well above-average wet seasons;
- Expansion of pit #3, with the need to have full-year pit access. Pit #3 is currently used to store excess pond water in the wet season;
- The "loss" of the Djalkamara wetland filter (due to expansion of the pit), which currently treats about one third of the pond water prior to release to dry-land irrigation.

To address this risk, ERA has successfully investigated water treatment processes that would complement the capacity of the existing passive pond water treatment systems, by allowing the treatment and release of pond and/or process waters. These processes are part of a number of strategies currently being considered for implementation at the Ranger site.

2.3. Water treatment processes

Over the last three years, ERA has developed/investigated water treatment processes for process and pond water (see Table 1).

TABLE 2. COMPOSITION OF RANGER WATERS

		Process water	Pond water
pH		4.5	6.6–9
EC	mS/cm	18	1.5
Ca	mg/L	468	30
Mg	mg/L	2920	190–250
Mn	mg/L	1520	1
NH_4^+	mg/L	826	nd
SO_4	mg/L	16 800	800
^{226}Ra	Bq/L	12.6	5–7

Both processes went through the stages of laboratory testing, mini-plant confirmation and finally pilot plant trials on-site at Ranger. Both of these projects were a close collaboration between ERA, Rio Tinto Technical Services and ANSTO.

2.3.1. Process water treatment

The accumulation of excess process water in the pit has not only reduced the available storage capacity of the pit, which is nearing the current limit but also compromises the consolidation rate of the deposited tailings. Good consolidation is the key to not only maximizing the solids storage capacity of the pit, but in the long term is critical to minimizing the cost of capping the deposited tailings.

The development of the water treatment process is described in detail [1], and only the pilot plant experience is described here. The plant treated water with the composition shown in Table 1. The process consisted of the five treatment stages, as described below.

Stage 1: Primary softening

The purpose of primary softening is to remove most of the dissolved elements, particularly Mg and Mn and the associated sulfate. This was achieved by adjusting the pH to 10–11 by addition of milk of lime, precipitating metal hydroxides and gypsum. Other trace elements, such as U and around 50% of the radium are also removed during this step.

A thickener removed the precipitated sludge produced during this stage. A feature of the design was the recycle of thickener underflow via a conditioning tank to the first primary softening tank. Recycle increased the thickener underflow density to >40 wt%, reducing the water loss and also decreasing the concentration of Ca in the feed to stage 2.

Stage 2: Secondary softening

The supernatant from primary softening is saturated with calcium. The purpose of secondary softening is to remove most of the calcium as well as other minor impurities such as strontium, barium and the remaining 50% of the radium. If these elements were not removed, problems due to scale formation in the following reverse osmosis stage would result.

The calcium was reduced to levels acceptable for downstream processing by sparging with CO_2 to precipitate calcium carbonate at pH 8.5–9. Power station flue gas was an available source of carbon dioxide, or alternatively, soda ash can be used.

Normally a base would have to be added to counter the acidity of the CO_2 gas and maintain the pH in the desired region. However, the ammonium hydroxide formed in stage 1 buffers the pH, eliminating the need for base and resulting in significant cost saving.

Stage 3: Microfiltration (MF)

The supernatant from secondary softening was adjusted to pH 6.0 and then subjected to microfiltration to remove any submicron solid or colloidal particles. These solids would otherwise foul the reverse osmosis membranes and detrimentally affect operation.

MF removes all species greater than 0.035 μm.

Stage 4: Reverse osmosis (RO)

The RO was designed specifically to remove ammonia from the water, with a target rejection of greater than 94%. The bonus of the RO plant is that it rejects most of the other remaining species (i.e. calcium, potassium and sulfate) to a brine, leaving a permeate essentially pure, except for some residual ammonia.

Stage 5: Biopolishing

RO permeate is then sent to a final polishing wetland filter to biologically remove the residual ammonium. The water is then suitable for discharge from site.

A key factor in the overall strategy for the treatment of process water is to use the sludges produced in primary and secondary softening in the mill for the neutralization of the acidic tailings slurry. This will require careful management as it will have a long term implication for salt buildup in process water.

Pilot plant design and operation

Schematics of the lime treatment/carbonation and MF/RO sections of the pilot plant are shown in Figures 2 and 3. The lime treatment/carbonation section was designed to treat 1 m3/h of water. The capacity of MF/RO was 2 m^3/h, as this was the minimum available industrial size equipment. Consequently the MF/RO was run in campaign mode for 12 hours per day on the first pass, and the opportunity was also taken to test two-pass RO.

The pilot plant was operated on a 24-hour continuous basis for a number of campaigns over a three-month period. There were no major problems encountered during operation, and results were consistent with expectations generated from the earlier mini-plant work.

The concentration data for the key major and trace elements measured at each stage of the optimized treatment process are presented in Table 2.

Typical concentration data for RP1 at the mine have also been included in Table 2 for comparison. This is the most relevant set of data to use for first pass performance assessment, since RP1 water is currently allowed to be discharged off the mine lease. It can be seen that for most of the major cations (?) and trace metals[1], and the key radionuclide 226Ra, single stage RO was sufficient to achieve concentration levels comparable to or much less than those in RP1 water.

Apart from the anticipated higher levels of ammonium in the RO permeate, the results demonstrated that single stage RO treatment should produce water of a quality that will be readily amenable to final biological polishing (wetland treatment). Wetland treatment has been used successfully on a large operational scale over the past eight years at the Ranger mine for the treatment of non-process water containing low levels of Mn, U and nitrate. Although published wetland performance data indicate that wetlands should be readily capable of treating water containing 10–20 mg/L of ammonium, a full-scale test in the existing constructed wetland was carried out to confirm capacity and optimum conditions.

2.3.2. Pond water treatment

While the process and pond water are quite separate systems, recent initiatives to reduce the quantity of good-quality runoff water entering the process water system have increased the pond water inventory. This, coupled with the need to eliminate the storage of pond water in the mining pit during the wet season, will move the pond water balance into surplus. To prevent this occurring, ERA has been investigating treatment options for pond water release during the wet season. This water has a relatively low TDS, and the option therefore exists to treat this water by a relatively simple polishing process, as softening is not required.

These options could be implemented either together with an integrated plant to treat process water or independently of process water treatment. Depending on the quantity of pond water to be treated and the path of release, the simplest treatment process would need only to remove uranium and radium to target total concentrations of 0.6 mg/L and 0.3 Bq/L, respectively. Further polishing by wetlands and dilution would see all approved water quality standards at the off-site compliance point achieved.

After an extensive period of investigation of a variety of water treatment techniques, ERA has recently (2004) carried out a six-week pilot plant operation to test the viability of a preferred process for treatment of pond water. As shown in Table 1, the quality of pond water is significantly better than process water.

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[1] Note the high concentrations of Zn, Cu and in particular lead are attributable to contamination from material used in construction of the RO unit.

TABLE 3. PERFORMANCE OF PILOT PROCESS WATER TREATMENT PLANT [1]

Element:	Units	Process water	Post lime addition	Post carbonation	RO pass 1 permeate	RO pass 2 permeate	Retention pond 1
Ca	mg/L	468	626	30	0.8	0.1	3.1
Mg	mg/L	2920	56	81	0.4	<0.1	25.4
Mn	mg/L	1520	0.016	2.4	0.013	0.010	0.011
SO_4	mg/L	16 800	1930	2490	10.6	0.4	74.2
NH_3	mg/L	826	721	755	13.6	1.7	<0.05
Al	µg/L	12550	41	39	13	12	25
Br	µg/L	425	201	195	<10	<10	53
Cd	µg/L	20.5	0.4	0.4	0.2	<0.2	<0.2
Co	µg/L	1410	2.3	2.1	<0.1	<0.1	<0.1
Cu	µg/L	4070	34	41	13.1	3.0	0.8
Ni	µg/L	2790	31	12.9	3.4	0.2	1.9
Pb	µg/L	3670	43	34	35	23	0.3
U	µg/L	6660	7.98	11.9	0.40	0.39	21.4
Y	µg/L	9250	<0.1	1.9	<0.1	<0.1	<0.1
Zn	µg/L	2930	13	21	10	<5	<5
^{226}Ra	Bq/L	12.6	7.40	0.65	0.01	n/a	0.05

The flowsheet, shown in Figure 4, consisted of three treatment steps:

Stage 1: Radium removal

In stage 1, the dissolved radium concentration is reduced by co-precipitation with barium sulfate, following the addition of 5–10 mg/L of barium chloride. Residence time was 20–30 minutes. The pH was decreased to 3.5 by addition of sulfuric acid to destroy any bicarbonate in the feed water. The presence of carbonate/bicarbonate reduces the uranium removal efficiency in stage 2.

Stage 2: Uranium removal

In stage 2, uranium was adsorbed from solution at pH 6–8 by ferric hydroxide flocs. The flocs were formed by the addition of 20–30 mg/L of ferric sulfate, with the addition of sodium hydroxide to control pH, in a flash mixing tank, with a ~2-minute residence time. A second mixing tank was provided for ease of pH measurement

Stage 3: Clarification

The suspended solids produced in stages 1 and 2 contain the precipitated uranium and radium. Efficient removal to a total suspended solids (TSS) of < 2 mg/L is required to achieve the target concentrations in treated water. Solids removal was achieved in stage 3 by flocculation and clarification. A conventional clarifier design and the patented ACTIFLO® process for clarification were compared for this stage.

A ferric flocculation process for removal of uranium was chosen for this application, as the addition of a coagulant is required, in any case, to ensure capture of the fine Ba/Ra sulfate precipitate, and the ferric hydroxide/U sludge can be returned to the plant uranium leach circuit, where the uranium is re-dissolved and recovered, and the ferric ion can act as an oxidant in the uranium leaching process.

Pilot plant design and operation

The pilot plant was designed to treat a nominal pond water flow of 1.2 m^3/h, but flows up to 2.3 m^3/h were tested. The circuit design was quite flexible, and various reagent addition sequences, sludge recycle conditions and residence times in the various stages were examined.

As expected, efficient clarification was essential to meet treated water total uranium and radium targets. It was found that addition of 2–4 g/L of graded sand with polymer to a small mixing/coagulation tank prior to the clarifier (the ACTIFLO® process) resulted in significantly improved rise rates. In practice, the sand is collected from the clarifier underflow by cycloning and returned to the process. Using this approach, a rise rate > 10 m/h could be achieved, compared to 0.7–0.8 m/h for a conventional clarifier.

Selected data from the pilot plant operation for a rise rate in the clarifier of 10–20 m/h, with the addition of sand, are presented in Table 3. The pilot plant operation confirmed the robustness of the selected process, and that treated water targets were readily achievable under optimized and steady clarifier operation.

2.4. Conclusions

The results from bench and large scale pilot plant testwork confirmed the technical viability of the proposed flowsheet for treatment of process and pond waters at the Ranger Uranium Mine. ERA is now well progressed in an assessment of the preferred strategy for reducing the volumes of pond and process water on-site. At this stage, treatment of both waters in an integrated plant may provide the greatest flexibility in terms of matching desired treatment rates and the capacity of potential receiving systems.

WATER MANAGEMENT IN ARID REGIONS

3. OLYMPIC DAM TOTAL WATER MANAGEMENT

3.1. Background

The Olympic Dam deposit is one of the world’s largest polymetallic ore bodies. Operation commenced in 1988 at an ore production rate of 1.5 million tonnes per year from the underground mine. Uranium and copper production rates were 900 and 45 000 tonnes per year, respectively. Since startup, several optimization/expansion projects have been undertaken that increased copper production to 85 000 tonnes per year.

TABLE 4. REMOVAL OF RADIUM AND URANIUM IN POND WATER PILOT PLANT

Dissolved ^{226}Ra (Bq/L)					Total ^{226}Ra (Bq/L)
Feed	Ra circuit tank 2 FFT2	Flash mix tank 1 FMT	Clarifier feed tank CFT	Clarifier overflow	Clarifier overflow
4.5	0.1	0.14	0.17	0.22	0.31
4.3	0.1	0.10	0.12	0.20	0.32

Dissolved U (mg/L)					Total U (mg/L)
Feed	Flash mix tank 1 FMT	Second mix tank FFT3	Clarifier feed tank CFT	Clarifier overflow	Clarifier overflow
2.9	0.1	0.3	0.2	0.18	0.5
2.9	0.25	0.1	0.28	0.30	0.6

[#] For $BaCl_2$ dose of 10 mg/L and Fe dose of 15 mg/L.

A major expansion costing US $1.9 billion was completed in 1999 to increase capacity to approximately 4500 tonnes of U_3O_8 and 235 000 tonnes of Cu and 100 000 ounces of gold per year. In May 2004, WMC Resources announced funding of US $50 million for the next stage of a pre-feasibility study to help determine whether there should be a multi-billion dollar expansion to double the capacity by the end of the decade.

The overall flowsheet at Olympic Dam is very complex because of the co-production of uranium, copper, silver and gold. However, in terms of water management, the uranium processes tend to dominate.

3.2. Water supply

The Olympic Dam mine and the township of Roxby Downs receive water supply from one of the largest underground water resources in the world, the Great Artesian Basin (GAB). The GAB covers about 1/5th of the area of Australia and is accessible in remote desert and semi-arid pastoral country. The water is slightly brackish and while suitable for cattle and industrial purposes, requires desalination for potable uses.

WMC (Olympic Dam Corporation) Pty Ltd has a Special Water Licence from the South Australian Government, which limits consumption by requiring that it cause a pressure draw-down of less than 5 m at specified boundary monitoring bores. Under the original hydro-geological model, this 5-m draw-down equated to approximately 42 ML/d (currently, Olympic Dam is extracting 32 ML/d from the GAB). By implementing savings in pastoral use, it may be possible to extract more than 42 ML/d without exceeding the draw-down limit.

Water from the GAB is provided from two wellfields located approximately 120 km and 200 km north of the mine site. Water is pumped from artesian wells via two 600 mm-diameter pipelines to a reverse osmosis plant and water storage facility at the mine site. At the mine site, various grades of water are produced for purposes including industrial process water, potable water, high-grade RO water and demineralized water for high-pressure boilers.

Protection of the groundwater dependant ecosystems known as GAB mound springs is of prime concern and importance to WMC Resources. There are several hundreds of these unique systems within the area of the two wellfields. These water production bores are located to minimize impacts on the ecosystems, and continued monitoring and hydrogeological modelling is carried out. A report for public release is provided to the government authority on a yearly basis. WMC's monitoring continues to show that any impacts are within predictions made in major Environmental Impact Statements published in 1982 and 1997.

To conserve the resource and reduce potential impact on the GAB, WMC Resources is actively pursuing a bore closure programme in conjunction with the Australian federal and South Australian governments. A number of free-flowing bore drains on pastoral properties have been replaced with networks of poly-pipe. This programme in 2003 has resulted in 92 bore drains being replaced with 320 km of reticulated piping to produce an expected water saving of 23 800 megalitres per year (WMC web site).

Water usage estimates from the Great Artesian Basin in South Australia are shown in Table 4 [2, 3].

3.3. Water use

Olympic Dam Operations is a totally integrated mine and metallurgical complex, which includes mining, mineral concentration, hydrometallurgy, pyrometallurgy and refining processes. Water is used in various qualities and quantities throughout the plant. Where possible, a hierarchy of uses of various quality streams is carried out to maximize the use of the GAB water supplied to the plant. In the concentrator, process water is used for milling and

TABLE 5. GAB USAGE IN SOUTH AUSTRALIA

	Megalitres/year	Megalitres/day
Pastoral bores	47 450	130
Mound springs	24 090	66
Gas and petroleum industry	8030	22
Roxby Downs township	1095	3
WMC	10 585	32
Vertical leakage	78 475	215

flotation, and high-compression dewatering thickeners are used to maximize the return of process water to the concentrator and minimize the amount of process water carried forward into the acidic hydrometallurgical circuit.

In the hydrometallurgical circuit, sulphuric acid is added to leach uranium from tailings and concentrate streams. In this area of the plant, there is opportunity to use acid solutions for a number of purposes such as dilution and cooling. Use is made of raffinate and liquor from the tailings evaporation ponds for these purposes.

In the smelter, high-quality blowdown water from the waste heat boilers is returned to the process water stream. Other waste streams are pumped to the de-slimes (?) thickener where the water combines with acidic liquor and is used for dilution of the feed to the mine backfill sand cyclones.

The majority of the water entering the plant eventually ends up in the tailings retention system (TRS). Acidic liquor or water from the tailings is decanted to evaporation ponds, and part of this liquor is recycled back to the hydrometallurgical plant for reuse. Table 5 shows typical water quality for GAB, process water, tailings discharge water and evaporation pond return liquor.

Evaporation pond liquor is recycled to the hydrometallurgical plant at a rate of 50 to 100 m^3/h where it is used for dilution or cooling. The copper and uranium levels are concentrated by solar evaporation and, on return to the processing plant, are recovered consecutively by copper and uranium solvent extraction. The liquor can be added back into the circuit at a number of points upstream of the solvent extraction plants.

The deleterious species in the evaporation pond liquor are the chlorides, ferric sulphate and silica. The impact of chloride ions cannot be avoided, as they carry through into uranium SX, where they tend to load up on the amine affecting the extraction efficiency of the process. The amount of evaporation liquor recycled is managed to prevent an excessive buildup of chloride in the pregnant liquor solution. Additional amine is added to the uranium SX circuit to offset the affect of higher chlorides on extraction efficiency. The impact of ferrous and ferric ion in the return solution is less significant and is dependant on where the solution is returned within the hydrometallurgical plant. Added to tailings leach or CCD, some of the ferric ion may be consumed by the leaching process along with part of the returned acid.

Figure 5 shows the site water balance for Olympic Dam Operations in 2003 [4].

TABLE 6. COMPOSITIONS OF VARIOUS WATERS USED AT OLYMPIC DAM

	Units	GAB water	Process water	Tailings liquor	Evaporation pond liquor
pH		7.6	8.2	1.02	≤ 1
Conductivity	µS/cm	3600	5390	65 900	
TDS	mg/L	2000	3000	18 000	
Calcium	mg/L	23	38	910	1260
Magnesium	mg/L	25.5	42.3	320	
Sodium	mg/L	760	1100	2750	
Potassium	mg/L	22.9	33.1	690	2000
Chloride	mg/L	668	1080	2816	7643
Sulphate	mg/L	122	222	39 300	132 000
Fluoride	mg/L	3	3.4	3300	
Sulphuric acid	mg/L	—	—	13 300	24 000
Total alkalinity (as $CaCO_3$)	mg/L	773	1020	—	
Silica	mg/L	22	27	400	2500
Iron	mg/L	<1	<1	11 000	28 000
Copper	mg/L	—	—	550	3000
Uranium	mg/L	—	—	35	444

3.4. Tailings retention system

The tailings retention system (TRS) consists of tailings surge tanks, delivery to storage dams, deposition system for tailings retention, liquor decantation system, evaporation ponds and evaporation liquor return system.

Tailings are collected in the process plant at the tailings surge tanks and from there are pumped via a pipe corridor to the tailings storage facility. The tailings are deposited in a controlled manner around the perimeter of tailings dams or cells using the subaerial deposition technique. There are currently four cells in the tailings retention facility with a volume of some 46 million cubic metres and occupying some 400 hectares. The cells are raised at a rate of 1 to 2 m per year and will have a forecast completion height of 30 m [2]. Tailings are deposited in thin layers to form tailings beaches at outlets placed along the edges of the retention cells. The sloping beaches that form allow the supernatant liquor in the tailings to drain to a low point in each of the cells.

Liquor collected in the tailings retention cells is decanted to evaporation ponds. These ponds are lined with 500 mm of compacted clay and have a synthetic geomembrane lining, including 1.5 mm thick HDPE, geotextile, where needed, and pipe boots and seals [2]. A management programme is in place to monitor and control the environmental performance of the evaporation ponds and tailings retention system. The tailings and acidic liquor system is shown in the photograph in Figure 6 (Figure 44?).

3.5. Future plans

As part of an expansion study about to commence, WMC Resources will be carrying out a detailed investigation of options for future water to supply the needs of a significantly larger operation. Such sources could include:

- Water from the coast at Port Augusta (desalination would be required);
- Water from the GAB;
- Tailings water, neutralized with local dolomite.

Calcined dolomite has been shown to be an effective neutralizing agent, but treatment costs were very high.

4. WATER MANAGEMENT AT BEVERLEY

4.1. Project background

Discovered in 1969, it was not until Heathgate Resources (HGR), a subsidiary of General Atomics (GA), obtained ownership that the Beverley Project was developed with a field leach trial in 1998 [5], and the construction of a 1000 tonne per annum plant in 1999.

The deposit consists of ore lenses in a mineralized channel within unconsolidated sand at a depth of 110–140 m, over a minable length of around 4 km. The ore lenses are concentrated in three main confined bodies (North, Central and South Beverley), with a total of 21 000 tonnes of uranium grading 0.18%.

Beverley is located in an arid region where the temperature from November to March can exceed 40°C regularly and where the average mean maximum temperature is over 30°C. During the winter months, mean maximum temperatures are around 15°C. Average annual evaporation for the region ranges from 2500 mm to 3700 mm, with the expectation of long term evaporation rates being around 3000 mm. This compares with the average yearly rainfall of only 192 mm.

This large discrepancy between rainfall and evaporation means that there is no access to surface water for the mining operation.

4.2. Process description

Uranium is present in the Beverley ore zone primarily as coffinite. The deposit is mined utilizing the in situ leach process, where the natural groundwater is fortified with an oxidant, and the pH is maintained between 1.6 and 2.5 with sulfuric acid.

In-situ leach mining, illustrated below for the Beverley operation, is a relatively low-impact mining method, in that there is minimal surface disturbance, no tailings disposal requirement, simple plant removal on completion of mining, relatively simple rehabilitation once a wellfield has completed its operational phase and comparatively little contaminated waste produced.

The lixiviant is pumped via a series of injection wells into the permeable orebody, where the uranium is leached from the ore. The resulting solution is pumped back to the surface via a series of extraction wells to the processing plant. The barren lixiviant from the plant is then re-fortified and recycled back to the injection wells.

The process plant consists of three trains of IX columns capable of treating in excess of 300 L/s of lixiviant, with a head grade of up to 200 mg/L. Each of the trains comprises five down-flow, rubber-lined, steel vessels containing anion exchange resin. Four of the columns are for capture, one for elution and one resting, with valving designed so that the columns can be configured in any arrangement of lead, tails, elution or resting. This design allows for continuous loading and elution of ion exchange resin.

The barren lixiviant from the ion exchange columns is pumped back to the wellfield, with the exception of a bleed stream of up to 5% of the total flow, which is directed to the plant holding ponds.

Elutions are undertaken by the application of high-ionic strength solutions (sulfate/chloride) to the loaded resin, producing a pregnant solution in excess of 10 g/L U_3O_8. Uranyl peroxide is precipitated by the addition of hydrogen peroxide and caustic soda, followed by thickening, washing, and finally drying of the precipitate to produce an 80% U_3O_8 final product.

4.3. Sources of water

The water for the operation is drawn from two main sources; the mining aquifer (Namba) and the Great Artesian Basin (GAB). The compositions of these waters are compared in Table 7.

The Namba Aquifer

The Namba aquifer is the confined aquifer associated with the uranium mineralization and is the main source of water for the project. The aquifer is essentially a closed system with water taken from the area prior to or near the mining operation and the bleed from the process fed back to the aquifer. Despite the poor quality of the Namba fluid, it can be used for a number of process water applications and is the dominant water supply used for:

- The make-up of elution solutions;
- Water for the drill rigs and air-lift water;
- First wash of the precipitated product.

The annual use of the Namba water is around 200 ML.

TABLE 7. COMPOSITION OF BEVERLEY WATER SOURCES

Element	Unit	Namba	GAB
Ca	(mg/L)	400	30
Na	(mg/L)	2000	750
Mg	(mg/L)	200	12
Cl	(mg/L)	3000	900
SO_4	(mg/L)	2000	60
^{226}Ra	Bq/L	50–1000	?
pH	—	7	8
Conductivity	(mS/cm)	9.6	3.6

The Great Artesian Basin (GAB)

The GAB water usage is lower, and due to its better quality, it is used for:

- Final washing of the product;
- Feed to the potable water RO plants;
- Dust suppression on roads;
- Periodic dilution of the lixiviant;
- Plant washdown.

The amount of GAB water is limited to less than 57 ML per annum.

4.4. Wellfield balance

It is important that the overall balance of water in the ore zone aquifer be maintained to limit the possibility for excursions of mining fluids under excessive pressures and to discourage the excessive ingress of groundwater from parts of the palaeochannel outside the mining zones.

This balance is maintained and controlled by a ring of ‘monitoring’ wells around the mining area. The accurate sampling and assay of these wells and other wells inside the monitor wells allows HGR to measure and then model the flows of mining fluid and aquifer water throughout the system. The monitor wells and ore outline for the central orebody are shown below in Figure 8 (Figure 46?).

4.5. Disposal of excess process liquor

Wastewater from the process plant consists mainly of fluid that is bled from the elution circuit, as it builds up in chloride concentration. This fluid is re-injected back into the Namba aquifer inside the monitoring well ring. Obviously the injection of this fluid must not impact on the mining operation and the environment outside the monitor well ring, and as such careful planning and attention is paid to the location and the volume of water injected into the aquifer.

The Namba formation shows signs of natural attenuation with increases in the pH of the wastewater, and this aids in the management of the fluids.

Due to the requirement of the process to maintain a slight inflow of fluid into the well-field and the small usage of GAB in the plant there is a buildup of process fluid over time. This balance is addressed by the use of four ponds that allow the evaporation of fluid prior to re-injection into the Namba aquifer.

Figure 9 shows diagrammatically the major and minor flows of water into and out of the process plant.

4.6. Impacts of water quality on the process

The largest impact of the water quality on the process is the effect of the chlorides on the loading potential of the IX resin. As HGR utilizes an anionic resin, the chlorides compete for sites with the uranium complex formed in leaching, $(UO_2(SO_4)_3^{-4})$. Testwork has indicated that the concentration of the chlorides in the lixiviant strongly affects the amount of uranium loaded on the resin. Higher concentrations of chlorides in the lixiviant, approaching 7000–9000 mg/L can reduce the resin loading capacity by twofold.

Consequently, the make-up water for the Beverley project should be as low as possible in chlorides, and GAB would be perfect in this regard (as shown in Table 6). However, the GAB is an important aquifer for a variety of purposes throughout South Australia, and the operation is limited to minimal use of the GAB water. Consequently Namba water is used for this process application.

4.7. HGR plans for the better management of water

In addition to the existing water management program, HGR is in the process of improving water management by a five-stage approach that:

- Reduces the quantity of disposal fluid;
- Controls the lixiviant composition to minimize unwanted ion concentrations (specifically chlorides);
- Reduces HGR's requirements for Namba and GAB water via recycle of water streams;
- Manages the lixiviant ionic concentrations via implementation of a water treatment system;
- Reduces the quantity of bleed required to manage ionic concentrations.

The five stages of development are:

(1) The installation of evaporation ponds. The addition of extra ponds will enable the Beverley Operation to decrease the amount of disposal fluid. An area of around 30 000 m^2 is proposed, and at a net evaporation rate of around 2100 mm per annum (lower than the pan evaporation rate due to the effects of large water bodies and suppression of rates from acidic liquors), this equates to in excess of 60 ML per annum of fluid that will evaporate rather than be injected back into the aquifer. This reduction will aid HGR in maintaining a slightly negative water balance and will be more flexible in water management, allowing more time for natural attenuation of ions in the aquifer.

(2) The introduction of a water recycle (recycling?) programme within the plant. This will involve the treatment of the disposal fluid (membrane treatment system or other) to maximize the amount of water recycled. It is envisaged that this recycle would reduce by around 50% the amount of both disposal fluid and fresh water make-up.

(3) The implementation of a desalination plant to remove unwanted ions. This is likely to operate at around 3 to 10 L/s, would be designed to specifically target chloride ions in the lixiviant and is likely to treat the Namba mining aquifer prior to mining, although the testwork on this concept in not yet completed.

(4) The implementation of a two-stage water treatment plant that would produce via pH modification two streams, one for feeding a desalinization plant and the other a small waste stream. This concept has been tested in the laboratory and on a pilot scale, and removes calcium, chlorides as well as sulfates from the lixiviant.

(5) The implementation of testwork and study of the natural attenuation of the ions in the water re-injected into the aquifer. This testwork is likely to be undertaken in conjunction with one of the local universities.

5. CONCLUSIONS

Water management at the Ranger and Olympic Dam mines has continued to evolve as these operations mature. Unlike most mine sites in Australia, Ranger has had to address the issue of surplus water and has successfully implemented and developed a number of passive and active water treatment systems to suit the needs of the unique environment in which they operate.

At Olympic Dam, emphasis has been on refining the water management systems as production capacity and water usage have increased. Important reductions in water use have been made by maximizing recovery and recycle of neutral water at the front end of the process, thereby reducing input to the acidic hydrometallurgical circuits and recycling acidic liquor from the evaporation ponds to the hydrometallurgical circuits.

Water quality and management is very important to the ongoing success of the Beverley operation. Reducing the volume of water injected back into the aquifer by the introduction of extra evaporation and/or plant recycle will allow for more flexible operation of the wellfield, reduce the amount of 'fresh' water required for the plant and allow longer time for natural attenuation to occur. The management of the chloride levels in the process water is also important for the operation with ongoing work to develop methods to deal with this issue.

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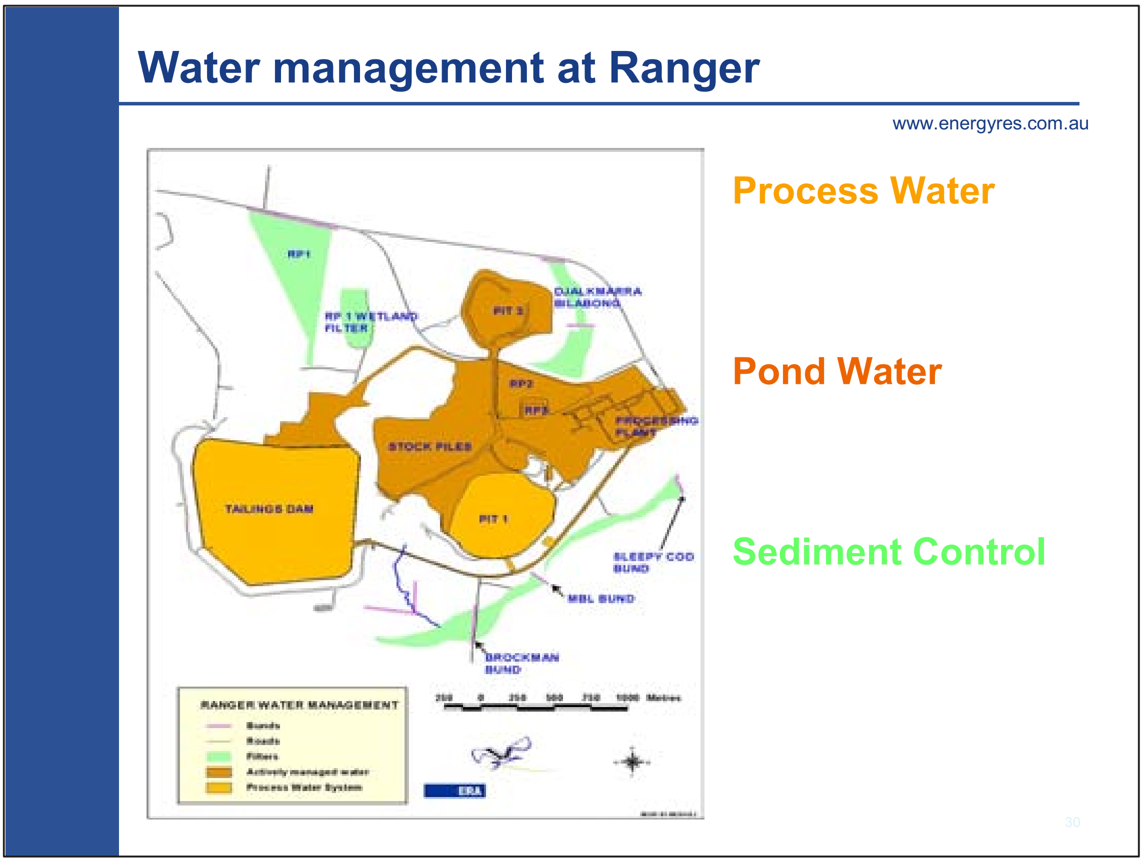

FIG. 39. Water management scheme at Ranger.

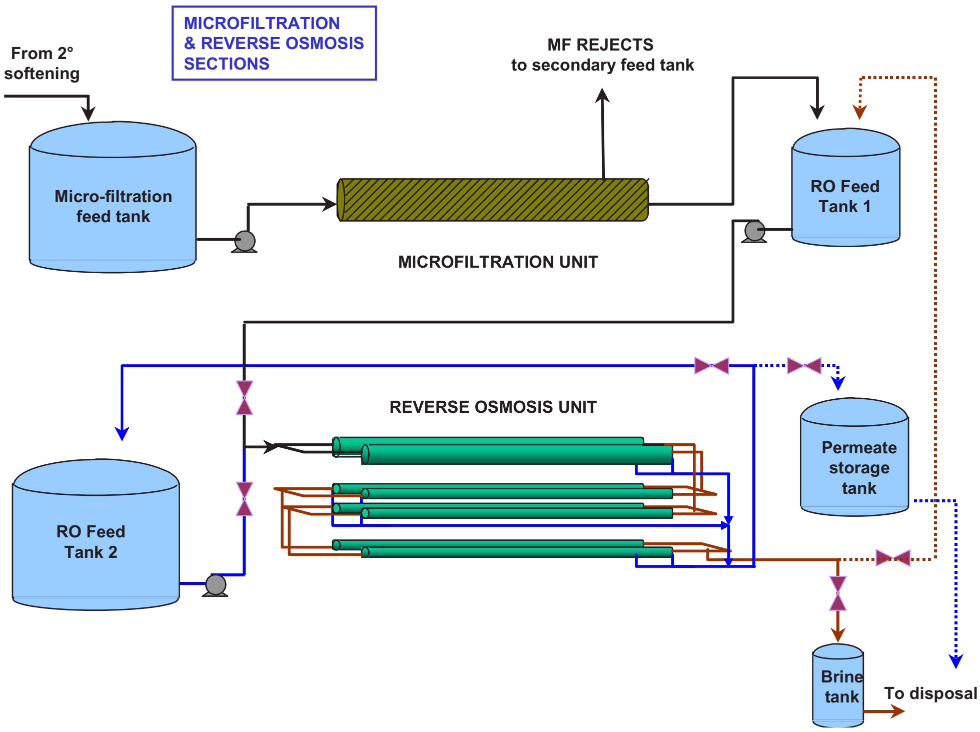

FIG. 40. Schematic of lime addition and carbonation stages.

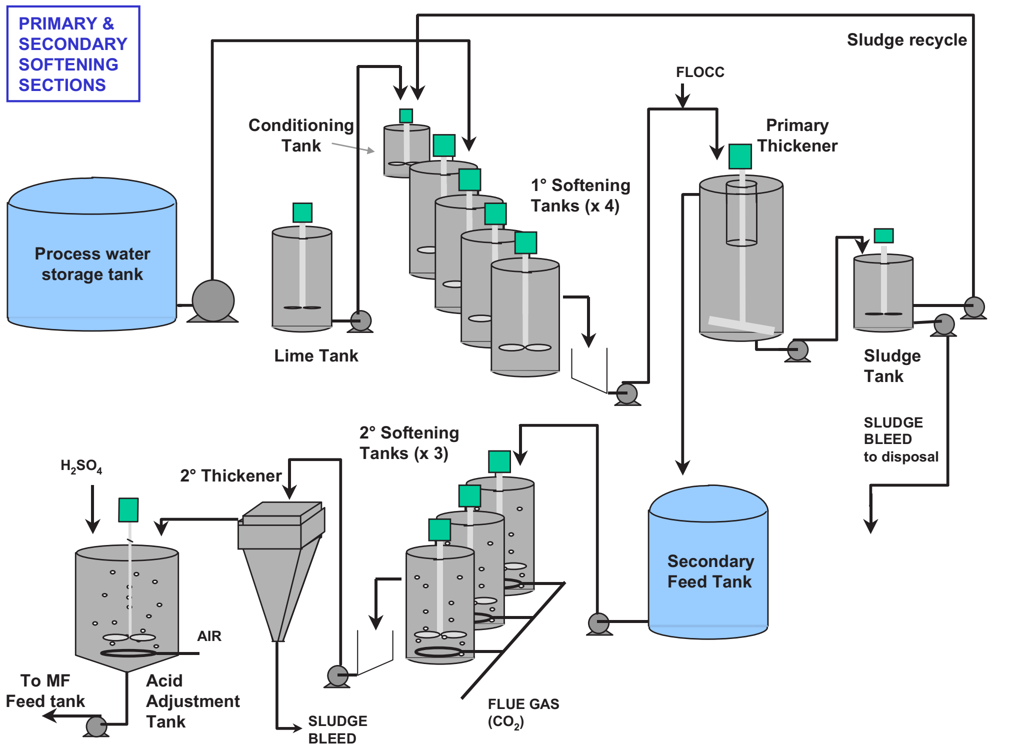

FIG. 41. Schematic of microfiltration and reverse osmosis stages.

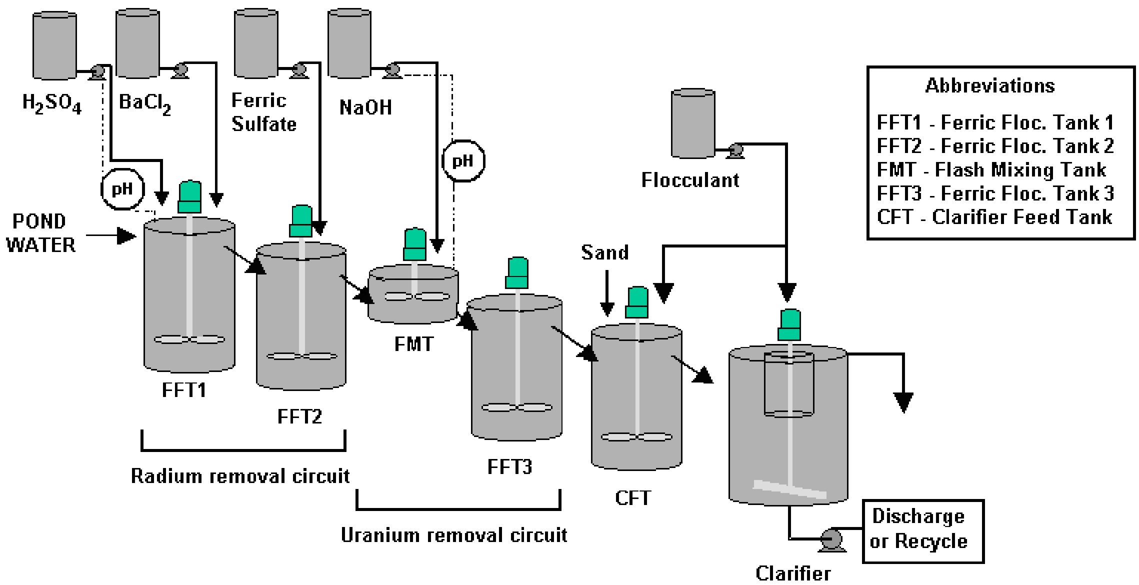

FIG. 42. Schematic of pond water pilot plant.

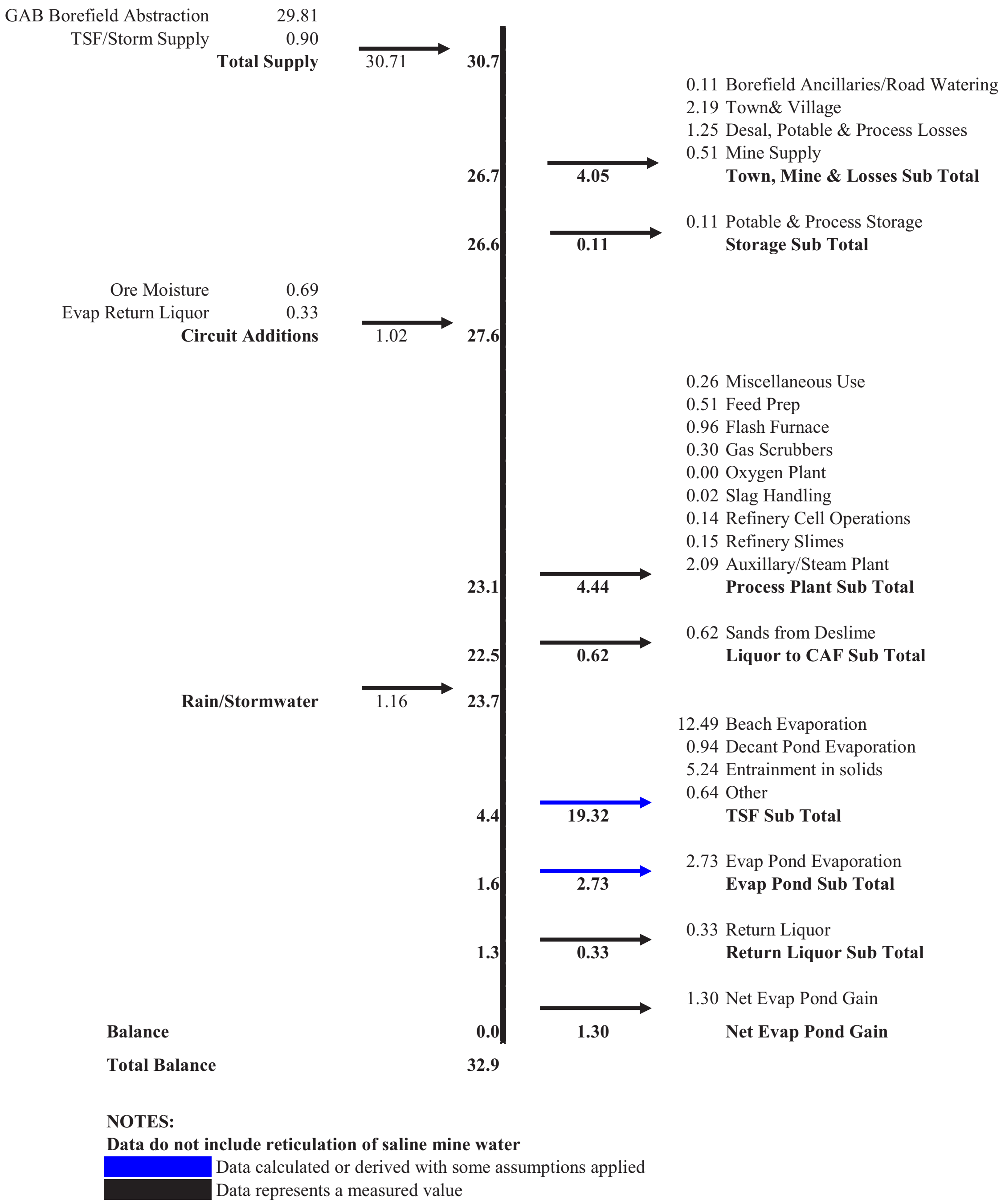

FIG. 43. Olympic Dam water balance in 2003.

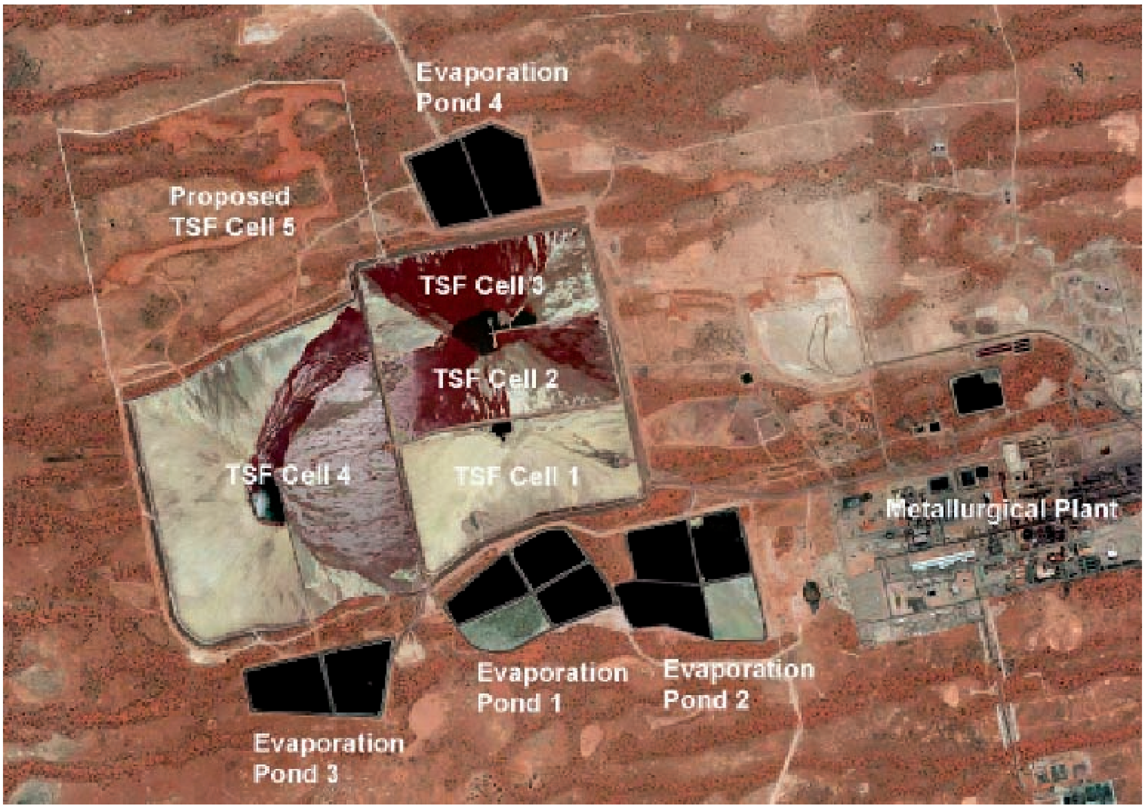

FIG. 44. Olympic Dam tailings retention and acid liquor evaporation.

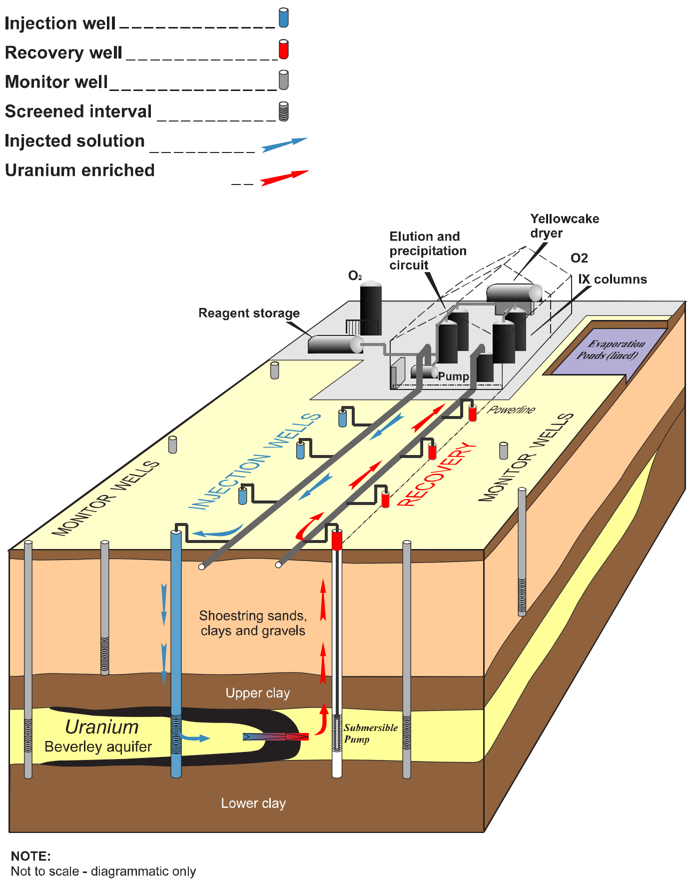

FIG. 45. Schematic of in-situ operation.

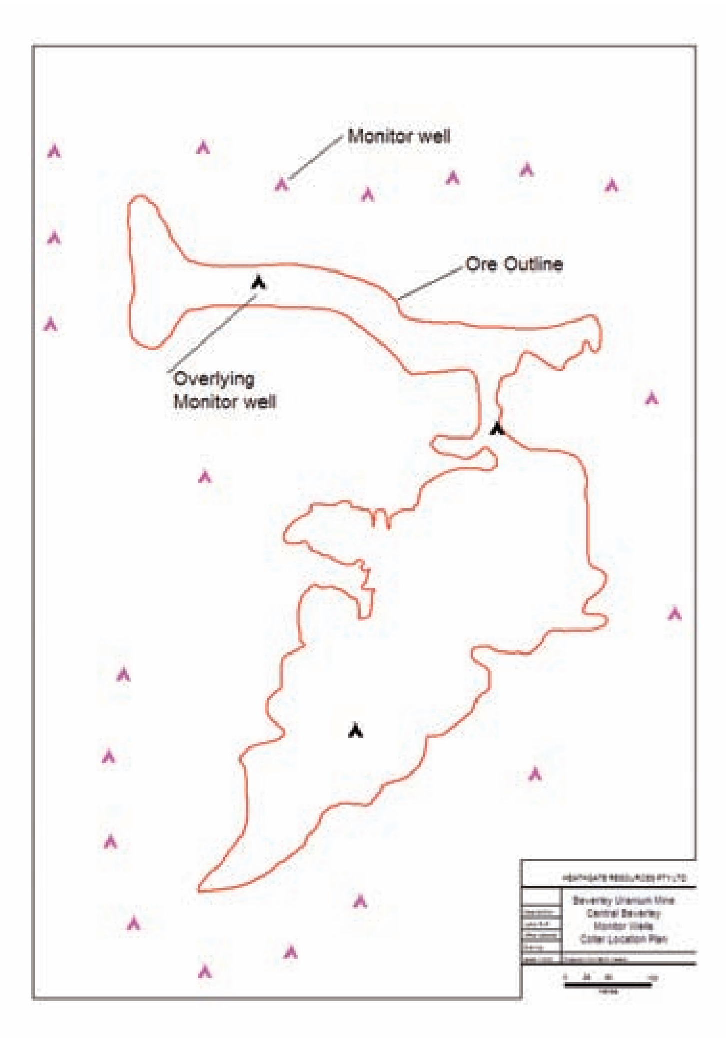

FIG. 46. Layout of Beverley central orebody.

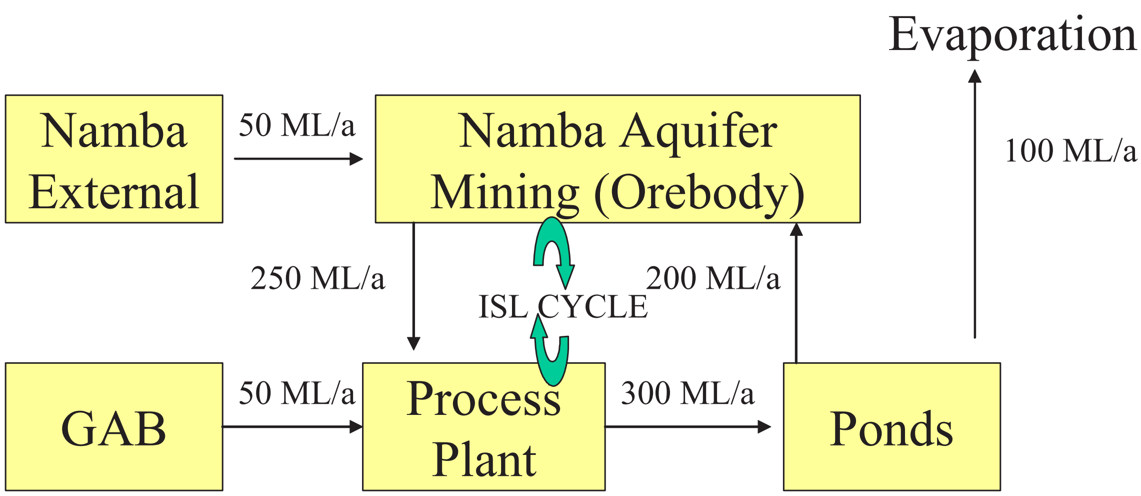

FIG. 47. Beverley water flows.

ENVIRONMENTAL MANAGEMENT STUDIES RELATED TO NEW BRAZILIAN URANIUM MINING AND MILLING

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1. INTRODUCTION

The new uranium project in Brazil is located in the Caetite municipality, in the semi-arid northeastern State of Bahia. This region has rainfall rates of 800 mm/a. Its known resources were estimated to be 85 000 t U at below US $80/kg U cost category.

The ore is mined by open pit methods, and uranium is extracted by acid heap leaching.

Figures 1a and 1b give an overview of the mine pit and one of the ore heaps (under construction).

At startup, this centre will have a nominal production capacity of 250 t/year and there are plans for expansion to 430 t U/year [1]. The conceptual operation plan did not include liquid effluent releases into the environment. Milling wastes are deposited in ponds covered with geotextile membranes. Liquid solutions are drained by means of subaerial drains and recirculated into the process. Leaching solutions are stocked in similar ponds prior to entering the process.

For mining operations, it is vital to plan for minimization of impact at the earliest stages, as few changes in layout are possible once operations have commenced. Accordingly, it is important that the company manages the Environmental Impact Assessment (EIA) process professionally and impartially from the outset, and carry out regular auditing after operations commence.

The company should set itself measurable environmental targets. These targets don’t need to be fixed in the licensing process (nuclear licensing and environmental licensing taken into account) since the implementation of Environmental Management Systems (EMSs) is still a voluntary action in Brazil. Because of the voluntary aspect of an EMS, it is important that the company recognize the valuable contribution of such a thing and implement management systems as soon as possible.

Obviously, there must be personnel with environmental expertise who carry out regular monitoring and report to top management. Senior management should require periodic audits of environmental performance. There should be adequate finance and staff to carry out these activities.

Many companies have found from experience the value of integrating environmental, health, and safety management. This integration may be regarded as a starting point for the present study case, since the Brazilian regulatory nuclear requirements already determined that the company should hold an implemented Quality Management System prior to the granting of any authorization.

2. PRELIMINARY ACTIONS TOWARDS THE IMPLEMENTATION OF THE EMS

In the implementation of an EMS one has to consider various approaches before deciding how to settle on the correct course of action. Ideally it should encompass the basic elements in the ISO 14001 standard, addresses the significant environmental needs, supports development of a good compliance infrastructure, integrates well with the existing management structure and systems, fosters continuous improvement, and engages all who should be engaged. Some methods are reported [2]:

- Fixing the gaps
- Environmental aspects
- Internal audits
- Documentation
- The beginner's filing system
- Custom-made

In our study, we decided to start with the definition of the relevant environmental aspects (i.e. the potential for an environmental impact). A good starting point is the elaboration of Material Safety Data Sheets (MSDSs) for all hazardous substances used and produced by the facility. This list does not preclude the characterization of the waste streams, including air emissions, wastewater, and solid and hazardous wastes to determine the applicability of air and water pollution control and waste management regulatory requirements.

Therefore, another important step is to correlate the environmental aspects with many of the environmental regulatory requirements that apply to the facility.

For the sake of simplicity, the environmental aspects were categorized in three major areas:

- Mining activities (Open pit area, ongoing operations)
  - Mining operations (excavation, land movement, etc);
  - Dust emissions;
  - Drainage water infiltration;
  - Radon exhalation;
  - Suspended solids transport;
- Milling activities (Heap leach areas, industrial facilities)
  - Dust emission caused by ore crushing;
  - Radon exhalation;
  - Water abstraction;
  - Ponds (containing uranium solution) leakage.
- Waste repositories (Leached ore, waster rock piles, tailings ponds) should envisage reasonable efforts to reduce effluent concentrations as low as possible.
  - Radionuclide and heavy metal leaching from the leached/waste rock piles;
  - Suspended solids transport;
  - Water infiltration.

The regulatory requirements concerning both the radiological and non-radiological aspects are compiled and put together in a spreadsheet in order to link a specific requirement to the pertinent environmental aspects. Limits, whenever applicable, are tabulated for each environmental compartment. However, it must be kept in mind that according to the prevailing radiation protection philosophy, the impacts should be as low as reasonably achievable (the ALARA principle).

The associated environmental impacts related to the above environmental impacts can be tabulated as:

- Environment impacts
  - Destruction of natural habitat at the mining site and at waste disposal sites;
  - Destruction of adjacent habitats as a result of emissions and discharges;
  - Changes in rivers' regimes and ecology due to siltation and flow modification (not so significant as rivers are not perennial);
  - Alteration in water tables;
  - Change in landform;
  - Land degradation due to inadequate rehabilitation after closure (to be examined in detail in the next step of the project);
  - Land instability;
  - Danger from failure of structure and dams.

- Pollution impacts
  - Drainage from mining sites and pumped mine water;
  - Sediment runoff from mining sites;
  - Effluents from mineral-processing operations (ideally the plant operates in a closed system);
  - Soil contamination;
  - Leaching of pollutants from tailings and disposal areas, as well as contaminated soils;
  - Air emissions from mineral processing operations;
  - Dust emissions from sites close to living areas or habitats.

It is important to observe that pollution from waste dumps (tailings ponds) may last considerably longer than the economic life of the mine. In addition to this observation environmental emergencies also need to be taken into consideration.

The aspects and impacts management flow diagram (Fig. 2) describes the sequence of management events inherent in the aspects and impacts identification and management process.

The process flow displayed includes a double feedback loop mechanism (identified in the lower portion of the chart) that allows for stakeholder input, reinforces management feedback, and refines organizational learning in the EMS process. The feedback and inputs loops are key to integrating aspects and impacts with facility planning and management. Improvement in organizational learning is critical to the ultimate success of the continual improvement process.

As a result of the above flow diagram objectives and targets need to be set. At the present stage of our study this is the point at we are implementing now. Establishing objectives and targets has to take into consideration the policy, environmental aspects, and legal and other requirements. Some already identified objectives may be pointed out:

- Increase uranium recovery in the leaching process (the leached wastes should no represent a significant source of pollution);
- Establishment of an efficient drainage management system in order to avoid the release of contaminated water into the environment as a result of heavy rainfall events.
- Decrease the use of waste disposal are by means of the adoption of more adequate waste disposal strategy;
- Minimize the use of clean water to reduce the consumption of underground water in the industrial operations;
- Development of sustainable economical activities so that local population may increase their living standards.
- Improvement of communication with local communities.

The last objective is articulated within the Ministry of Science and Technology (MCT) and is part of the Project Semi-Arid Thematic Network. The project consists of a partnership involving IRD, INB along with the National Observatory (ON) and Center for Mineral Technology (CETEM). As it has been mentioned before, the area is not supported by perennial watercourses. The local population depends to a great extent on rainfall to produce food for their subsistence. In dry years, the situation can turn out to be critical. This project has a very important component of social responsibility and is addressed to identify underground water resources; provide water of good quality for human consumption and for agriculture; provide water treatment whenever applicable (e.g. desalinization); provide use for the residues of water treatment; provide continuous monitoring of these waters and assist the local population with technical support for the sustainable development of economical activities. Other mining areas in Brazil have already been identified in order to start up similar approaches.

3. PRELIMINARY RESULTS

In order to monitor the potential impacts associated with the mining and milling operations, a comprehensive and detailed monitoring programme was designed and is being developed by the mining company. The programme includes ambient radon measurements, sampling of groundwater, superficial waters, soil, aerosols, foodstuff, sediments and effluents. Samples are analysed for ^{226}Ra, ^{228}Ra, ^{210}Pb, U_{tot}, Th_{tot}.

Whenever appropriate, sample pH values are measured. In addition, heavy metals and relevant anions are also determined in water samples.

In the plant licensing stage, it was considered that the critical environmental aspects would be dust emissions from the pit operations and comminution to reduce particle size. However, it was observed by means of the monitoring programme that some radionuclide groundwater concentrations began to increase in the area of the mine pit. As groundwater is a very sensitive environmental compartment in this region and one of the only water resource supplies to the population, attention has been focused on understanding the possible causes of this phenomenon. In addition to this, heavy rainfalls observed during summer have caused undesired liquid effluent emissions into the environment. Seepage waters from the waste rock/leached ore piles probably caused the observation of above background uranium concentrations in these effluents. However, it is not probable that mine pit waters have influenced these concentrations. Table 1 shows the average concentrations of the relevant radionuclides in the leached ore. The results come from the sampling of six heaps after the sulfuric acid leaching.

The figures in Table 1 represent total concentration values. However, after the sulfuric acid leaching, it may be the case that a relevant fraction of the total content may still be available.

Despite the fact that these emissions were not of relevance in respect to radiological impacts into the environment, the overall management plan will have to be revised in order to meet appropriate standards. On the other hand, the impacts associated with dust emissions, causing the potential deposition of radionuclides onto agricultural items, did not show so far to be of any significance. Table 2 shows the average radionuclide contents in the soil of the area surrounding the mine site.

Radionuclide concentration in the soil of the area surrounding the mine site is lower if compared with samples from the Poços de Caldas Plateau, especially if Th and ^{228}Ra contents are taken into consideration. The reason for that relies on the geological formation of both areas. In the Lagoa Real Province, the uranium mineralization occurs in albitites, which are characterized by the presence of sodic plagioclase, aegirine-augite andradite with the rocks being a product of intensive Na-metassomatism of granitic-gneissic, and migmatitic rocks. The deposits are monomineralic, the uraninite being the sole economic mineral. The uranium mineralization occurs in elongated, lenticular albitite bodies. In the case of Poços de Caldas uranium is associated with molybdenum and zirconium. The principal host rocks of the uranium mineralization are tinguatites, phonolites and pyroclastic rocks where diffuse mineralization and "pockets" of reduced soil, preserved in oxidized rocks, may be found. However, the most outstanding issue arising from soil studies is that no significant increase in radionuclide concentrations has been observed if data of the pre-operational stage are taken into account. This information allows us to assume that emissions into the atmosphere will not be a major issue in terms of radiological impacts; however, this assumption demands some more evidence to be formally accepted.

TABLE 8. Radionuclide concentrations in different foodstuffs cultivated in the surrounding areas of the mining site are shown in Table 3. Data from the Poços de Caldas Plateau are also shown in parenthesis for the sake of comparison. It can be seen that despite the higher soil radionuclide concentrations at Poços de Caldas the content in Lagoa Real samples are at least one order of magnitude higher.

TABLE 1. RADIONUCLIDE CONCENTRATIONS IN THE LEACHED ORE HEAPS AFTER LEACHING

Activity concentration in MBq/tonne				
U_{total}	Th_{total}	Ra-226	Ra-228	Pb-210
11.88	0.07	25.99	0.57	20.37

TABLE 2. RADIONUCLIDE CONCENTRATIONS IN SOILS [3]

U_{total}	Th_{total}	Ra-226	Ra-228	Pb-210
100 +/– 41	95 +/– 24	80 +/– 33	94 +/– 31	97 +/– 34

TABLE 3. RADIONUCLIDE CONCENTRATIONS IN VEGETABLES ($Bq.kg^{-1}$) [3]

	U_{total}	Ra-226	Pb-210	Th_{total}	Ra-228
Black beans	1.52×10^{-2}	1.41×10^{-2} (4.0×10^{-3})	4.05×10^{-2} (3.40×10^{-3})	2.89×10^{-3} (1.4×10^{-4})	3.55×10^{-2} (7.5×10^{-3})
Corn	2.18×10^{-3}	1.38×10^{-3}	5.29×10^{-3}	3.45×10^{-4}	4.02×10^{-3}
Manioc	1.61×10^{-3} (6.2×10^{-4})	7.15×10^{-3} (3.3×10^{-3})	5.14×10^{-3} (2.4×10^{-3})	4.03×10^{-4} (6.0×10^{-5})	2.33×10^{-2} (6.40×10^{-3})
Pasture	2.8×10^{-2}	3.4×10^{-2}	2.4×10^{-2}	3.7×10^{-3}	4.5×10^{-2}

The estimated effective dose incurred by local inhabitants due to the ingestion of black beans, corn and manioc, cultivated in neighbor areas (with average concentrations equal to those in Table 3) of the mining area would be about 1.33 μSv/a. In these calculations, the dose conversion factors recommended at the IAEA BSS [4] were used. Ingestion rates similar to those reported by Amaral [5] were taken into consideration.

The estimated dose is low enough to pose undue health risks to the population. It must be expressed that the calculated value is associated to natural concentrations since no evidence of impacts (concentration increase) caused by the mining and milling operations were observed so far. Despite this evidence, populations of neighbouring cities are still concerned about the potential radiological impacts caused by the industrial operations. It is evident that an improvement in the communication process with the local communities must take place.

4. CONCLUSIONS

Some of the actions/studies to be considered as a result of this preliminary assessment should involve:

i) Modeling the mobilization and transport of radionuclides from the waste rock/leached ore piles → in order to define if these entities are really relevant sources of pollution, especially in the case of heavy rainfall;
ii) Waste disposal area minimization → the potential advantages of the co-disposal of milling wastes along with the leached ore must be addressed;
iii) In connection with the above item, the long term efficiency of the milling wastes depositional systems must be evaluated;
iv) Geochemical modeling of the water-rock interaction in order to understand the increase of radionuclide concentrations in groundwater under the influence of mining operations;
v) Revision of the relevant socioeconomical aspects and their possible relationship with the potential impacts caused by the plant operations → intensive communication campaigns must be put into place;
vi) Investment in the development of sustainable economical activities by the local communities.

DISCLAIMER

This work is, at the present moment, an academic/research initiative. Most of the information in the text comes from M.Sc. and D.Sc. studies that are being developed altogether in an articulated operational framework. Neither IRD nor INB have any responsibility for the pieces of information and points of view expressed in the text.

ACKNOWLEDGEMENTS

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FIG. 1a. Mine pit.

FIG. 1b. Uranium ore heap.

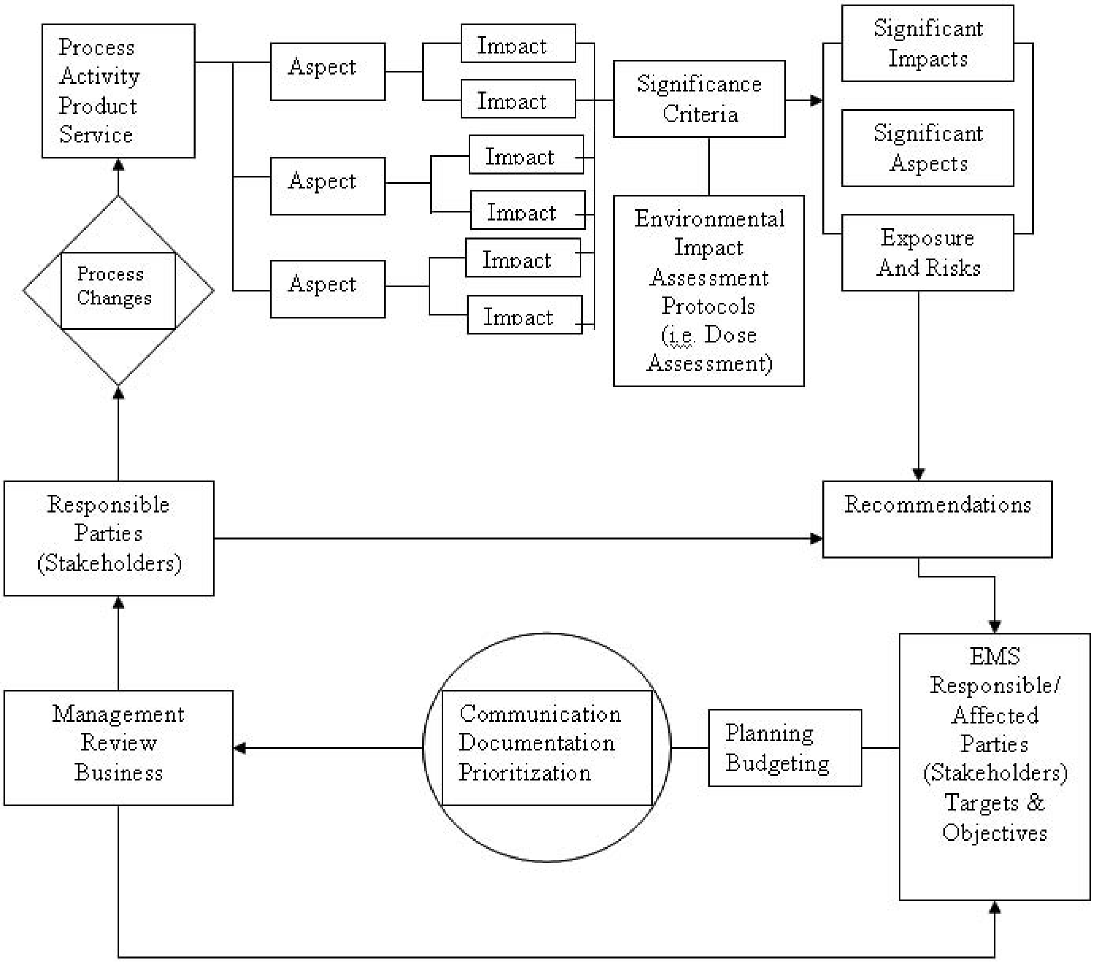

FIG. 2. Aspects and impacts management flow diagram [2].

ENVIRONMENTAL MANAGEMENT OF THE POCOS DE CALDAS OPEN PIT MINE*

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Abstract

The Pocos de Caldas mine is located in the district of Caldas, in the southwest of the Minas Gerais state of Brazil. Prior to the startup of the Lagoa Real mine in 2001, it was the only facility in Brazil where uranium concentrate was produced. The facility is an open pit mine with a surface diameter of 1000 m and an average depth of 120 m. Some 47 million m^3 of overburdened ore and waste have been mined from the pit. About 1250 tonnes of uranium concentrate were recovered. The mine was closed in 1995, and actions were undertaken by INB to restore adequate environmental conditions to the site. The treatment of water percolating the waste rock pile is placing a burden on the company. The treatment consists of neutralization of the acid water percolate with CaO, recovery of the precipitate and its dumping into the open pit. Experiments have been carried out for the covering of the waste rock pile with native vegetals. The results have been promising. The chemical installation was adapted for the production of rare earth composites from monazite ore. Production is now starting with an installed annual capacity of 450 tonnes of cerium oxide and 1800 tonnes of lantanium chloride. INB is now starting a process which calls for the contracting of a specialized entity for the establishment of a global environmental restauration programme.

* Only an abstract is given here as the full paper was not available.

PLANNING FOR DECOMMISSIONING AT THE CLUFF LAKE URANIUM MINE IN NORTHERN SASKATCHEWAN*

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Abstract

COGEMA Resources Inc., part of the Areva Group, is a Canadian company with its head office in Saskatoon, Saskatchewan. It owns and operates mining and milling facilities in Northern Saskatchewan, where it produces uranium concentrate. The Cluff Lake Project operated from 1981 to 2002, producing more than 60 million pounds of concentrate. This paper discusses the development of the decommissioning plan. The decommissioning plan for the Cluff Lake Uranium Mine has recently been approved by the Minister of the Environment following a comprehensive study under the Canadian Environmental Assessment Act. The plan involves soil covers for an above-ground tailings area and a waste rock pile with acid generating properties, flooding of two open pits and two underground mines. A large mill and associated infrastructure will also be demolished and disposed within a backfilled pit. Several alternative methods were considered for the decommissioning of each of the major areas. Protection of the aquatic environment is a key long term consideration. Success of the decommissioning will be judged by comparison to objectives for water and sediment quality. Surface water will meet Saskatchewan Surface Water Quality Objectives (SSWQO), with the exception of iron, which is naturally elevated in the groundwater fed lakes of the area. As there are no SSWQO for uranium, molybdenum or cobalt, site-specific criteria were developed from scientific literature. A series of benchmarks for sediment quality were considered as well as pertinent information available in the scientific literature. Additionally, radiological clearance criteria have been developed which are protective of the public and ensure the safe use of the area for traditional purposes after decommissioning. Extensive hydrogeological modelling was conducted to select the most appropriate environmental options. This included the development of a regional groundwater flow model, extensive waste rock sampling and testing, tailings characterization and contaminant transport modelling. Modelling offered a methodology to quantitatively compare the principal alternatives for each area and provided an opportunity to assess and minimize the key sources of potential environmental impact. Environmental effects were compared through the use of ecological risk assessment techniques. This assessment included risk to biota as well as to humans, taking into consideration the predicted post-decommissioning use patterns. A comprehensive follow-up programme has been developed to monitor the key risk areas and demonstrate that the assumptions made with respect to the modelling are appropriate and that the decommissioned site will perform as designed.

* Only an abstract is given here as the full paper was not available.

CANADIAN EXPERIENCE IN DECOMMISSIONING OF URANIUM TAILINGS FACILITIES — ELLIOT LAKE, CANADA*

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Abstract

Commencing in the 1950s, a total of approximately 12 uranium mining operations were commissioned primarily near Elliot Lake, Ontario. Many of the mines operated for only a few years before being shut down. Beginning in the early 1970s, reactivation of four mines in the Elliot Lake area commenced. The Denison Mine was owned and operated by Denison Mines Limited. The Quirke, Panel and Stanleigh Mines were owned and operated by Rio Algom Limited.. With the discovery of high-grade uranium deposits in Northern Saskatchewan and the slump in uranium prices as a result of the end of the Cold War, decommissioning of the Elliot Lake Uranium Mines began in the early 1990s. Studies related to the decommissioning commenced in the late 1980s. The last operating mine, the Stanleigh Mine, was closed in 1996. The permitting, operation and decommissioning of uranium mines in Canada is primarily regulated by the Canadian Nuclear Safety Commission (CNSC), formerly the Atomic Energy Control Board (AECB). However, the provincial Departments of Environment are also involved in the process. Studies related to the decommissioning of the Denison, Quirke, Panel and Stanleigh mines commenced in the late 1980s. The Environmental Assessment Panel issued its report "*Decommissioning of Uranium Mine Tailings Management Areas in The Elliot Lake Area*" in June, 1996. Monitoring, care and maintenance of the sites is ongoing. This paper will review the process of closure planning and the review process for these mines.

* Only an abstract is given here as the full paper was not available.

ENVIRONMENTAL AND QUALITY MANAGEMENT SYSTEM AT AREVA/COGEMA RESOURCES, INC.*

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Abstract

COGEMA Resources Inc. (part of the Areva Group) is a Canadian company with its head office in Saskatoon, Saskatchewan. It owns and operates mining and milling facilities in Northern Saskatchewan, where it produces uranium concentrate. The company is also active in uranium exploration, decommissioning and joint ventures with other organizations at various operating sites within Canada. The company has adopted an integrated approach to environmental and quality management of all its operational activities, which comprise a complete cycle from uranium exploration to development to mining and milling through to decommissioning. This commences with exploration projects mainly in the Athabasca Basin of Northern Saskatchewan, continues with the McClean Lake site — a uranium mining and milling facility that started production in 1999 and closes with the decommissioning of the Cluff Lake site — a uranium mine which ceased production in 2002. The system is designed to provide an integrated approach to ensure that: All activities are conducted in a safe and efficient manner, meeting all applicable regulatory and internal requirements; the requirements of the ISO 14001 standard are met; The principles of sustainable development are implemented throughout the organization. To this end, the McClean Lake site and exploration activities (both were the first for the uranium industry within Canada) are ISO 14001 certified, while the Cluff Lake site should follow very shortly. The development of the integrated management system and operational experience are discussed with examples drawn from the various operating activities. Challenges and further development opportunities will be mentioned.

* Only an abstract is given here as the full paper was not available.

HYDROGEOLOGY AND GROUNDWATER MODELLING OF THE COLLINS CREEK BASIN*

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Abstract

COGEMA Resources Inc. (part of the Areva Group) is a Canadian company with its head office in Saskatoon, Saskatchewan. It owns and operates mining and milling facilities in Northern Saskatchewan, where it produces uranium concentrate. Understanding groundwater flow at the regional scale underlies long term predictions for the performance of decommissioned tailings management facilities and waste rock disposal sites. A three dimensional regional groundwater flow model was developed to update and integrate the hydrogeological information relevant to environmental assessments or licensing analyses of the JEB, Sue, McClean Lake and Midwest sites operated by COGEAM Resources Inc. in Northern Saskatchewan. The regional model is based on a comprehensive geological and hydrogeological database, including more than 4200 exploration boreholes, 1000 hydraulic conductivity test results and water levels recorded at approximately 150 monitoring wells. Monthly surface water and groundwater quality data are also available from approximately 1996. The model was calibrated on both pre-mining and dewatered conditions. It was used to identify the hydraulic role of key regional features, including numerous surface water bodies, major fracture/fault zones and the sandstone unit, which constitutes the main aquifer over the study area. The regional model was also used to identify natural boundaries for local sub-models, which were extracted for the purpose of predicting post-decommissioning flow and contaminant transport from the Sue C Pit waste rock disposal area and from the JEB Tailings Management Facility. A follow-up programme was identified based on the data analysis and the results of the regional model. The follow-up programme includes research-related and ongoing actions, with the objective of improving the robustness of model predictions for regulatory purposes and optimizing monitoring as data continues to be collected.

* Only an abstract is given here as the full paper was not available.

CANADIAN NUCLEAR SAFETY COMMISSION REGULATION OF URANIUM MINES AND MILLS

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Abstract

The Canadian Nuclear Safety Commission (CNSC) is responsible to the public as its primary stakeholder for carrying out the mandate of the *Nuclear Safety Control Act* (NSCA). The CNSC regulates the use of nuclear energy and materials to protect health, safety, security and the environment and to respect Canada's international commitments on the peaceful use of nuclear energy. One of the areas of control from the NSCA stipulates that no person shall mine or process uranium except in accordance with a licence issued by the CNSC. The NSCA further stipulates that the CNSC may not issue a licence unless it is of the opinion that the applicant is qualified to carry out the activity that the licence authorizes, and that in carrying out the activity, the applicant will make adequate provision for the protection of the environment, the health and safety of persons, the maintenance of national security and measures to implement international obligations to which Canada has agreed. In order to safely manage the uranium mine facility and monitor compliance with regulatory requirements, the CNSC: 1) sets and documents clear requirements, using a process that includes public consultation; 2) verifies that the operator's processes and programmes satisfy regulatory requirements; 3) provides stakeholders with the opportunity to be heard; 4) bases decisions on thorough, unbiased assessments performed by CNSC staff of objective, factual evidence; and 5) assesses the performance of licensees with respect to their protection of the environment, as well as the health and safety of persons and security. The paper will describe these activities in the context of best environmental protection practices and the CNSC licensing and compliance processes for existing, new or historical legacy uranium mine facilities.

1. INTRODUCTION

The Canadian Nuclear Safety Commission (CNSC) regulates uranium mining to prevent unreasonable risk to the environment, to the health and safety of persons and national security, and to achieve conformance with Canada's international obligations. As the theme of this meeting is "Best Practices in Environmental Management," the scope of this paper will be limited to regulation to prevent unreasonable risk to the environment from uranium mining and milling facilities.

The CNSC's regulatory programme is based on two accountability principles:

- Those persons and organizations that are subject to the *Nuclear Safety and Control Act* and associated regulations are directly responsible for ensuring that the regulated activities in which they engage are managed so as to protect the environment; and
- The CNSC is responsible to the public for regulating persons and organizations that are subject to the Act and associated regulations in order to assure that they are properly discharging their obligations.

It is the policy of the CNSC that the measures taken by licensees to protect the environment should:

- Be commensurate with the likelihood and significance of adverse environmental effects;
- Recognize that variability exists in environmental effects as a consequence of differences in regulated activities, substances, equipment, facilities, the environment, and its human components;
- Recognize that uncertainty exists in science, and therefore, prevent unreasonable risk by keeping all releases to the environment as low as reasonably achievable, social and economic factors taken into account (ALARA); and
- Be judged against performance indicators and targets, which are based on sound scientific knowledge.

2. REGULATORY FRAMEWORK

The Canadian Nuclear Safety Commission works within a legal framework that includes law and supporting regulatory documents. Law includes such legally enforceable instruments as acts, regulations, licenses and orders. Regulatory documents such as policies, standards, and guides support and provide further information on these legally enforceable instruments. Together, law and regulatory documents form the framework for the regulatory activities of the CNSC.

The *Nuclear Safety and Control Act* (Act) prohibits uranium mining except in accordance with a licence issued by the CNSC. It further stipulates that the CNSC may not issue a licence unless it is of the opinion that the applicant is qualified to carry on the activity that the licence will authorize and that in carrying on the activity, the applicant will make adequate provision for the protection of the environment. The Act also grants the Commission authority to make regulations respecting uranium mining and milling. The principle requirements for uranium mining and milling may be found in the following regulations:

- General Nuclear Safety and Control Regulations;
- Uranium Mines and Mills Regulations;
- Radiation Protection Regulations;
- Nuclear Substances and Radiation Devices Regulations; and
- Packaging and Transport of Nuclear Substances Regulations.

A regulatory policy is a document that describes the philosophy, principles and fundamental factors that underlie the Commission's approach to its regulatory mission. It is issued for the guidance of Commission staff and the information of stakeholders.

Policies related to environmental protection include:

- P-223, Protection of the Environment, February 2001;
- P-290, Draft Regulatory Policy – Managing Radioactive Waste; and
- P-299, Regulatory Fundamentals.

A regulatory standard is a document describing requirements that must be met. It imposes obligations on the regulated party once it is referenced in a licence. The following environmental standards are under development and will be issued for public review and comment in the near future:

- S-224, Draft Regulatory Standard – Environmental Monitoring at Class I Nuclear Facilities and Uranium Mines and Mills; and
- S-296, Draft Regulatory Standard – Environmental Protection Policies, Programs and Procedures at Class I Nuclear Facilities and Uranium Mines and Mills.

A regulatory guide is a document that indicates acceptable ways of meeting the Commission's requirements, as expressed in the Act, regulations or licence. It is issued for the guidance of licensees and other stakeholders. Licensees are permitted to propose alternative methods of meeting requirements. The following Regulatory Guides are related to environmental protection:

- G-224, Draft Regulatory Guide – Environmental Monitoring at Class I Nuclear Facilities and Uranium Mines and Mills (to be issued for public review in the near future);
- G-296, Draft Regulatory Guide – Environmental Protection Policies, Programs and Procedures at Class I Nuclear Facilities and Uranium Mines and Mills (to be issued for public review in the near future);
- G-217, Licensee Public Information Programs, January 2004; and
- G-225, Emergency Planning at Class I Nuclear Facilities and Uranium Mines and Mills, August 2001.

3. LICENSING

Regulatory oversight of uranium mines and mills occurs during their entire life cycle; from site preparation, through construction, operation, decommissioning, and finally abandonment. Each stage requires a separate licence. The *Canadian Environmental Assessment Act* (CEAA) requires that environmental impacts from proposed activities be assessed and considered prior to issuing a uranium mine or mill license. Every subsequent licence application is reviewed to determine if further environmental assessment is required. If required, the environmental assessment must be completed before the Commission can issue a licence to allow the proposed activities to be carried out.

The *General Nuclear Safety and Control Regulations* and the *Uranium Mines and Mills Regulations* set out information that must be provided in a licence application. In relation to the environment and waste management, the application must contain the following information:

- A description of the anticipated liquid and solid waste streams within the mine or mill, including the ingress of fresh water and any diversion or control of the flow of uncontaminated surface and groundwater;
- The name, quantity, form, origin and volume of any radioactive waste or hazardous waste that may result from the activity to be licensed, including waste that may be stored, managed, processed or disposed of at the site of the activity to be licensed, and the proposed method for managing and disposing of that waste;
- The proposed measures to control releases of nuclear substances and hazardous substances into the environment;
- The proposed location, the proposed maximum quantities and concentrations, the anticipated volume and flow rate of releases of nuclear substances and hazardous substances into the environment, including their physical, chemical and radiological characteristics;
- The effects on the environment that may result from the activity to be licensed and the measures that will be taken to mitigate those effects;
- The proposed measures to prevent or mitigate the effects of accidental releases of nuclear substances and hazardous substances on the environment;
- The programme to inform persons living in the vicinity of the mine or mill of the general nature and anticipated effects of the activity to be licensed on the environment and the health and safety of persons;
- The programme to determine the environmental baseline characteristics of the site and surrounding area;
- The proposed effluent and environmental monitoring programmes;
- The proposed environmental protection policies and programmes; and
- The proposed positions for, and qualifications and responsibilities of, environmental protection workers.

Applicants must demonstrate through performance assessments, measurements, or other evidence, that their proposed provisions to protect the environment are adequate. Applications are assessed by "CNSC staff" to verify that processes and programmes satisfy regulatory requirements. The term "CNSC staff" denotes a multidisciplinary team comprised of specialists that may include the disciplines of biology, ecology, geotechnical engineering, hydrogeology, geochemistry, mining and milling, environmental impact assessment, quality assurance, radiation protection, transport, training, public information, security and safeguards. When conducting assessments, CNSC staff also consults with other federal and provincial agencies that have responsibilities associated with uranium mining and milling. They include Environment Canada, Fisheries and Oceans Canada, the Canadian Environmental Assessment Agency and Saskatchewan Environment.

CNSC staff conducts a thorough unbiased assessment of objective factual evidence to verify that processes and programmes satisfy regulatory requirements. Licence application requirements are grouped into nine or ten programme areas. Quality Assurance, Environmental Protection, Public Information, Operations and Maintenance, and Emergency Preparedness are programme areas related to environmental protection and waste management. Each programme is rated against requirements. In the case of an application from an existing licensee, a rating is also assigned to the licensee's performance during the current licence term as observed by CNSC staff during inspections, audits, event reviews, and using performance indicators that are part of the CNSC's compliance programme. A rating of "A" is indicative of meeting and consistently exceeding requirements. A rating of "B" indicates that requirements are met. A rating of "C" is merited when either performance deteriorates and falls below expectations, or programmes deviate from the intent or objectives of CNSC requirements to the extent that there is moderate risk that the programmes will ultimately fail to achieve expectations. Although the risk of failing to meet regulatory requirements in the short term remains low, improvements in performance or programmes are required to address identified weaknesses. The licensee or applicant has taken or is taking appropriate action to make improvements. Complete descriptions of ratings "A" through "E" are provided in Attachment I. CNSC staff report their assessment findings, conclusions and licensing recommendations in a Commission Member Document (CMD) and in a presentation, which is made during a public hearing of the application.

The Commission hears licence applications for uranium mines and mills over a two-day hearing process; Public Hearing Day One and Public Hearing Day 2. The hearings are open to the public, and transcripts of the proceedings are published. The CNSC staff CMD and the applicant's CMD are available for public review 30 days before Public Hearing Day 1.

At Public Hearing Day 1, the applicant presents their application and requests that a licence be issued. CNSC staff present their evaluation of the application and the applicant's past performance and makes recommendations to the Commission. The primary objective of Public Hearing Day 2 is to consider stakeholder concerns with the proposed activities. The hearing is held approximately 60 days following Day 1. During this 60-day interval, members of the public and other interested parties can review the transcripts of presentations and discussions from Public Hearing Day 1. They must submit their questions and concerns to the Commission in writing 30 days prior to Public Hearing Day 2. They may then make an oral presentation of their concerns at Public Hearing Day 2.

Following Public Hearing Day 2, the Commission will make its decision with respect to issuing a licence. In making its decision, the Commission considers the information provided by the applicant, CNSC staff, the public and other interested parties. In relation to protection of the environment, the Commission will consider the following factors:

- The environmental effects that may be associated with the mining activities;
- The measures proposed or taken to mitigate residual environmental effects to allow future uses for the site;
- The measures proposed or taken to mitigate the potentially significant adverse environmental effects of the mining activities under normal conditions and for accidents and malfunctions;
- Stakeholder concerns; and
- Any other information that the Commission considers relevant.

The Commission's decision and the reasons for the decision are published and available for public review.

4. COMPLIANCE

Once a licence is issued, the activities authorized by the licence are subject to the CNSC Compliance Program. Licensees are expected to exhibit a high level of compliance with the CNSC's regulatory framework. The objectives of the programme are to make sure that licensees understand regulatory requirements, verify that licensees are in compliance with the requirements, and when required, take action to bring licensees into compliance.

Promotion activities encourage voluntary compliance. The CNSC promotes compliance in a planned risk informed manner. The CNSC provides guidance on regulatory expectations, involves the industry in the development of standards and shares their views on regulatory issues with the mining industry. A licensee with a good performance record is considered to be of lower risk and requires a reduced level of regulatory oversight. For example, facilities with a performance rating of "A" or "B" do not require special verification activities beyond the base level of regulatory effort. A performance rating of "C" will require additional regulatory oversight in the form of provision of guidance on regulatory expectations; more frequent focused inspections, and specific requests and action notices with clear objectives and timeframes. Ratings of "D" or "E" will require proportionally higher levels of regulatory oversight.

Verification of compliance is determined by conducting inspections, evaluations, audits, and reviewing the licensee's measurements, records, and reports in order to assess the performance of the licensee with respect to their protection of the environment. The CNSC has entered into a formal arrangement with the Province of Saskatchewan to harmonize the compliance verification activities of these two agencies. Saskatchewan Environment inspectors, who are certified as CNSC inspectors, conduct inspections on behalf of the CNSC.

Enforcement is a set of activities designed to re-establish compliance; and/or discourage future noncompliance. Enforcement measures progressively escalate from discussions, action notices and licensing actions through to orders and prosecution.

5. SERVING THE PUBLIC INTEREST

The CNSC is responsible to the public as its primary stakeholder. Key stakeholders are individuals or groups that the CNSC regularly or periodically interacts with, and have at least a general knowledge of the CNSC and its roles and responsibilities. They include municipalities, aboriginal communities and residents near licensed facilities, licensees, non-governmental organizations, industry associations and all levels of government. General stakeholders are any individuals or groups from the Canadian public in whose interest the CNSC regulates the Canadian nuclear industry, but who are largely unaware of the CNSC and its roles and responsibilities.

It is the policy of the CNSC to communicate openly and clearly with stakeholders in an unbiased fashion while respecting Canada's access to information and privacy laws. Stakeholders are provided with the opportunity to be heard. The CNSC consults with stakeholders when establishing priorities, developing policies and when planning programmes and services. The CNSC cooperates with other jurisdictions to increase efficiency and effectiveness.

The CNSC outreach programme is a coordinated approach to increasing levels of communication with stakeholders on issues or information of mutual interest, listening to the views received and acting where appropriate. It includes activities that are over and above licensing and compliance activities.

The CNSC uses outreach to communicate information to and consult with stakeholders, and to be aware of issues and concerns that stakeholders have relating to the CNSC as the nuclear regulator or the CNSC's regulatory regime.

The following CNSC activities are considered to be outreach:

- Meetings with municipal officials and community groups in the vicinity of licensed facilities;
- General, often unanticipated, interactions with members of the public;
- Public hearings of the Commission, particularly when they are held in a local community;
- Meetings with licensees on non-licence specific issues;
- Consultations with licensees on regulations, regulatory documents and Environmental Assessments; and
- Participation of CNSC staff at seminars, meetings of stakeholders, conferences and events.

6. CONCLUSION

The Canadian Nuclear Safety Commission regulates uranium mining to prevent unreasonable risk to the environment in a manner that is consistent with Canadian environmental policies, acts, regulations, and with Canada's international obligations.

This is achieved by:

- Setting and documenting a clear regulatory framework, using a process that includes consultation;
- Verifying that proposed processes and programmes satisfy regulatory requirements during the licence application review process;
- Providing stakeholders with the opportunity to be heard at public hearings and through outreach initiatives;
- Basing decisions, in part, on thorough, unbiased assessments performed by CNSC staff of objective, factual evidence; and
- Assessing licensees' performance with respect to protection of the environment through the Compliance Program.

The CNSC is committed to increasing the public's confidence in the effectiveness of our nuclear regulatory regime by operating with a high level of transparency. This involves engaging stakeholders through a variety of appropriate consultation processes and effective information sharing and communications.

Attachment I

DEFINITION OF CNSC PROGRAMME AND PERFORMANCE RATINGS

A – Exceeds requirements

A rating of 'A' is merited when assessment topics or programmes meet and consistently exceed applicable CNSC requirements and performance expectations. Performance is stable or improving. Any problems or issues that arise are promptly addressed such that they do not pose an unreasonable risk to the maintenance of health, safety, security, environmental protection or conformance with international obligations to which Canada has agreed.

For topics or programmes meriting an 'A' rating, no special compliance activities will typically be required; the usual CNSC compliance programme will be applied.

B – Meets requirements

A rating of 'B' is merited when assessment topics or programmes meet the intent or objectives of CNSC requirements and performance expectations. There is only minor deviation from requirements or the expectations for the design and/or execution of the programmes, but these deviations do not represent an unreasonable risk to the maintenance of health, safety, security, environmental protection, or conformance with international obligations to which Canada has agreed. That is, there is some slippage with respect to the requirements and expectations for programme design and execution. However, those issues are considered to pose a low risk to the achievement of regulatory performance requirements and expectations of the CNSC.

For topics or programmes meriting a 'B' rating, CNSC compliance activities can typically include the provision of additional information and recommendations to promote better compliance or to suggest improvements. There should be no deficiencies in programmes or gaps in performance such that special compliance activities are warranted.

C – Below requirements

A rating of 'C' is merited when either assessment topics or programmes deviate from the intent or objectives of CNSC requirements, or performance deteriorates and falls below expectations to the extent that there is a moderate risk that the programmes will ultimately fail to achieve expectations for the maintenance of health, safety, security, environmental protection or conformance with international obligations to which Canada has agreed. Although the risk of programmes and performance falling significantly below requirements in the short term remains low, improvements in performance or programmes are required to address identified weaknesses. The licensee or applicant has taken, or is taking appropriate action.

For topics or programmes meriting a 'C' rating, CNSC compliance activities can typically include providing further information to promote compliance, the identification of issues to be followed up by CNSC staff in subsequent compliance reviews and inspections, and specific requests and action notices with clear objectives and timeframes to be met. Consideration may also be given to recommending the addition of licence conditions to address the identified deficiencies.

D – Significantly below requirements

A rating of 'D' is merited when assessment topics or programmes are significantly below requirements, or there is evidence of continued poor performance to the extent that whole programmes are undermined or compromised. Without corrective action, there is a high probability that the deficiencies will lead to an unreasonable risk to the maintenance of health, safety, security, environmental protection or conformance with international obligations to which Canada has agreed. Issues are not being addressed effectively by the licensee or applicant. The licensee or applicant has neither taken appropriate compensating measures nor provided an alternative plan of action.

For topics or programmes meriting a 'D' rating, CNSC compliance activities can typically include progressively more stringent enforcement action, recommending licensing action to add more restrictive licence conditions and, where conditions warrant, the issuing of an order.

E – Unacceptable

A rating of 'E' is merited when there is evidence of either an absence, total inadequacy, breakdown or loss of control of an assessment topic or a programme. There is a very high probability of an unreasonable risk to the maintenance of health, safety, security, environmental protection or conformance with international obligations to which Canada has agreed. An appropriate regulatory response, such as an order or restrictive licensing action has been or is being implemented to rectify the situation.

Depending on the nature of the risk and topic, CNSC compliance activities for programmes with an 'E' rating can typically involve progressively more stringent enforcement action, including formal investigation for the purpose of considering prosecution, as well as recommending licensing action to add more restrictive licence conditions or, where conditions warrant, the issuing of an order to take remedial action or to suspend activities.

MAINTAINING PUBLIC INVOLVEMENT — SASKATCHEWAN STYLE*

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Abstract

To meet the continuous challenges of maintaining public involvement in a dynamic uranium industry in northern Saskatchewan, three unusual partners have come together to maximize the awareness of the residents in the mining area. The Northern Mines Monitoring Secretariat consists of representatives from every provincial government department that has a role in the uranium mining industry. The Canadian Nuclear Safety Commission (CNSC) and Indian and Northern Affairs Canada (INAC) are also members. Representatives of the NMMS member departments act as resource people to the MNNS manager and the Environmental Quality Committee. The Environmental Quality Committee is made up of representatives of 32 northern communities described as ‘impact communities’ under appendices to the mining surface lease agreements. Representatives are responsible to bring forward community concerns to the EQC and to return to their home communities with information presented by the mining industry and their regulators at the meetings of the EQC. The EQC is provided administrative and technical support by the NMMS Manager. The mining industry is instrumental in supporting the EQC through expertise, facility tours and community visits. By working together with northern Saskatchewan communities in this manner, both the uranium mining industry and government agencies have established a knowledgeable, available link with those impacted by the developments.

* Only an abstract is given here as the full paper was not available.

OVERVIEW OF ENVIRONMENTAL MONITORING PROGRAMMES REQUIRED BY CANADIAN URANIUM PRODUCERS*

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Abstract

Canadian federal authorities are paying close attention to industrial development so they can detect and measure changes in the receiving aquatic ecosystems. Currently, the pulp and paper, and metal mining industry in Canada are required under federal regulations to conduct Environmental Effects Monitoring (EEM) on their receiving environments. The implementation of EEM programmes began in the early 1990s and in 2002, the Metal Mining Effluent Regulations became law. EEM is a science-based tool of monitoring and interpretive phases that can be used to help assess the effectiveness of environmental management measures. The objective of EEM is to evaluate the effects of effluents on fish, fish habitat and the use of fishery resources by humans. EEM is a nationally consistent approach, which provides direction on what to monitor, how frequent the monitoring should be conducted, how to complete the monitoring and how to interpret the results. All data collected by metal mines are supplied to a national database where a team of research scientists evaluate the overall activity of operations in Canada. In addition to the EEM programme requirements, the uranium mining sector in Saskatchewan is regulated by a joint agreement between the Saskatchewan government (Saskatchewan Environment) and the federal Canadian Nuclear Safety Commission (CNSC). The regulations through this joint agreement monitor the air, land and water resources. The uranium mines must conduct regular monitoring of these resources according to their specific licensing requirements. This paper will outline the EEM programme and other monitoring programmes implemented at uranium operations in Saskatchewan. It will also review the application of these environmental monitoring programmes in more detail at an active uranium operation in northern Saskatchewan and will explore ongoing efforts to improve and harmonize the various programmes.

* Only an abstract is given here as the full paper was not available.

AN ANALYTICAL APPROACH FOR ENVIRONMENTAL ASSESSMENT AND MANAGEMENT OF URANIUM MINING OPERATIONS*

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Abstract

Environmental assessments for uranium mines in Canada are conducted under the Canadian Environmental Assessment Act (CEAA), which requires ecological and human health risk assessment as a key component for the proposed project. The assessment requires quantification of release rates from the operation in water and air in order to calculate exposure of valued ecosystem components (VECs) and humans to radiological and non-radiological constituents. A case study of a reference uranium mining facility is presented to demonstrate an analytical approach for conducting ecological and human health risk assessments under CEAA. The approach is based upon mass balance and associated environmental effects rather than solely upon local concentration standards. The methodology accounts for the total mass of chemicals and radionuclides released from the facility over its operational, decommissioned and post-decommissioned life, and estimates the total distribution of released materials throughout the surrounding environment (i.e. air, water, soil and sediment) and associated exposure of VECs and humans. The methodology provides a rationale basis by which to manage the potential environmental effects of the facility throughout its life cycle. Specifically it provides a means to: (1) identify the specific chemicals of potential concern; (2) derive airborne and aquatic release limits that are protective of the environment over the long term; (3) assess the potential environmental impacts or benefits of alternative management strategies; and (4) develop a rationale and targeted environmental effects monitoring programme through which ongoing environmental compliance can be assessed. The reference facility example draws from experience from several mine operations in Australia, Canada, Germany and South Africa. It demonstrates the similarity and differences between geographically distant and geologically different mine operations.

* Only an abstract is given here as the full paper was not available.

BEAVERLODGE MINE/MILL OPERATION AND DECOMMISSIONING: BEST PRACTICES OF THE DAY (1950–1985) AND ISSUES AND CHALLENGES FOR TOMORROW (1986–2004)
*A case study**

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Abstract

The Beaverlodge uranium mining and milling facility, located near Uranium City in northern Saskatchewan, operated for a period of 32 years between 1950 and 1982. During the operational years, "best practices," as defined by the time, in both an industrial and regulatory sense, where employed in response to various issues and challenges that arose. Two of the most significant changes affected by the application of the "best practices" at the time occurred in the areas of the management of wastes produced by operations and those associated with change in the regulatory political oversight of the end use of the U_3O_8 produced by the Beaverlodge facility. At the end of operations, "best practices," as defined at that time in history, were again applied in the planning and implementation of the final decommissioning strategy. The plan was implemented in 1982 and concluded in 1985. Since that time, "best practices" have continued to be applied, in the ongoing period of post-decommissioning transitional phase monitoring. A number of the issues and challenges, which have arisen during this current phase, can be traced back to the initial application of the "best practices" used during the operational and decommissioning phases. In addition, issues and challenges have arisen as a result of changes in our understanding of the biophysical environment and the regulatory framework. The paper gives the operator's perspective of the issues and challenges that have developed during the post-1985 transitional phase and our responses from both an industrial and a regulatory perspective. Finally, based on the Beaverlodge experience and similar experiences from other jurisdictions in Canada, recommendations are provided on the future application of "best practices" to the operational, decommissioning and transitional phases, and the eventual final disposition of former uranium mining and milling properties in Saskatchewan.

* Only an abstract is given here as the full paper was not available.

ESTABLISHING EFFECTIVE ENVIRONMENTAL AND SAFETY PERFORMANCE INDICATORS: A BEST PRACTICE APPROACH IN URANIUM PRODUCTION

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1. INTRODUCTION

Cameco Corporation (Cameco), with headquarters in Saskatoon, Saskatchewan, Canada, is the world's largest, low-cost uranium producer, currently supplying sufficient uranium to meet 20% of the world's demand. It is characterized by a diverse range of operations in Canada, the United States and Central Asia, for which Cameco is the majority owner and/or operator, including exploration, mining, milling, refining and conversion.

Cameco had four business segments [5]:

- Uranium;
- Conversion services;
- Nuclear energy generation; and
- Gold

Also, in 2002, Cameco revised its vision statement to indicate, "Cameco will be a dominant nuclear energy company producing uranium fuel and generating clean electricity". Commensurate with this, Cameco has re-confirmed its overall measures of success as follows [4]:

- A safe, healthy and rewarding workplace;
- A clean environment;
- Supportive communities; and
- Solid financial performance – all reflected in a growing return to shareholders.

Like most organizations, Cameco recognizes the importance of conducting its operations in ways that promote continual improvement in environmental and safety performance. Demonstrating the environmental advantages of nuclear is a vital part of the overall best management practices approach. Detractors often try to point to the uranium production side of the nuclear fuel cycle in pursuit of trying to make the case that the nuclear option does not carry any special environmental advantage. These attempts are mostly based on performance from eras past, not modern performance. The uranium sector must be able to present its case in a modern context, which is largely based on sustainable development principles.

This paper focuses on establishing environment and safety performance indicators for the uranium production and conversion aspects of Cameco's business, as well as in support of the environmental advantages of nuclear energy generation.

2. ENVIRONMENT AND SAFETY PERFORMANCE MEASUREMENT IN CAMECO — BACKGROUND

It is Cameco's belief that it is not enough for a company who is truly committed to sustainable development to be satisfied with making the workplace safe or to not hurting or harming its workers or the environment. The true measure of our commitment to sustainable development lies in our efforts to measure and continually work towards improving overall environmental performance and employee health, employee engagement and satisfaction, and to investing in their futures through training and education. We are also committed to ensuring that members of the public are safe.

As in many companies today, Cameco is committed to regulatory compliance and low frequency and severity of safety and environmental incidents. As we progress towards further development and implementation of sustainable development, new focus areas will also become those of stewardship, lowering our impact on ecosystems, research to improve our understanding of the safety and environmental impacts of our operations, commitment to new products that will improve safety and enhance nuclear plant performance, and of course waste reduction and management.

Further, the mining and nuclear industries must move beyond conventional notions of community support through corporate philanthropy to issues of building trust in the community through a number of ways, including:

- Community-based environmental monitoring;
- Formal and informal community engagement; and
- Training community emergency responders.

3. THE ENVIRONMENTAL ADVANTAGES OF NUCLEAR

The World Nuclear Association has estimated that the world's nuclear reactors prevent emissions of up to 2.5 billion tonnes of carbon dioxide annually [2]. This is a key, measurable component of overall risk to the environment with respect to commercial power generation, and despite the Kyoto accord's failure to recognize the environment advantages of nuclear, it is our strong belief that this advantage cannot be ignored. It is thus Cameco's intention to continue to closely monitor and promote this advantage.

4. DEVELOPMENT OF INDICATORS FOR SAFETY, HEALTH AND ENVIRONMENTAL PERFORMANCE

In support of sustainable development and to further build long term community trust, companies will be required to go beyond conventional notions of corporate profit and earnings in the following areas:

- Relationship between solid financial performance and risk management;
- Securing our production and the relationship between this and our regulatory licenses to operate;
- Maintaining our social license through sound environmental and safety management;
- Building community capacity to help monitor and manage our environmental impacts; and
- Building a proud and committed workforce.

At present, the main operational strategies of Cameco are [5]:

- To maintain and leverage the company's competitive advantages in the uranium and conversion businesses;
- To continue vertical integration within the nuclear fuel supply; and
- To expand nuclear generation capacity.

Further, Cameco's overall safety, health and environmental targets for 2004 [5] are:

- Reduce the combined accident frequency of all Cameco-operated sites below the average frequency of the last three years; and
- Incur no significant environmental incidents.

Targets of this nature have been historically used to measure site-based performance, and continue to be both used and useful as such. However, in order to support a company-wide sustainable development initiative, it is necessary to track additional performance indicators and associated metrics and to then use these as a basis for the setting of meaningful objectives and targets.

Cameco has been debating for some time the issue of performance indicators and metrics. In our attempt to identify the most appropriate ones, we have focused on those that we believe bring value to Cameco and its five key stakeholders — shareholders, customers, employees, communities and regulators. This has been a challenging journey and although we have not confirmed our list of SD indicators, the identification process is instructive. For example, to date Cameco has identified the following safety, health and environmental indicators and metrics in support of a sustainable development initiative:

- Safe, healthy and rewarding workplace
  - Indicator 1 — Encourage positive employee engagement, satisfaction and well-being
    - Metric 1 — employee attitudes and opinions in annual survey(s)
    - Metric 2 — employee total compensation versus industry and jurisdictional averages
    - Metric 3 — employee retention and absentee rates
  - Indicator 2 — Ensure a safe and healthy work environment
    - Metric 1 — employee radiation exposures in all Cameco nuclear facilities
    - Metric 2 — number of safety incidents, severity and resulting harm or potential to harm employee health
    - Metric 3 — overall health of employees
  - Indicator 3 — Maximize employee opportunity
    - Metric 1 — internal transfers and promotions relative to total available positions
    - Metric 2 — diversity participation by job category and classification
    - Metric 3 — Cameco's investment in its intellectual capital through expenditures on employee training and development
- Clean environment
  - Indicator 1 — minimize the ecological footprint of our production facilities
    - Metric 1 — amount of land under reclamation or reclaimed as a per centage of total land disturbed by operation
  - Indicator 2 — Control the risk to the ecosystem that may result from our operations
    - Metric 1 — number of environmental incidents, severity and potential impact to the environment

There must be a balance between the environmental management system needs for routine emission control, for prevention of significant environmental harm from accidents, and for effective management of long term liability. All too often it seems that published indicators tend to focus on routine emissions, which are the least difficult aspect of environmental performance to measure. Traditional safety performance measurements (i.e. frequency and severity) can be manipulated and, with company return-to-work programmes, reduce safety performance statistics, but injuries are still occurring. As such, it is important to also address and manage both environment and safety risks.

5. ESTABLISHING A PERFORMANCE EVALUATION SYSTEM

A variety of performance measurement and management models are in use by companies working to continually improve their environmental and safety performance. However, despite apparent differences, most models typically include aspects of both operational performance [1] and management performance [11][12]. Both of these aspects also form the core of the ISO 14031 model for environmental performance evaluation (EPE) [3]. This international model applies a 'plan–do–check–act' approach for continual improvement and can also be applied to safety performance evaluation. With this generic model in mind, the following steps are currently being given consideration for application in Cameco (bracketed numbers indicate references to selected companies that show evidence, via sustainable development annual reports, of similar approaches).

‘Plan’

Planning includes the following three steps:

- Identify key business units
  - For Cameco, these include:
    - Uranium (including exploration, mining, milling); and
    - Fuel services, including uranium conversion and fuel fabrication (SEU).
  - At AREVA [1], these include the following (elements similar to Cameco are underlined):
    - Uranium mining;
    - Uranium conversion;
    - Uranium enrichment;
    - Fuel fabrication;
    - Reactor construction;
    - Spent fuel processing;
    - Recycling: MOX fuel fabrication; and
    - Connector manufacturing.
- Identify ‘measures of success,’ including need to demonstrate the environmental advantages of nuclear.
  - For Cameco, these are ‘clean environment’ and ‘ensure a safe and healthy work environment.’
- Identify major inputs and outputs, including:
  - Operational performance indicators (e.g. AREVA [1]); this includes focus on ‘routine’ emissions (e.g. to air, water, land etc.);
  - Management performance indicators (e.g. Rio Tinto [11], BHP Billiton [12]); these are inherently more difficult to measure, and this is where health and safety risk can be considered once appropriately quantified.

For Cameco’s uranium and conversion business units and in consideration of both the ISO 14031 framework and the AREVA [1] approach, key safety, health and environmental inputs and outputs can be depicted in the ‘process-based’ model shown in Table 1 below.

‘Do’

The main results of this step is the quantification (i.e. measurement) of both management performance indicators and operational performance indicators. This will first require the development and implementation of a safety and environmental performance monitoring plan [14] comprised of:

- A detailed definition of each performance indicator;
- The source, method, frequency and schedule of data collection;
- The responsibility centre for ensuring data are generated on schedule;
- Determining how the performance data will be analysed; and
- Determining how the performance data will be reported.

‘Check’

This step is completed by comparing quantified measures to the overall ‘measures of success.’ For Cameco, this will involve determining how the performance data generated through the ‘Do’ step will be reviewed and used to make informed decisions.

‘Act’

This is the final step in the plan–do–check–act continuum. For Cameco, this can be met through the setting of meaningful, company-wide safety and environmental objectives and targets. This can only be done once measurement processes are in place and the resulting measures have undergone review to identify opportunities for improvement.

TABLE 1. CAMECO'S PRIMARY INPUTS AND OUTPUTS FOR SAFETY, HEALTH AND ENVIRONMENT.

Business unit	Sub-segment	Inputs	Outputs		
		Resource consumption	Atmospheric emissions	Wastes	Releases to water
Uranium	Exploration Mining Milling Refining Conversion Fuel production (SEU)	Water Energy Reagents	Greenhouse gases Radon Radioactive dust	Tailings Waste rock Domestic waste	Radioactive substances (e.g. Ra-226, U) Non-radioactive substances
Fuel services		Water Energy Reagents — nitric acid, hydrofluoric acid	Greenhouse gases Radon Radioactive dust	Radioactive waste Fluorine; ammonium nitrate Domestic waste	Radioactive substances (e.g. Ra-226, U) Non-radioactive substances

6. SAFETY AND ENVIRONMENT INDICATORS AND METRICS

Developing a set of common indicators and associated metrics for a wide variety of operations in multiple regulatory jurisdictions must therefore be addressed. Indicators that are most effective in driving change within the organization and hence promoting best practices are not necessarily the best indicators to use in public reporting.

As a first step towards meeting the plan–do–check–act cycle described above and in direct support of Cameco's measures of success for safety and the environment, an integrated model is proposed in Figure 1.

Also, the risks associated with potentially significant safety or environmental incidents (e.g. large scale spills) are difficult to put into performance indicators and then measure accurately, however this is a vital part of effective overall management for safety, health and environmental performance. It is suggested that risk be assessed using appropriate evaluative methods applied to the applicable metric information (e.g. number of environmental incidents).

7. CHALLENGES TO IMPLEMENTATION

Some of the key challenges presently being faced are:

- Reaching consensus on indicators and metrics – each operation possesses unique traits that are challenging to capture in an integrated model;
- Identifying the 'right' indicators and metrics – the model proposed in Figure 1 suggests a wide variety of measures, which will likely be consolidated into a shorter list of the most important indicators and metrics once one or two annual measurement cycles have been completed; and
- Advancement of safety performance to ultimately include injuries at home.

8. SUMMARY

This paper discusses the setting of meaningful safety and environment indicators and metrics for Cameco Corporation to use in its efforts to achieve further improvements in both safety and environmental performance. Further, it provides an approach to implementation based on the internationally recognized ISO 14031 model for environmental performance evaluation (EPE). It is also proposed that the environmental advantages of nuclear can be best expressed through the measurement and reporting of carbon dioxide emissions saved per unit of energy produced, in comparison to historical fossil fuel based energy production. Once the performance management system is up and running in a stable fashion, attention can then be turned to the setting of meaningful safety and environmental objectives and targets that go beyond the standard measures of environmental incidents and lost-time injuries

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Category	Indicators	Metrics	Applicable to: All mines, refining, conversion	Mines only	Refining / Conversion only	Power Plants only
Clean Environment						
	Ecological Footprint	percent of total leased land under reclamation or reclaimed	x	-	-	N/A
	Risk to Ecosystem	environmental incidents - total # reported	-	-	-	N/A
	Risk to Ecosystem	environmental incidents - severity (risk to environment)	-	-	-	N/A
	Risk to Ecosystem	volume of groundwater consumed	-	x	-	N/A
	Risk to Ecosystem	volume of surface water consumed	-	x	-	N/A
	Risk to Ecosystem	volume of water consumed from the public distribution system	x	-	-	N/A
	Risk to Ecosystem	consumption of heavy fuel oil	x	-	-	N/A
	Risk to Ecosystem	consumption of light fuel and gasoline	x	-	-	N/A
	Risk to Ecosystem	consumption of electricity	x	-	-	N/A
	Risk to Ecosystem	consumption of natural gas	x	-	-	N/A
	Risk to Ecosystem	consumption of propane	x	-	-	N/A
	Risk to Ecosystem	direct emissions of greenhouse gases	x	-	-	N/A
	Risk to Ecosystem	indirect emissions of greenhouse gases	x	-	-	N/A
	Risk to Ecosystem	comsumption of copper and copper alloys	x	-	-	N/A
	Risk to Ecosystem	consumption of plastics	x	-	-	N/A
	Risk to Ecosystem	consumption of lead	x	-	-	N/A
	Risk to Ecosystem	consumption of pure nitric acid (HNO3)	x	-	-	N/A
	Risk to Ecosystem	consumption of sulfuric acid (H2SO4)	x	-	-	N/A
	Risk to Ecosystem	consumption of pure hydrofluoric acid (HF)		-	x	N/A
	Risk to Ecosystem	consumption of pure ammonia (NH3)	x	-	-	N/A
	Risk to Ecosystem	consumption of gaseous chlorine (Cl2)	x	-	-	N/A
	Risk to Ecosystem	consumption of pure chlorinated solvents	x	-	-	N/A
	Risk to Ecosystem	emissions of VOC's (chlorinated, fluorinated solvents, genzole and allied products)	x	-	-	N/A
	Risk to Ecosystem	atmospheric emissions of SO2	x	-	-	N/A
	Risk to Ecosystem	atmospheric emissions of NH3	x	-	-	N/A
	Risk to Ecosystem	atmospheric emissions of HF		-	x	N/A
	Risk to Ecosystem	atmospheric emissions of HCl	x	-	-	N/A
	Risk to Ecosystem	atmospheric emissions ofNO2	x	-	-	N/A
	Risk to Ecosystem	atmospheric emissions ofCFC	x	-	-	N/A
	Risk to Ecosystem	Halon emissions	x	-	-	N/A
	Risk to Ecosystem	HCFC emissions	x	-	-	N/A
	Risk to Ecosystem	Total nitrogen release (NO3, NO2, NH4OH, hydrazine) in aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Copper (Cu) release in the aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Zinc (Zn) release in the aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Lead (Pb) release in the aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Cadmium (Cd) release in the aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Mercury (Hg) release in the aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Uranium (U) release in the aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Ra-226 release in the aquatic environment	x	-	-	N/A
	Risk to Ecosystem	Quantity of hazardous industrial waste	x	-	-	N/A
	Risk to Ecosystem	Quantity of non-hazardous industrial waste	x	-	-	N/A
	Risk to Ecosystem	Volume of radioactive waste shipped to a licensed disposal facility	x	-	-	N/A
	Risk to Ecosystem	CO2 emissions saved per unit of energy produced	-	-	-	x
	Risk to Ecosystem	Regulatory assessment ratings (CNSC - Cdn. Operations only)	x	-	-	N/A

Cameco Corporation

FIG. 48. Proposed environmental indicators and metrics.

Category	Indicators	Metrics	Applicable to: All mines, refining, conversion	Mines only	Refining / Conversion only	Power Plants only
Safe, Health and Rewarding Workplace						
	employee engagement, satisfaction and well-being	employee attitudes and opinions in annual survey(s)	x	-	-	N/A
	employee engagement, satisfaction and well-being	employee total compensation v.s. industry and jurisdictional averages	x	-	-	N/A
	employee engagement, satisfaction and well-being	employee retention and absentee rates	x	-	-	N/A
	safe and healthy work environment	Average dose for employee exposure to radiation	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of less than 2 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 2 mSv to 3.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 4 mSv to 5.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 6 mSv to 7.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 8 mSv to 9.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 10 mSv to 11.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 12 mSv to 13.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 14 mSv to 15.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 16 mSv to 17.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 18 mSv to 19.99 mSv	x	-	-	N/A
	safe and healthy work environment	Employees exposed to an effective cumulative dose of 20 mSv	x	-	-	N/A
	safe and healthy work environment	Average dose from exposure to radiation foor contractor personnel	x	-	-	N/A
	safe and healthy work environment	Absentee rate	x	-	-	N/A
	safe and healthy work environment	Retention	x	-	-	N/A
	safe and healthy work environment	Frequency of work-related accidents with lost work time (excluding commuting accidents	x	-	-	N/A
	safe and healthy work environment	Severity rate for work-related accidents (excluding commuting accidents)	x	-	-	N/A
	employee opportunity	Diversity of total workforce by job category and classification	x	-	-	N/A
	employee opportunity	Training expenditures ($ CAD per employee)	x	-	-	N/A

FIG. 49. Proposed safety and health indicators and metrics.

ENVIRONMENTAL ASSESSMENT, CONTINUAL IMPROVEMENT AND ADAPTIVE MANAGEMENT WITHIN THE AREVA SUSTAINABLE DEVELOPMENT FRAMEWORK*

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Abstract

COGEMA Resources Inc. (part of the AREVA Group) is a Canadian company with its head office in Saskatoon, Saskatchewan. It owns and operates mining and milling facilities in northern Saskatchewan, where it produces uranium concentrate. McClean Lake Operation commenced production in 1999, and its environmental management system represents an integrated approach to environmental assessment, continual improvement and adaptive management based on operational results. In Canada, sustainable development is promoted through the application of the Canadian Environmental Assessment Act. Environmental Assessment (EA) is a planning tool, which incorporates environmental considerations before irrevocable decisions are taken. The basic tenet of the Act is the determination of whether the potential environmental effects of a project are adverse, significant and likely, taking into consideration mitigation measures. Thus, project planning and design entails an iterative process that incorporates mitigation measures to minimize potentially significant adverse effects. As part of the EA process, conservative approaches are taken to predict potential effects. Several important elements are generated through the EA process. These elements include a set of environmental effect predictions, a compliance and environmental effect monitoring programme, a follow-up programme to address uncertainties in the prediction of environmental effects, and the identification of contingency measures that could be implemented should non-conservative assumptions be identified in the original assessment framework. The challenge is to integrate each of these elements into the Environmental Management framework of the operating facility and develop an iterative mechanism to evaluate operational performance relative to what was originally predicted. In Saskatchewan, a requirement of operational licenses is the periodic evaluation of the “Status of the Environment” surrounding operational facilities. These periodic evaluations, conducted every three to five years, provide a useful mechanism to evaluate the operational performance of a facility, facilitate continual improvement and outline adaptive management objectives, when necessary. This provides an iterative basis for effective continual improvement and adaptive management throughout the life of the project. The framework is commensurate with AREVA sustainable development principles to limit the environmental effects of waste and emissions from our activities. The concepts of continual improvement and adaptive management are discussed and examples drawn from the AREVA McClean Lake Operation to illustrate how the EA elements can be integrated into an operational environmental management framework.

* Only an abstract is given here as the full paper was not available.

TAILINGS MANAGEMENT BEST PRACTICE: A CASE STUDY OF THE McCLEAN LAKE JEB TAILINGS MANAGEMENT FACILITY*

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Abstract

COGEMA Resources Inc. (part of the Areva Group) is a Canadian company with its head office in Saskatoon, Saskatchewan. It owns and operates mining and milling facilities in Northern Saskatchewan, where it produces uranium concentrate. McClean Lake Operation commenced production in 1999, and its tailings management facility represents the state of the art for tailings management in the uranium industry in Canada. Tailings disposal has the potential to cause effects in the surrounding receiving environment primarily through migration of soluble contaminants from the facility to surface water receptors. In-pit disposal of mill tailings has become the standard in the uranium mining industry in Northern Saskatchewan. This method of tailings management demonstrates advances in terms of worker radiation protection and containment of soluble contaminants both during operations and into the long term. Sub-aqueous deposition of tailings protects personnel from exposure to radiation and airborne emissions and prevents freezing of tailings, which can hinder consolidation. The continuous inflow of groundwater to the facility is achieved during operations through control of water levels within the facility. This ensures hydrodynamic containment, which prevents migration of soluble radionuclides and heavy metals into the surrounding aquifer during operations. The environmental performance of the decommissioned facility depends upon the rate of release of contaminants to the receiving environment. The rate of contaminant loading to the receiving environment will ultimately be governed by the concentrations of soluble contaminants within the tailings mass, the mechanisms for contaminant release from the tailings to the surrounding groundwater system and transport of contaminants within the groundwater pathway to the receiving environment. The tailings preparation process was designed to convert arsenic into a stable form to reduce soluble concentrations within the tailings mass. The design of the TMF itself relies on the high permeability sandstone unit to provide a preferential flow path for groundwater around the low permeability tailings mass. This provides a passive means of minimizing the long term release of contaminants from the decommissioned facility to the environment. A comprehensive tailings optimization and validation programme was developed to reduce uncertainties related to the performance of the tailings management facility associated with the chemical and physical properties of tailings. This paper will describe the JEB tailings management facility and provide a summary of the findings of this research programme.

* Only an abstract is given here as the full paper was not available.

IMPROVING REGULATORY CERTAINTY IN CANADA'S URANIUM MINING INDUSTRY

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Abstract

Regulatory uncertainty figures significantly in a company's determination of the feasibility of uranium mining projects. The sustainability of a company can also be jeopardized in a regime where regulatory uncertainty leads to delays in the regulatory approval process. In Canada, the Government of the Province of Saskatchewan, home to 30 per cent of the world's current uranium mining production, has raised this concern over the past two decades with the federal Canadian Nuclear Safety Commission (CNSC). During this time, the uranium mining industry in Saskatchewan (Cameco Corporation and AREVA) have made numerous attempts to encourage both parties to seek out opportunities to streamline the regulatory approval process. In February 2003, the Government of Saskatchewan and the CNSC signed a landmark agreement that is designed to provide a "one-window" approach to the regulatory approval process for Saskatchewan's uranium mining industry. Since signing the agreement, the parties have developed a harmonized compliance programme, trained Saskatchewan inspectors to conduct CNSC inspections and are working towards harmonization of the regulatory approval process. As provided for in the 2003 administrative agreement, the Province of Saskatchewan and the CNSC have agreed to enter into further negotiations to expand upon this initiative by no later than February 2006. These next efforts will include evaluating options such as the incorporation of provincial legislation into regulations made pursuant to the CNSC's *Nuclear Safety and Control Act*, revising existing CNSC regulations, as well as expanding on the regulatory role played by provincial inspectors. Future work by the Province of Saskatchewan may also include the negotiation of agreements between other federal and provincial regulatory agencies where regulatory overlap and duplication is identified. The goal of the Province of Saskatchewan is to ensure that the uranium mining industry continues to be regulated in an effective and efficient manner that ensures the protection of workers, the public and the environment.

1. INTRODUCTION

Regulatory overlap and duplication has long been an issue for both provincial regulators and the uranium mining industry in Saskatchewan. The root of this overlap and duplication stems from similar regulatory requirements imposed by the Province of Saskatchewan (primarily through the requirements of *The Environmental Management and Protection Act, 2002 [1]* the *Occupational Health and Safety Act, 1993 [2]* and the *Radiation Health and Safety Act, 1985* [17]*)* and by those imposed by the Government of Canada through the requirements of the *Nuclear Safety and Control Act* (NSCA) [5]. The recent enactment of the NSCA has given the Canadian Nuclear Safety Commission (CNSC) broad explicit powers over the health and safety of workers and protection of the environment.

Industry has long expressed concern regarding the significant level of regulatory overlap and duplication in the uranium industry. Industry contends that regulatory overlap and duplication has caused significant delays in project reviews and approvals and has greatly impacted project costs. Therefore, regulatory uncertainty is a major factor for industry when it assesses project feasibility and long term project viability.

Overlap and duplication also affects the Province, which has a direct interest in, and is publicly accountable for, the health and safety of Saskatchewan uranium miners, protection of the environment and for the management of Crown lands/resources in and around the mine sites. This is particularly important when one considers that Saskatchewan produces approximately 30 per cent of the world's supply of uranium.

Examples and implications (in parentheses) of this regulatory overlap and duplication include:

— Federal and provincial inspectors conducting similar inspections (can result in conflicting requirements being placed on the companies);

— Companies are required to obtain both federal and provincial licenses (requires multiple negotiations with federal and provincial regulators to obtain the licenses required for activities such as: construction, operation, decommissioning and reclamation, and abandonment);
— Similar reporting requirements but different formats are required by federal and provincial regulators (requires numerous report submissions and responses to similar concerns by the regulators); and,
— Separate meetings held by the companies to address similar issues with both federal and provincial regulators (requires industry to address similar regulatory concerns a number of times with various regulators).

These and other activities can result in project delays and significant costs without providing additional benefits from either a worker health and safety standpoint or from a standpoint of environmental protection. The Province, CNSC, the uranium mining industry, Natural Resources Canada, the Auditor General of Canada and a Federal Court Justice have all agreed that the significant overlap and duplication that exists in the uranium mining industry must be addressed.

It was with the goal of reducing overlap and duplication that the Province of Saskatchewan (through the departments of Environment and Labour) and the Government of Canada (through the Canadian Nuclear Safety Commission) entered into a Memorandum of Understanding (MOU) [5] in 2000 and subsequently entered into an Administrative Agreement (AA) [6] in 2003. Work by both provincial and federal regulators have been ongoing since the signing of the AA to ensure the successful implementation of the agreement.

While this document deals specifically with the harmonization of federal and provincial regulatory activities, it is also important to note that the federal and provincial governments have also entered into an agreement on environmental assessment [7], the goal of which is to ensure that a project undergoes a single assessment and is administered cooperatively by both governments. This agreement provides a mechanism by which a lead agency (federal or provincial) is identified for a given assessment.

2. BACKGROUND

The Province of Saskatchewan has a long history of effectively regulating uranium mining and milling facilities in Saskatchewan due in part to the strength of recommendations made by the Bayda Commission [8] in 1978. One of these recommendations was “that the Government of Saskatchewan accept full responsibility for ensuring that uranium mine safety and environmental standards are enforced.”

Provincial standards, among the most stringent in the world, are rigorously enforced, and the province has consistently provided effective and efficient regulation of the industry. This fact was confirmed by the reports of the Joint Federal/Provincial Panel on Uranium Development in Northern Saskatchewan [9–11] after conducting a six year independent assessment.

In reviewing the federal regulatory programmes at nuclear facilities in Canada, the Auditor General of Canada made specific recommendations to the Atomic Energy Control Board (predecessor of the Canadian Nuclear Safety Commission), regarding the need to reduce overlap and duplication. The recommendations contained in the 1994 Auditor General Report [12] included:

> 15.111: To reduce the regulatory burden on taxpayers and licensees, a regulator must ensure that it effectively manages the interfaces with other jurisdictions. This can be achieved through various methods of cooperation, such as harmonizing regulatory standards and processes; mutually recognizing standards, qualifications or technical specifications; delegating to other government the responsibility for regulating or administering regulations; and sharing work and exchanging information.

More effort is required to reduce regulatory duplication, overlaps and gaps. *(Emphasis in original)*

The Atomic Energy Control Board should review existing inter-agency agreements to ensure that they accurately reflect roles and responsibilities as well as current circumstances. It should define, as quickly as possible, the administrative arrangements to carry out the agreement with the Saskatchewan government to reduce regulatory duplication in uranium mines, and with all provinces to provide for enforcement of AECB's regulatory requirements relating to the transport of radioactive materials." *(Emphasis in original)*

A history of commitment to cooperate with the federal regulator includes a previous MOU between Saskatchewan Environment and Resource Management (predecessor of Saskatchewan Environment) and the Atomic Energy Control Board (AECB) [13] The efficiency of the Federation Initiative Agreement between the Government of Canada and the Government of Saskatchewan [14] and the 1996 MOU between the AECB and Saskatchewan Environment and Resource Management [29]. The 1996 MOU focused on improving communication between SERM and AECB on issues at uranium mine sites but did not address the more significant issue of regulatory overlap and duplication.

As indicated above, these initial efforts by the Province to engage AECB were somewhat successful but did not lead to the reduction of overlap and duplication.

In March 1997, the *Nuclear Safety and Control Act* was passed by Parliament. This new Act provided broad explicit powers over the health and safety of workers and protection of the environment. New regulations were subsequently developed by AECB to support this expanded mandate. The broadened powers entrenched in the new NSCA and the accompanying regulatory requirements provided in the new regulations further exacerbated the overlap and duplication issue.

In the November 1997 report by the Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan [10], recommendations were made regarding the roles and responsibilities of federal and provincial regulatory agencies. The Panel stated:

"Jurisdictional ambiguities between the federal and provincial governments should be clarified. The department responsible for monitoring worker health and safety should also have the authority to prosecute violations."

In December 1998, the province expressed its concern to the AECB and the federal government regarding the proposed regulations [16, 17]. In conducting its review, the Province determined that the new regulations would virtually duplicate the existing requirements of Saskatchewan legislation related to the health and safety of workers and protection of the environment at Saskatchewan uranium mines and mills.

As a result of the concerns raised by the Province and industry, Natural Resources Canada (the federal department responsible for the AECB) commissioned Justice Halvorson to evaluate the Province's claim regarding excessive overlap and duplication in the regulation of the uranium mining industry. Justice Halvorson agreed with industry and the Province that significant overlap and duplication existed.

Due to the concerns raised by the Province and by the findings of Justice Halvorson, the coming into force of the NSCA and its regulations was delayed until the spring of 2000. In order for the AECB to move forward with the new Act, the Province was provided with assurances by the AECB that they would continue to negotiate in good faith towards the development of a MOU that would reduce overlap and duplication at uranium mines and mills in Saskatchewan. The NSCA subsequently came into force on 31 May 2000.

The NSCA includes a clause that allows the CNSC to enter into arrangements with a province in order to carry out all or a portion of its regulatory mandate. Specifically, section 21 (1) of the NSCA states:

"the Commission may, in order to attain its objects, (a) enter into arrangements, including an arrangement to provide training, with any person, any department or agency of the government of Canada or of a province, a regulatory agency or department of a foreign government or any international agency."

Also included in the NSCA is a provision that allows the Commission to incorporate provincial Acts or instruments. Section 44 of the NSCA allows the CNSC to, with the approval of the Governor in Council, make regulations. Subsection (6) of that section states that any regulation made that incorporates by reference, in whole or in part, an Act of the legislature of a province or an instrument made under such an Act, may incorporate the Act or instrument as amended. Section 44, subsections (8) and (9) state that any regulation made that incorporates a provincial Act or instrument shall, with the consent of the appropriate provincial minister, be administered and enforced by the person or authority that is responsible for the administration of the Act or instrument within that province.

The federal government's intent regarding Section 44 was very clearly made in March 1996 by the then Minister of Natural Resources, Anne McLellan. When introducing the proposed new Act, Minister McLellan stated [32]:

> "This legislation acts on commitments outlined in the recent Speech to the Throne for sustaining our environment and for ensuring a modern regulatory regime that will meet the needs of the 21st century," she added. "It is designed to eliminate unnecessary overlap and duplication by encouraging cooperative regulatory arrangements between federal and provincial agencies."

The Atomic Energy Control Board President, when giving evidence in March 1997 to the Standing Senate Committee on Energy, the Environment and Natural Resources, on the proposed *Nuclear Safety And Control Act,* further elucidated on the intent of the federal government by stating .[33]:

> "This legislation (*Nuclear Safety and Control Act)* contains provisions to assist the federal and provincial governments to reduce or eliminate regulatory overlap and duplication in the nuclear industry. Specifically, Bill C-23 will allow the government to incorporate provincial regulations as federal legislation and to delegate the administration of these regulations back to the province. In addition, Bill C-23 will allow provincial officials to be appointed as inspectors and designated officers of the commission and permit them to conduct federal responsibilities as agents of the commission."

As a result of the commitments made by the federal government, negotiations on the development of a MOU between the federal and provincial governments were undertaken, with a formal MOU being established in October 2000.

The MOU outlined the process to be used by the parties to evaluate the current uranium mining and milling regulatory regime in Saskatchewan, including areas of regulatory overlap and duplication. This MOU paved the way for the development of an Administrative Agreement between Saskatchewan and the Canadian Nuclear Safety Commission, which was signed in February 2003 by the provincial Ministers of Environment and Labour and the President of the CNSC.

It should also be noted that the Government of Canada also acted to reduce overlap and duplication in the area of occupational health and safety at Saskatchewan uranium mines. This was accomplished through the coming into force of the *Saskatchewan Uranium Mines and Mills Exclusion Regulations* [34]. These regulations exempted uranium mines from specific requirements of the *Canada Labour Code[21]* and the *Non-smokers' Health Act* [36].

3. THE ADMINISTRATIVE AGREEMENT

The Administrative Agreement was developed as a mechanism by which the parties could reduce the administrative burden on the industry while ensuring the protection of workers, the public and the environment.

In a joint press release issued by the Government of Saskatchewan and the Canadian Nuclear Safety Commission, the parties clearly outlined the goal of the Administrative Agreement. The joint press release stated [37]:

> "The Government of Saskatchewan and the Canadian Nuclear Safety Commission (CNSC) today announced the signing of an agreement that will lead to greater administrative efficiency in regulating the uranium industry. This initiative responds to a recommendation made by the Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan and lays the groundwork for the two groups to coordinate and harmonize their respective regulatory regimes."

The Administrative Agreement reached by the Province of Saskatchewan and the Canadian Nuclear Safety Commission in 2003 had the following key objectives:

(1) Protect the health, safety and security of Canadians and their environment.
(2) Harmonize the CNSC's and Saskatchewan's regulatory requirements and regulatory activities, where practicable.
(3) Optimize the participation of Environment and Labour in the CNSC's assessment, licensing and compliance programmes for uranium mines and mills, where practicable.
(4) Improve the delivery of the regulatory programmes through a single window.

In broad terms, Saskatchewan and the CNSC agreed to:

(1) Develop and implement, in a phased manner, a harmonized compliance programme, leading to, within three years, the administration and enforcement by Saskatchewan of agreed upon elements of the CNSC's compliance programme.
(2) The appointment of provincial inspectors as CNSC inspectors under the NSCA.
(3) Develop and implement a pilot project in which the Province will participate in the CNSC's licensing assessment process.
(4) Continue with the detailed review of the legal framework that could lead to incorporation by reference of provincial regulations into the NSCA.
(5) Enter into further discussions regarding the harmonization of assessment and licensing following successful implementation of the harmonized compliance programme but no later than three years after signing of the AA.

In developing the Administrative Agreement, Saskatchewan and the CNSC developed a set of guiding principles that would form the foundation of this collaborative effort to effectively and efficiently harmonize their respective regulatory requirements. The guiding principles agreed to by the parties for the AA included:

(1) **Protection of health, safety and the environment —** The Parties undertake that, when developing and implementing any arrangements or measures as part of this Agreement, the Parties' priority will be to ensure the protection of health, safety and the environment.
(2) **Commitment to action —** The Parties to this Agreement commit to timely action on matters within their jurisdiction while respecting the jurisdiction of the other Party.
(3) **Commitment to collaboration —** The Parties commit to recognizing each other's strengths and capabilities and to consult and cooperate with each other in the spirit of collaboration on matters of mutual interest.
(4) **Transparency and stakeholder involvement —** Agreement is in accordance with any CNSC or provincial practices or policies regarding regulatory transparency, and undertakes to provide licensees and other stakeholders affected by this agreement opportunities to comment on its scope and provisions, and on its administration.
(5) **Improved access to regulatory regime —** The Parties undertake to improve the delivery of their regulatory programmes for industry and the public though increased accessibility and responsiveness and by minimizing, where possible, stakeholders' points of interaction with the regulatory agencies through a "single window" regulatory process.
(6) **Timely sharing of information on interjurisdictional impacts —** The Parties undertake to share, in a timely manner, information on regulatory activities and regulatory initiatives that is pertinent to activities and decisions within the jurisdiction of the other Party or Parties, subject to any provisions of federal and provincial legislation related to access to information.
(7) **Regulations, standards and guides —** The Parties undertake to consult with the other Party in the development of regulations, standards and guides affecting uranium mines and mills, so as to avoid conflicting regulatory requirements and to minimize duplication to the extent possible.
(8) **International obligations —** The Parties commit to share information on measures to prevent unreasonable risk to national security and to achieve conformity with national measures of control and international obligations to which Canada has agreed, as they relate to uranium mines and mills.

(9) **Integration —** The Parties undertake to integrate, to the extent practicable, their respective compliance, assessment and licensing activities related to the regulation of uranium mines and mills.

(10) **Reducing overlap and duplication —** The Parties commit to harmonizing their regulatory regimes and activities, where practicable.

(11) **Incorporation by reference of provincial statutes —** The Parties commit to work together to incorporate by reference provincial statutes as regulations pursuant to the NSC Act, where such incorporation is an effective and efficient means of reducing regulatory overlap and duplication.

(12) **Audit of regulatory activities administered by another party —** The Parties agree that, where regulatory activities are undertaken by a Party on behalf of the other Party, the regulatory activities undertaken will be clearly identified and the expectations with regard to the performance of the regulatory agency carrying out the activity will be clearly articulated and subject to audit.

(13) **Adequate resources —** The Parties undertake to ensure that adequate resources are available within the regulatory system, so as to ensure that the Parties and stakeholders have confidence in the regulatory work being performed.

(14) **Timeliness —** The Parties undertake to ensure that undertakings, strategies and objectives are commenced and completed in a timely manner in accordance with the timelines set out in this agreement and any subagreement.

(15) **Cost sharing —** The costs associated with activities taken pursuant to this agreement shall be borne by the Party for whom or on whose behalf such activities are carried out.

(16) **Accountability —** The Parties agree that each Party remains accountable for the administration of their respective regulatory requirements and for demonstrating that this Agreement and its implementation is effective and efficient in achieving its purpose and objectives.

4. IMPLEMENTATION

Since the signing of the Administrative Agreement, a committee consisting of one member from each of the parties has been tasked with coordinating and implementing each of the major commitments. Accomplishments made to date have been substantial and include the following [24, 25]:

(1) Development of a harmonized compliance programme has been initiated. The development of the inspection component of this programme has been completed and has undergone several field tests in the first half 2004. These harmonized inspections have been conducted jointly as part of the training programme and will soon be conducted by qualified provincial personnel, a major step towards fulfillment of the first commitment. Discussions on the harmonization of licensee reporting were initiated in May 2004 and will continue during the remainder of the year. A committee, consisting of representatives from the parties, industry licensees and other relevant regulatory agencies is currently being formed to develop a harmonized licensee reporting framework.

(a) Training of provincial personnel has been conducted. A programme for training provincial personnel such as CNSC inspectors was developed in the first half of 2003. Key personnel from Saskatchewan Labour and Saskatchewan Environment have undergone training in the last half of 2003 and first half of 2004. This training will culminate in the designation of provincial personnel as CNSC inspectors under the NSCA. As of 8 June 2004, one Saskatchewan Labour inspector and one Saskatchewan Environment project officer have been appointed as CNSC inspectors, with others to follow. It is expected that the remaining provincial personnel that have undergone the training will receive their appointments by the end of 2004. These appointments will represent the fulfillment of the second commitment.

(2) Provincial personnel will be observing and assisting CNSC licensing activities for two major projects, McClean Lake Operation re-licensing and McClean Lake Sue E Pit licensing. This will form the basis for continued discussions on the development and implementation of a harmonized assessment and licensing process at the end of the second year of the Administrative Agreement in 2005.

(3) Discussions between Saskatchewan Environment and Saskatchewan Justice have been initiated. These discussions are necessary for reviewing the legal framework for incorporation by reference of provincial legislation into regulations made pursuant to the NSCA. To date, these discussions have included the identification of the particular legislation that should be considered and the level of involvement that may be required from other regulatory agencies (based on the requirements of their legislation). Because of the various levels of involvement required between several agencies, it is expected that this commitment will require some time to meet, likely beyond the current three-year term of this Administrative Agreement.

5. THE FUTURE

The major success of the Administrative Agreement to date has been the development and implementation of a harmonized inspection programme, culminating with the appointment of provincial personnel as CNSC inspectors. This will be the basis for, and an integral part of, an overall harmonized compliance programme that will include: inspections, evaluations, audits and licensee reporting. Expanding on the compliance programme and fulfilling the other major commitments described in the Administrative Agreement will make up the bulk of the work that is planned for the next two years. In the last quarter of 2005 and the first quarter of 2006, discussions will focus on renewing and expanding the current agreement.

It is likely that future negotiations will need to involve representatives from other federal agencies, particularly Environment Canada, and Fisheries and Oceans Canada. This is becoming more evident as efforts to evaluate legislation continue. Ideally, regulation of the uranium mining industry in Saskatchewan should be as effective and efficient as present legislation allows, while ensuring the continued health and safety of workers and the public, and protection of the environment.

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THE ATHABASCA WORKING GROUP ENVIRONMENTAL MONITORING PROGRAMME IN NORTHERN SASKATCHEWAN — BUILDING RELATIONS BETWEEN INDIGENOUS GROUPS AND THE URANIUM MINING INDUSTRY

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Abstract

In the 1990s, representatives from the Saskatchewan uranium industry and the seven indigenous bands and communities living in the Athabasca region of northern Saskatchewan formed the Athabasca Working Group (AWG) and signed one of Canada's first Impact Management Agreements. In the agreement, the companies committed to providing compensation for losses of specified resources that could be attributed to emissions from uranium projects. The AWG established an environmental monitoring programme to act as the primary method for assessing whether a loss had occurred. A key element of the monitoring programme is community involvement, which includes community members deciding what environmental components to sample, where to collect the samples and taking part in the sample collections. An independent consultant helps coordinate the programme and presents the results to each community in a user-friendly format. The AWG environmental monitoring programme is currently in its fifth consecutive year of operation and it continues to be an important programme to help build relations between indigenous groups and the uranium mining industry in northern Saskatchewan.

1. INTRODUCTION

Saskatchewan is the world leader in uranium production, and the uranium industry serves to provide jobs, investment and economic development in the province. All of the uranium mining and milling operations are located in the Athabasca region of northern Saskatchewan, which is home to seven indigenous bands and communities, including the Hatchet Lake, Black Lake and Fond du Lac bands as well as the northern settlements of Wollaston Lake, Stony Rapids, Uranium City and Camsell Portage (Fig. 1). With the increased development of uranium projects in northern Saskatchewan, concerns were raised by the communities of the Athabasca region regarding employment, training, business development, environmental protection and economic benefits. In 1993, a series of meetings took place between representatives from each of the bands and communities, and the three mining companies operating in northern Saskatchewan: Cameco Corporation, AREVA (COGEMA Resources Inc.) and the Cigar Lake Mining Corporation[1]. These representatives formed a group called the Athabasca Working Group (AWG), which established principles to address the above mentioned concerns and to ensure that the uranium mining industry maintains a positive working relationship with the residents of northern Saskatchewan. The purpose of this paper is to discuss the community-based environmental monitoring programme that was initiated by the AWG as part of the Impact Management Agreement (IMA) that is discussed in the following section.

[1] Cigar Lake Mining Corporation no longer exists as a separate entity. With Cameco assuming majority interest in the company, Cigar Lake has become one of Cameco's northern Saskatchewan operating sites.

2. IMPACT MANAGEMENT AGREEMENT

One of the most important accomplishments of the AWG was the signing of one of Canada's first IMAs. Development of the IMA began in 1993 and evolved through approximately 20 formal meetings and discussions by the AWG. A draft agreement was reached in December 1997, and a final agreement was signed by the bands, communities and mining companies in 1999. The IMA requires that the mining companies provide compensation for losses of personal property, country food (meat, fish and wild plants), traditional medicines, harvest incomes and any loss of the use and enjoyment of community land, air and potable water supply that results directly from emissions from the uranium projects in northern Saskatchewan. An emission is defined as "an environmentally harmful substance from a project that detrimentally affects air, land, water, fauna, or flora in the region, but outside of the boundaries of the surface lease of the particular project in question." The IMA outlines a claimant settlement process by which residents of the communities can seek compensation for a loss.

3. THE AWG ENVIRONMENTAL MONITORING PROGRAMME

3.1. Sampling plan

The AWG established an environmental monitoring programme that would be the primary method for identifying emissions and assessing whether a loss had occurred as a result of the emissions. The programme began in 2000 and is currently in its fifth consecutive year. The monitoring programme focuses on the detection of contaminants in environmental components that were selected based on their importance to the communities (Table I). It was acknowledged that claims could potentially be made based on the claimants opinion that plant or animal populations are decreasing, however, it was decided that it would be difficult to conduct a monitoring programme to adequately prove these population changes are directly linked to emissions from uranium projects. Hence, the monitoring programme centers on measuring contaminant concentrations in selected components.

Sampling locations were established near each community utilizing input from the residents. Prior to sampling, maps with proposed sampling locations were posted in each community so that local knowledge could be incorporated. Water, sediment, and fish tissues are monitored at "effects" and "reference" locations close to each community. The "effects" stations are along the flowpath of waterbodies downstream from the uranium projects, namely Wollaston Lake, Lake Athabasca, and the Fond-du-Lac River system. Conversely, the "reference" stations are in bays or waterbodies that are not potentially exposed to treated effluent release from the uranium projects.

Since contaminants that may accumulate in the terrestrial components (air, plants and animals) are largely spread by wind dispersion, no distinction is made between "reference" and "effects" locations. Air quality is monitored by measuring radon gas levels from two stations located near each community. Samples of Labrador tea, bog cranberry, blueberry, caribou, lynx and moose are bought from community members.

TABLE 9. SAMPLING COMPONENTS AND FREQUENCIES OF THE AWG MONITORING PROGRAMME

Component	Sample type	Frequency
Air quality	Radon gas	Twice annually
Water quality	Water samples, limnology measurements	Twice annually
Sediment quality	Sediment samples	Once annually
Fish	Northern Pike, Lake Whitefish	Once annually
Plants	Blueberries, bog cranberries, Labrador tea	Once annually
Animals	Lynx, caribou, moose	Once annually

3.2. Coordination of the programme

The AWG environmental monitoring programme is administered by Cameco Corporation and is entirely funded by the uranium mining companies. Canada North Environmental Services (CanNorth), an indigenous owned environmental consulting firm, manages the programme, which involves coordinating the logistics, providing the sampling equipment, submitting the samples for analyses and reporting the findings. The northern field coordinator is Mr. Bill Layman who resides in northern Saskatchewan and acts as a liaison with the northern residents and assists in the field sampling. One of the most important elements of the programme is that local residents take part in the sample collections each year. This provides employment, training, and business development to each community. In addition, further money is directed to the communities through extraneous expenses such as accommodation, boat rental, gasoline, etc. In the past, a member of each community conducted the water, sediment, fish and radon sampling alongside the northern coordinator, however, many of the community members are now trained and conduct the sampling independently. The samples are shipped to the CanNorth office, located in Saskatoon, Saskatchewan, and are submitted to accredited laboratories for analyses.

3.3. Data reporting

One of the challenges of the AWG programme is communicating the results to the community members. All of the data is maintained in a database and is presented annually in a report that is available to the public. However, it was found that these extensive data reports are not an effective means of communicating the results to the residents of northern Saskatchewan. In the past two years, brochures have been produced for each community that summarize the information in a concise and graphical format. The front page of an example report from the community of Uranium City is presented in Figure 2. The front page outlines the monitoring programme, while the inner two pages present the highlights of the results, and the back cover provides conclusions and acknowledgements. These brochures have been widely distributed throughout the north and have received much positive feedback from the community members. The brochures produced for the 2003 AWG programme are currently linked to the Cameco Corporation (www.cameco.com) and AREVA (www.cogema.ca) websites.

3.4. Programme results

It is important to note that the AWG environmental monitoring programme is not designed to be scientifically rigorous and does not include a high degree of sample replication. It is stated in the IMA that if the monitoring results are increasing in any of the mediums, a more specific and detailed research programme will be undertaken by the applicable company concerning those contaminants and their potential sources. The concentrations of selected contaminants of concern in the samples from the “effects” stations are compared to government guidelines, where possible, and to the natural levels measured in the samples from the “reference” stations. Investigations for potential loss from an emission will be initiated if contaminant levels increase to a point where they may have a harmful effect on humans or the biota within the region. The results to date have not indicated that contaminant levels measured near each community exceed guidelines or are elevated as a result of active uranium projects. This is not surprising considering the large distances from the mine sites to the communities in northern Saskatchewan. Each mine site conducts its own rigorous environmental monitoring programme to ensure that any effects from the uranium mining and milling processes remain non-existent or near-field. In addition, the government of Saskatchewan conducts a cumulative effects monitoring programme, which is a more scientifically sound programme that monitors the environment far-field from the uranium projects.

4. CONCLUSIONS

The uranium mining companies that operate in northern Saskatchewan have recognized the importance of including and compensating the residents that inhabit the region where their projects are located. The AWG environmental monitoring programme enables the community members to sample the components of the environment and the locations that are of most concern to them. A key element of the programme is that the sampling is conducted by local residents and is independent of government and industry environmental monitoring programmes. This type of monitoring programme and IMA helps to build trust between the residents of northern Saskatchewan and the uranium mining industry and can serve as a model for the initiation of similar programmes by other industries worldwide.

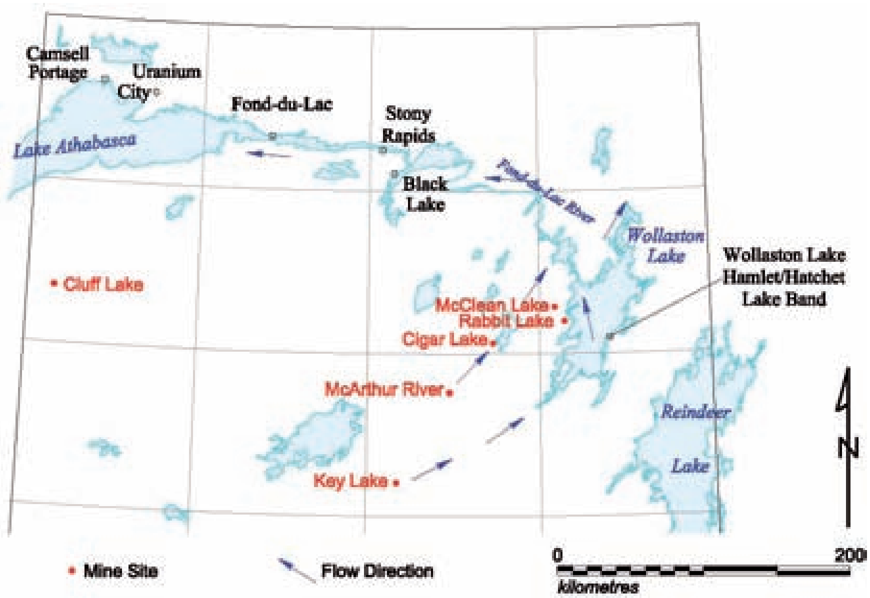

FIG. 50. Locations of the uranium projects and communities in the Athabasca region of northern Saskatchewan.

CanNorth

URANIUM CITY

Athabasca Working Group Environmental Monitoring Program 2003

The AWG program tests the environment near each community in the Athabasca region of northern Saskatchewan for contaminants that could come from active uranium mining and milling operations. The goal of this community-based program is for community members to decide what and where to sample in the environment and to assist in all sample collections. The AWG program began in 2000 and this pamphlet presents the results of the 2003 environmental testing completed near Uranium City.

Contaminants from uranium mines would mainly enter the water, but small amounts may also be spread through the air. Therefore, the AWG program samples lakes and rivers, as well as plants, wildlife, and air quality near each community. This is the same type of sampling that is done near each mine site to test the environment close to the mines.

James Augier

STUDY AREA

Water, sediment, and fish are sampled from "reference" and "effects" stations near Uranium City. Lake Athabasca is sampled as the "effects" station since it is along the flowpath of waterbodies that could potentially carry contaminants from active upstream uranium mines. Fredette Lake, northeast of Uranium City, is sampled as the "reference" station as it is an isolated lake not connected with flowpaths from areas of active upstream uranium mining activities.

Uranium City

CanNorth

Air quality is sampled at two stations. One station is located just east of Uranium City and the other is on the north shore of Lake Athabasca. Plant and wildlife samples are collected around Uranium City. There are no specific "effects" or "reference" stations for air, plant, and wildlife sampling as the contaminants that may affect them are spread by wind.

FIG. 51. The front page of the 2003 Uranium City brochure for the AWG programme.

THE PRESENT ENVIRONMENTAL PRACTICE OF URANIUM MINING AND MILLING IN CHINA

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Abstract

The paper introduces current environmental practices in the mining and milling industry in China. It includes both how to deal with the closed mines and how to administer the present mines. The uranium industry is 100% owned by the Chinese government, which is responsible for the remediation of the closed uranium mines. Since the middle of the 1980s, a total of 26 uranium mines and mills were closed. Decommissioning work on 12 uranium facilities had been completed by the end of 2003. It also tells which standards to apply to reclamate the closed uranium sites in China. The typical way to deal with the special contamination by uranium production is introduced because of lack of environmental protection consciousness in the early years, such as reclamation of contaminated farmland and fishing ponds. How to avoid taking the old way to contaminate the environment in the new uranium production centre? This paper does not give a very detailed case of the best practice in dealing with environment issues, but it presents the overall environmental solution for uranium mining operations in China. This solution will definitely protect the environment better than ever before.

1. REVIEW OF URANIUM MINING/MILLING INDUSTRY

Uranium mining and milling in China began in the late 1950s. Uranium mines and milling plants were put into operation subsequently. Two research institutes and one design institute were organized to supply the technology development and assistance. Uranium production was booming in the 1970s. Uranium output reached its peak in the late 1970s. From the middle of 1980s to the middle of 1990s, a total of 26 uranium mining and milling facilities were closed because of exhausted uranium reserves or high operational costs. Remediation of these closed facilities commenced in 1990. Remedial works were completed at 12 facilities by the end of 2003, while nine other facilities are still under remediation.

At present, there are five uranium mines operating in China. With the development of the nuclear power plant, the demand for uranium has increased. A pilot test in the Shihongtan deposit close to Tulufan city is ongoing and is intended to increase uranium production capability in the Xinjiang autonomous region. Uranium exploration efforts are focused on ISL-amendable sandstone type uranium deposits.

2. CURRENT ENVIRONMENT ACTIVITIES IN CLOSED URANIUM MINES AND MILLS

All closed uranium mines and mills will be remedied by the central government of China. The priority is assessed and decided every five years. Then the numbers of mines/mills will be remedied according to the government's budget.

Following are the remediation procedures in China.

2.1. Remedial steps

Prophase study

Three reports should be finished at this stage:

- The first one is the feasibility study report. In this report, the optional remediation projects and their cost are described. The optimization of the projects is done after comparison of different remediation projects.

- The second one is the environmental impact report in which the environmental impact is assessed. It must meet the relevant national standards.
- The safety analysis report is the third one. In this report, the engineering work of remediation is described to make sure some facilities (i.e. dams and covering layers) will be able to withstand natural forces, such as rain, wind, seismic activity and others, for a long time.

Approval phase

- All three reports are approved by the relevant government agencies, at which time the remedial work can be started. The environmental impact report of facilities should be approved by the China National Environmental Protection Agency. The feasibility study and safety analysis should be approved by the Commission of Science Technology and Industry for National Defense. Formerly they were approved by the National Planning Committee.

Implementation phase

- Organize the team to complete the work. Usually former employees of uranium facilities are organized to do the remedial work.
- Progress and quality control. The progress of remediation is controlled by CNNC. Quality control was supervised by an independent company chosen by CNNC.
- Data collection, collation and report writing

Check, verification and acceptance phase

- Governmental agencies examine the work done. Justification and auditing of the expenditure. Government officials invite a group of experts in this field to visit the site and examine the remedial work completed. The expenditure of remediation is audited.

Long term stewardship

- There are two kinds of long term stewardship nowadays. One is that the remediated sites are supervised by local environmental agencies. It often happened that all former employees of a uranium facility were moved to another place after remediation of the facilities was completed. Another is that facilities are supervised by the former entities, which were entrusted power by the local environmental agency. Some employees are still living there. They make a living on other industrial operations rather than uranium production.

2.2. Relevant standards and laws

The criteria and standards in China were learned from IAEA and are therefore consistent with those of IAEA.

However, some people criticize the fact that our limit is too strict in some areas. More money was invested in the reclamation of these sites.

2.3. Factors considered in reclamation

Site specification includes traffic and geographic location, topography, climatology, ecology, geology, hydrogeology, engineering geology, hydrology, hydrogeochemistry, natural resources and natural disaster.

Operation characterization: methods and procedures of mining and milling, methods of treatment, storage and disposal of residues and wastes, layout and location of all facilities, including operation facilities and auxiliary industrial facilities.

Geotechnical aspects: stability of waste rock piles and tailings impoundments, stability of slopes of open-pit.

TABLE 10. MAJOR LIMITS IN URANIUM PRODUCTION FACILITY REMEDIATION

Parameter		Limits
Annual average individual effective dose		≤ 0.25mSv/a
Annual average radon flux		≤ 0.74 Bq/(m^2·s)
$\alpha(\beta)$surface contamination levels	Restricted reuse or recycle	≤ 0.08 (0.8)Bq/cm^2
	Unrestricted reuse or recycle	≤ 0.04 (0.4)Bq/cm^2
Mean ^{226}Ra concentration in land over any 100 m^2 below the surface	The first 15 cm	≤ 0.18Bq/g + background
	The second 15 cm	≤ 0.56Bq/g + background
Uranium concentration of remedied surface water		≤ 0.05mg/L
Safety stability period	Mining debris	≥ 100 years
	Tailings dam	≥ 200 years

2.4. Decommissioning technology

Capping, single layer and multi-layers were used in the China remediation practices. All the covering material is selected according to the property of waste rock piles and local covering resources.

- In the northern part of China, clay and soil is redundant. It is very windy, low precipitation (250 mm–450 mm), high evaporation (1200 mm–1500 mm). Multi-layers of covering are used. The lower layer is covered with soil to prevent radon release; the upper layer is covered with pebble to keep the soil humid in order to grow grass.
- In southern China, there is a mine, which contains rich sulfide, reacting with rain water, and then producing sulphate acid. The seepage containing sulphate acid polluted the environment heavily, especially in the rainy season. The first objective of the covering layer is to prevent rain from infiltrating into the waste rock piles and, inthe mean time, to prevent radon release. A kind of combined material of lime and clay were applied. After many tests, a certain proportion of lime (3) and clay (7) is economical and practicable.
- The third one is single layer, usually 0.7–1.5 m soil or clay, according to the value of radon flux.

Reinforcement of the tailings dam and waste rock piles

Usually, we regrade the slope to ensure stability, but more land would need to be occupied. In some cases, waste rock piles are not allowed to regrade the slope because of topographic conditions. In these cases, concrete rock grids with a net 310×310 (? Not sure about these numbers) m are used to ensure that the covering material (usually soil) is stable. Then grass was grown on the soil to keep the slope stable.

Mine effluent and seepage treatment

The waste water treatment plant is used to process the mine effluent and seepage from waste rock piles and tailings ponds and last until no effluent goes out or the quality of the effluent meets relevant standards.

Reshaping the waste rock piles and tailings pond help make sure that the tailings pond will hold less raining water. The raining can be discharged with less precipitation infiltration underground. The ditches are constructed to collect the rain water and discharge it through them. Therefore water infiltrated into the tailings or waste rock will be reduced to a minimum.

Farmland decontamination and reutilization

Because most of the mines or mills are interconnected with farmland or fishing ponds, lots of them were contaminated. Different ways to deal with the contaminated farmland are selected according to different contamination. The most effective way to handle this problem is to reconstruct the agriculture. For example, the farmland in the Anhua mine in southern China was contaminated by the heavy metal cadmium. Cd of farmland range 0.57~34.5 mg/kg and average 6.84 mg/kg, exceed the Cd contamination threshold of the farmland (1.5 mg/kg). A series of investigations and experiments found that mulberry was adapted to the Cd contaminated circumstances. Cd absorbed by mulberry from the soil is concentrated in roots and trunks. The cadmium can hardly go into the leaves of the mulberry. It is indicated that Cd content in leaves is less than 2.5 mg/kg, which have no harmful effects on silkworm breeding. Mulberry planting is economical; farmers like to grow them and benefit from silkworm breeding. Other contaminated lands are still under investigation and testing. It should be transferred to other usage, which can not only prevent the contamination from extending but also benefit from the lands.

Backfill, flood and sealing of the mining tunnels

Basically two kinds of sealing methods were used to seal the mining tunnel. One was to seal the mining stope to prevent the flooding water from contacting the orebody and then flood the mine and finally seal the main entrance. The other is to seal all the mining tunnel entrances, which may lead to the mine effluent going out. We applied both in the remediation of two mines

2.5. Cost constitute of completed remediation

Remediation in seven single mines and three regional mill plants were completed. Their operation infrastructures were dismantled and industrial land was cleaned up, and metal equipment was decontaminated and recycled according to the regulations. The mine tunnels were backfilled with waste rock and sealed. The cost ranges from 4 million yuan RMB to 40 million yuan RMB. The detailed classification is as follows: the constitutes of cost varied greatly because of different local conditions.

3. THE ENVIRONMENT PROTECTION IN EXISTING AND POTENTIAL URANIUM MINES

3.1. The potential uranium mine

The environment protection will be implemented through the following steps.

3.1.1. Decision making

The following factors should be considered when a site is chosen to operate a uranium mine and milling facilities.

- Water resources: the site must be isolated with a local water supply system, ideally with a potential connection to a reservoir.
- Tourist site: the site should be away from important tourist sites.

TABLE 11.

Constitute	Anhua mine (yuan RMB)	Xifeng mine (yuan RMB)
Waste rock piles	5 250 000	6 700 000
Industrial land occupation	300 000	1 170 000
Flooding	7 390 000	870 000
Backfilling the mine shaft, open pit, surface subsidence pit, etc	150 000	420 000
Farmland reconstructing	2 940 000	700 000
Equipment purchase	1 450 000	1 310 000
Indirect expenditure	6 100 000	2 050 000

3.1.2. *Approval phase*

After the decision making, the designated owner of the mine should prepare three reports. The first is the feasibility study report. The second is environmental impact assessment report. The third one is risk based assessment report.

- The feasibility study report should be approved by the administration agency, the Committee of Science Technology and Industry for National Defense (COSTIND).
- The environment impact assessment report should be approved by the China National Environmental Protection Agency. The provincial government has no authority to approve this report, but their opinions are considered and included in the final decision.
- The risk-based assessment report includes the safety assessment of the employees who will be working in the mines. Whether the employees' personal doses are below national standards?

These three reports must be firstly verified by independent consultant agencies. Then they will be approved by the respective authorities.

3.1.3. *Construction phase*

- Through the whole phase, the construction process will be under the inspection of approval agencies. The environmental protection facilities are the important parts in the inspection.
- Living facilities are separated from operational facilities. Onsite, only simple apartment buildings will be built for technicians and workers so that less people will be affected by the operation than before.
- Whenever the work is done, it will be approved by the relative agencies before they are allowed to begin operations.

3.2. The existing uranium mine

For the existing uranium mines, the environment protection practice is to adopt new technology to reduce waste dispersal.

Operational phase

- New technology adopted in mining and milling.
  - Heap-leaching technology is very popular in China's uranium operations. The technology saves special uranium tailings impoundment so that less land will be occupied. Remediation of this kind of uranium tailings can be separately implemented and is therefore easy to be remedied. The long-time effect from uranium tailings will be limited.
  - Stope leaching is applied in two mines. Special control blasting technology is used to blast the orebody into necessary size to be leached, saving two-thirds of the ore to be transported to surface. As a result, less surface land will be occupied.
- Plan of remediation is part of the integrated operation plan
  - Remediation is done along with the operation rather than it being done after the mines were completely closed as is currently done in other closed mines. This makes the remediation more effective, and the impact on the environment is much less.
  - More careful layout and planning result in waste being contained as planed rather than carelessly piled everywhere as was done previously. The effluent from uranium mining and milling is discharged only when meeting the relevant standards after treatment.

4. CONCLUSION

Ten years of remediation has resulted in many experiences in remediation of conventional uranium mines and mills. Remediation has resulted in improvement of the local environmental quality. During the last 10 years, remediation, a set of regulation systems and relevant standards and limits, has been established. A couple of regulations have been amended. For the existing operation mines, new technology reduced greatly the quantity of solid waste on the surface. Careful planning and layout has made the remediation easier and cost-effective. The impact on the environment is much less than before. But new problems are aroused from new mining technology, such as restoration of underground water of ISL mine; the impact on underground water by in stope leaching is still an unknown issue. We are still assessing the impact and seeking solutions to improve this technology.

POLYMERIC COATS FOR THE STABILIZATION OF CONTAMINATED SURFACES OF URANIUM MILL TAILINGS

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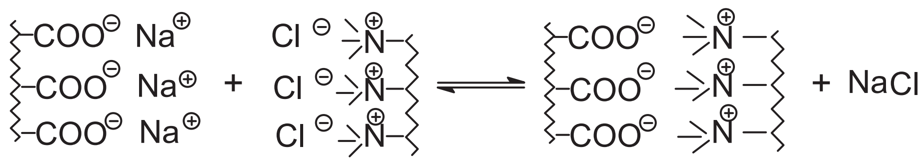
Abstract

The worldwide experiences in the field of uranium mill tailings close up and remediation demonstrate a complex strategy in this matter. First, it is a multibarrier strategy for prevention of the spread of radionuclides. We have proposed the creation of additional polymeric barriers for better prevention of the upper layer of tailings or soils against water and wind erosion, and for better vegetation of seeding grasses for its long term localization.

RESEARCH WORK CARRIED OUT IN VNIINM

Fine particles of materials accumulate the bulk of radioactivity. One of the ways of its stabilization/localization is to create additional barriers based on water-insoluble high molecular compounds (HMC) in the contaminated material bulk. Similar compounds based on interpolyelectrolyte complexes (IPEC) have been developed by VNIINM and MSU to immobilize radioactivity

IPECs are the products of interactions between oppositely charged macromolecules. The interpolyelectrolyte reaction proceeds by the following mechanism:



(1)

The polycation interacts with negative silanol groups located on the silica surface. The negative charge results from replacing Al^{3+} cations in montmorillonite by cations of lower charge. Partial dissociation of silanol Si-OH groups produces a negative charge on the irregularities of the kaolinite surface

IPEC microgels

The polyelectolytic gels under study were found to be capable of sorbing oppositely charged linear polyelectrolytes from aqueous solutions, with a maximum of sorbed polyelectrolytes corresponded to the stoichiometric ratio of oppositely charged linear polyions to *cross-link network*. Because the sorption requires for at least partial charge of both components, the interpolyelectrolytic reaction (IPR) (schematically shown below) producing an electroneutral *(#IPEC*) within the gel body is expected to be the moving force of this activated sorption.

It is important that IPR goes until linear polyions are completely exhausted when their starting amount is not sufficient to convert the entire gel to #IPEC.

Below is a schematic of the conversion of an initial highly swollen polyelectrolyte gel to a final sorption product — #IPEC:

As soon as a transparent gel is immersed into aqueous an oppositely charged linear polyelectrolyte solution, it swells, highly showing a very thin dull film developed on its surface. As time passes, the film increases in thickness while the gel decreases in volume. In section, this intermediate product shows a macroscopic phase separation into an outer poorly swollen dull #IPEC shell and the internal core of the initial highly swollen gel. Elemental analysis of these phases evidences that the whole sorbed linear polyelectrolyte is contained only in the outer IPEC shell. There is a marked boundary between the polycomplex layer and the intact gel that persists as long as the unfinished products (A,B,C) are allowed to stay in water.

The polycomplex layer and the residual (intact) gel are separated by a sharp dividing line that persists as long as the unfinished products (A,B,C) are allowed to stay in water.

Creation of protective polymeric layer

The technology for the preparaton and application of IPECs is quite simple:

- — Preparation of dilute aqueous polyelectrolyte mixtures when ionic interactions between oppositely charged polyions are completely suppressed;
- — Application of these water solutions into dispersed systems usually by spraying;
- — Washing of disperse systems by water in order to remove mineral salts.

Commercially-made synthetic and natural constituents are non-toxic.

The main objective of IPEC applications is the best interaction between small negative charges located onto the surface (resulting from particle dissociation of silanol Si-OH groups) and polycation included in the IPEC composition. The joint application of polication and polyanion result in formation of a long term stable surface polymer complex (Fig 2).

The IPEC treatment of soils produces a polymer coat 3–6-mm thick, which tightly binds fine grains to each other by way of aggregation of small particles and by coagulation of soil colloids.

As a result of application, 1.0–2.0 $l \cdot m^{-2}$ of diluted (2.0 wt% of polymers in water media) created a protective layer with approximately 90–98%.stability against wind and water erosion.

Mechanism of structurization

The microstructure of protective soil polymer layers has been studied by light microscopy. Sandy particles can be attached together as a function of the polymer nature and amount.

Soil particles stick together only at their juncture. This provides the soil filtration and the aeration of the lower most layers. The protective crust that is water insoluble but water and air-penetrable promotes vegetation.

Laboratory tests

Tests using of Uranium mill tailings samples

In the period from 2001 to 2003, polymeric structure formers were successfully tested under laboratory conditions and on the mill tailings beach of the Ulba Metallurgical Plant (UMP) jointly with IAEA CRP KAZ-11111 and in the laboratory tests with modeling tailing materials (Zovtny Vody, Ukraina IAEA CRP # 11116).

For the tests, we used actual samples from Ulba; it was dispersed material with 5.0 kg in mass, the initial moisture content was 18%. Prior to the investigations, the material was dried to the air-dry conditions. The results of the sieve analysis are summarized in Table ?? (data of Dr.Gagarin).

TABLE 12. CHARACTERIZATION OF ULBA SAMPLES

Content in dry sample, %							H_2O, %
Ca	Mg	Al	Fe	Si	SO_4^{2-}	Be	
12.1	8.07	1.4	0.67	21.2	28.35	0.2	42.1

TABLE 13. GRAIN SIZE DISTRIBUTION OF TAILINGS FROM ULBA METALLURGICAL PLANT

Sizes, mm	Content, %
>1	1.9
1 >0.63	9.4
0.63 >0.4	10.9
0.4 >0.315	9
0.315 >0.2	19.1
0.2 >0.1	38.2
0.1 > 0	11.5
Total:	100.0

TABLE 14. CHEMICAL COMPOSITION OF ZOVTNY VODY MODEL SAMPLES [SOLID, WT %]

Composition	Actual	Model	Composition	Actual	Model
SiO_2	59.3÷64.0	62.0	ZrO	0.10÷9.13	5.8
Fe_2O_3	2.4÷3.84	2.7	PbO	0.010÷0.012	0.0
FeO	0.58÷1.67	0.9	CaO	2.0÷3.26	2.6
MgO	0.87÷1.82	0.0	TiO_2	0.29÷0.37	0.3
Na_2O	7.87÷11.6	10.1	Al_2O_3	15.38÷16.8	15.6
K_2O	0.48÷0.8	0.0	P_2O_5	0.17÷0.40	0.0
S_{total}–	0.04÷0.09		pH –	8÷9	

TABLE 15. GRAIN SIZE DISTRIBUTION OF ACTUAL ZOVTNY VODY AND MODEL SAMPLES

Size, mm	>0.25	0.25>0.14	0.14>0.10	0.10>0.074	0.074>0.04	>0.04
Content, wt %, actual	1.0	5.4	8.7	9.8	15.3	59.8
Content, wt %, model	0.95	5.6	8.5	10.1	14.1	60.75

Wind tunnel

Radioactive sediments can again rise in the air from topsoil by wind (deflation) to generate dust. For dispersed soils, there are a few dusting alternatives occurring singly or in combination. In actual practice, aerosols can be produced by the joint action of a variety of mechanisms.

In tests, the laser size analyzer and a photometer were used for aerosol generation analysis. Samples were placed in a rectangular container, rolled smooth and slightly compressed. The density of all specimens of 1.50 g·cm^{-3} was constant. The rolled and compressed specimen was exposed to an air stream over a velocity range from 10.0 to 40.0 m/s in the wind tunnel.

Experiment №0-control sample.

The sample was dried to air-dry condition, having the bulk density of 1.56 g·cm^{-3} .

The loss of the mass in the course of the experiment was 108.5 g.

The intensive dust carry-over already began at 6.38 m·s^{-1}; after the sample purging at the velocities <10.2 m·s^{-1} the material was almost completely carried away.

***Experiment №1*–water treated sample (simulation of natural atmospheric precipitation).**

— Sample dried to air-dry condition and treated with distilled water at 2.0 $dm^3 \cdot m^{-2}$ dose.
— Air flow: 3.9 to 27.1 $m \cdot s^{-1}$. The loss of the mass: 86.5 g. The intensive dust carry-over began at 22.9 $m \cdot s^{-1}$; Sample has a medium resistance to wind erosion.

***Experiment 3* Sample treated with MJ-1**

The sample treated MJ-1 at 2.0 $dm^3 \cdot m^{-2}$ Exposed to an air flow of 3.9 to 27.1 $m \cdot s^{-1}$. The sample was not destroyed; the aerosol concentrations of the air flow did not exceed 5,0 $mg \cdot m^{-3}$. The mass loss was only 2.5 g. The sample has a very high resistance to wind erosion.

It follows from laboratory tests on a wind tunnel that the protective layers of a mechanical strength of no less than 60 $kN \cdot m^{-2}$ provides an adequate resistance to weathering. Laser analyzer measurements reveal no secondary rise and carry-over of even a fine soil fraction of <10 μm (mass transfer loss 0.125 $mg \cdot cm^{-2} \cdot min$).

Protective coat resistance to water erosion

The experiment on how IPEC influences the magnitude of soil wash-out was conducted in model furrows. It was shown that the sewage sludge application has noticeably reduced erosion-preventive stability of the soil; therefore, in the given situation, the application of increased dozes of IPEC is required. The doze of IPEC equal to 4 $l \cdot m^{-2}$ has made it possible to increase the scouring velocity almost three times (comparison with control) — up to 15 $cm \cdot sec^{-1}$. So high velocities of the flows at roadside slopes is improbable, as their length does not exceed several tens of meters. Thus, the IPEC application can become an important component in technology of reliable fixing of roadside slopes and other slope surfaces. The suggested methodical approach can be used for quantitative estimation of aggregate stabilizers in order to make correct choices of doses for concrete soil and climate conditions and on slopes with different morphometric characteristics.

Experiment

- Time – six hours
- Velocities of water flow in hydrodynamic facility — 0.10–1.50 $m \cdot s^{-1}$
- Water flow height in hydrodynamic testing facility — 0.01 m
- Surface area of sample loaded into cell –0,02 m^2
- Mass of sample loaded into –130 g
- Dose of agent –4,0 $l \cdot m^{-2}$

The experiment on how IPEC influences the magnitude of soils wash-out was conducted in model furrows. It was shown that sewage sludge applications have noticeably reduced the erosion-preventive stability of soil, therefore, in the given situation, the application of increased dozes of IPEC is required. The dose of IPEC equal to 4.0 $l \cdot m^{-2}$ has made it possible to increase the scouring velocity almost three times (comparison with control) — up to 15 $cm \cdot s^{-1}$. Such high velocities of the flows at roadside slopes is improbable, as their length does not exceed several tens of meters.

TABLE 16. MASS TRANSFER FROM MM-1 AND MT-1 — TREATED SAND SURFACES

Sample weight, g	Loss of mass in 10 min, g	Sand transfer $g \cdot cm^{-2} min$	Sample weight, g	Loss of mass in 10 min, g	Sand transfer $g \cdot cm^{-2} min$
	MM-1			MT-1	
949.84	0.9	$1.1*10^{-3}$	983.22	0.77	$0.9*10^{-3}$
948.85	0.9	$1.1*10^{-3}$	969.25	0.92	$1.1*10^{-3}$

TABLE 17. THE EROSION RESISTANCE OF SAMPLES TREATED WITH MJ-1

Water flow velocity, $m \cdot s^{-1}$	Amount of washed away materials, g		Effectivenes of polymeric coat K=Pc/PIPEC
	Control (without treatment) Pc	MJ-1 PIPEC	
0.10	0.7	<0.5	1.4
0.10	0.7	<0.5	1.4
0.28	1.8	<0.5	3.6
0.40	1.5	1.2	1.25
0.50	2.6	2.0	1.3
0.67	8.7	3.7	2.35
0.83	>40	9.4	>4.25
1.20	—	>40	—
1.45	—	—	—

TABLE 18. MECHANICAL STRENGTH OF PROTECTIVE COATINGS BASED ON IPEC FORMULATIONS AFTER IRRIGATION WITH WATER

№	Formulation	Formulation consumption, $dm^3 \cdot m^{-2}$	H_2O consumption, $dm^3 \cdot m^{-2}$	Description	Mechanical strength, $N \cdot cm^{-2}$
1	Control	—	50	Irrigation with water for 3 hr	67.5
2	Control	—	50	Irrigation with water for 7 hr	77.8
3	MLA-1	1	50	Irrigation with water for 2 hr after formulation applied	37.1
4	MLA-1	1	50	Irrigation with water for 7 hr after formulation applied	53.9
5	MLA-2	1	50	Irrigation with water for 2 hr after formulation applied	23.4
6	MLA-2	1	50	Irrigation with water for 7 hr after formulation applied	23.4
7	MJ-1	1	50	Irrigation with water for 2 hr after formulation applied	103.4
8	MM-1	1	50	Irrigation with water for 2 hr after formulation applied	85.2

Thus, the IPEC application can become an important component in technology of reliable fixing of roadside slopes and other slope surfaces. The suggested methodical approach can be used for quantitative estimation of aggregate stabilizers in order to make correct choices of doses for concrete soil and climate conditions and on slopes with different morphometric characteristics.

Mechanical strength tests

Coatings applied on samples showed a high mechanical strength in indenting a rod measuring 25 $kN \cdot m^{-2}$ for a coating of 2 mm thick. The mechanical strength of IPEC-based coats is 1.5–2 times that of those based on IPEC components. The mechanical strength of coatings exposed to rainfall of normal acidity (20 mm of rain imitated and allowed to dry) is found to be within 20.0 $kN \cdot m^{-2}$ (at a formulation consumption of 1.0 m^{-2})

Green house experiment

To study the influence produced of IPEC components and their concentration on the growth and evolution of perennial plants used for lawns a green house experiment was carried out. IPEC components were applied surface after seeding. It is established that when polycation and polyanion were successively introduced in the quantity 0.5 $l \cdot m^{-2}$ of mixture the highest crop of plants was achieved in the experiment with made up 157 % in relation to the control. Growing dozes of IPEC, applied to soil after seeds sowing, have rendered positive influence on plant growth and development .

To study the influence produced by IPEC components and their concentration on the growth and evolution of perennial plants used for pastures, a greenhouse experiment was carried out. Clover *(Trifolium repen*s), timothy *(Phleum protenz*e), Sudan grass *(Sorghum sudanens*e) and mixed pasture grasses for arid conditions were used in the greenhouse experiment. IPEC components were applied to soil surfaces after sowing. The application of seeds was 16.0 $g \cdot m^{-2}$. During the whole vegetation period, plastic containers with plants stayed in a greenhouse at a temperature of +23ºC. The green mass of the shoots was gathered after 68 days.

When the soil was placed into containers and humidified up to 70% from a field moisture capacity, clover, timothy, a mixed lawn grass crop of 150 seeds each and 50 seeds of Sudan grass were introduced.

The seeds were covered with a 5-mm thick soil layer and treated with 100 ml of solutions containing IPEC or IPEC components per container. After the addition of the polymers, each container was filled with 200 ml of water to promote copolymerization of the IPEC components.

The introduction of IPEC and KNO_3 substantially influenced the evolution of vegetation. With the introduction of increased quantities of IPEC, the biomass of clover and weed increased from 0.8 $g \cdot m^{-2}$ the control, to 2.45 $g \cdot m^{-2}$ (that makes 306% in comparison with the control) upon introducing the highest dose of IPEC (i.e. 4.0 $l \cdot m^{-2}$).

The Chernobyl dust suppression experience

For the purpose of eliminating consequences of the Chernobyl accident, polymeric mixtures based on polyvinyl alcohol (PVA), lignosulfonate, latex and petroleum residue were initially used, but up until July 1986, their inadequacy for long term dust suppression was obvious.

Field tests of MM-1 (July 1986, Chernobyl) and MT-1 (1989, Chernobyl) demonstrated their high efficiency and long term resistance to weathering (13 months). IPECs offer ease of preparation and application under plant and field conditions. Dissolved polycation, polyanion and low-molecular electrolyte are mixed to form a solution containing 2–4% of the polymer in the industrial and field conditions. The polymeric solution can be sprayed in amounts of 1–1.5 $l.m^{-1}$ on topsoil. Rainfall removes the low-molecular electrolyte from the system to form a superficial water-insoluble soil polymer protective coat 3–5 mm thick containing 1.2–2.0 wt.%. The polymerization time is dependent on soil humidity and ambient temperature. The polymerization comes to a close when the coat runs dry.

The Chernobyl experience with dust suppression revealed that the application of a polymer protective coat is necessary but imperfect for long term immobilization. A joint application of polymers and perennial herb seeds proved to be successful. During the first year after the treatment, the polymeric coat does the protection, also improving the vegetation. Following the polymer biodegradation, the soil protection is effected by the sod. A sower-sprinkler around a wheel tractor has been developed for adequate treatment of soils.

TABLE 19. IPECS DUST SUPPRESSING EFFICIENCY

Activity before treatment 10^4 $Bq \cdot m^{-3}$	Activity after treatment 10^4 $Bq \cdot m^{-3}$	
	MM-1	MT-1
278	10.5	13.4

TABLE 20. PROPERTIES OF PROTECTIVE SOIL-POLYMER LAYER

Parameter	MM-1	MT-1
Protective efficiency, %	as much as 98	as much as 98
Consumption, $l{\cdot}m^{-2}$	1.0	1.5
Thickness of the protective layer, mm	3–5	4–6
Resistance to mechanical attack, $kg{\cdot}cm^{-2}$	3–4	5
Service life, not less than, months	12	12
Weathering resistance, mm	not less than 600	not less than 600
Combustibility	non-combustible	non-combustible
Toxicity LD_{50}, $g{\cdot}kg^{-1}$	44.98	—

SUMMARY

The erosion resistance of polymer-based protective coatings was assed under laboratory conditions in a wind tunnel and a hydrodynamic test channel. Samples from a mill tailings beach at Ulba Metallurgical Plant (Kazakhstan) and of simulated wastes from the Zovtny Vody Plant (Ukraine) were tested. It was shown that the application of polymeric structure formers significantly improves the wind and water erosion resistance of unconsolidated powder materials. The erosion threshold of wind erosion increased from 6.8 m/s for a dry untreated sample to 70.5 $m{\cdot}s^{-1}$ for a sample treated with MJ-1. The water erosion resistance of the mill tailings increased by a factor of 1/5–2 (Keff > 11).

As result of IPEC treatment, the erosion resistance even for soils unprotected by a vegetation layer increased by 1.4 times at a water flow velocity of 0.10 $m{\cdot}s^{-1}$ and 3.78 times at a water flow velocity of 0.67 m/s. The greatest effect estimated as increase of erosion resistance on aggregates is noted in an interval of doses 1.5–2.5 $l{\cdot}m^{-2}$. The increase of a dose of polymer up to 4.0 is, if necessary, possible, thus high parameters of mechanical durability of units are kept.

It is established that when polycation and polyanion were successively introduced at a quantity of 0.5 $l{\cdot}m^{-2}$ of mixture, the highest crop of plants was achieved in the experiment with made up 157% in relation to the control.

Techniques for full-scale site remediation using polymers and seeding grassed developed and successfully tested in laboratory and field conditions.

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ISTC PROJECTS #589 AND #567

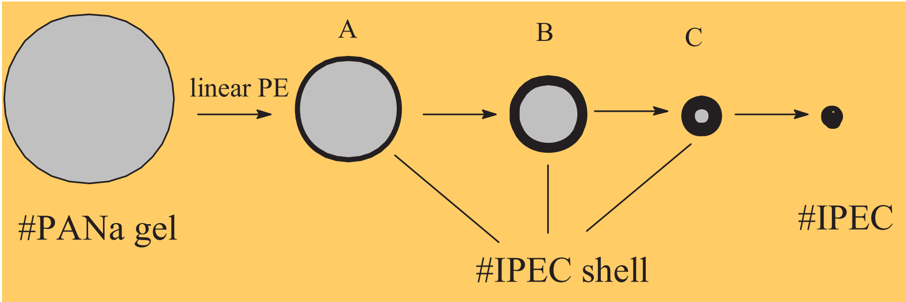


FIG. 52.

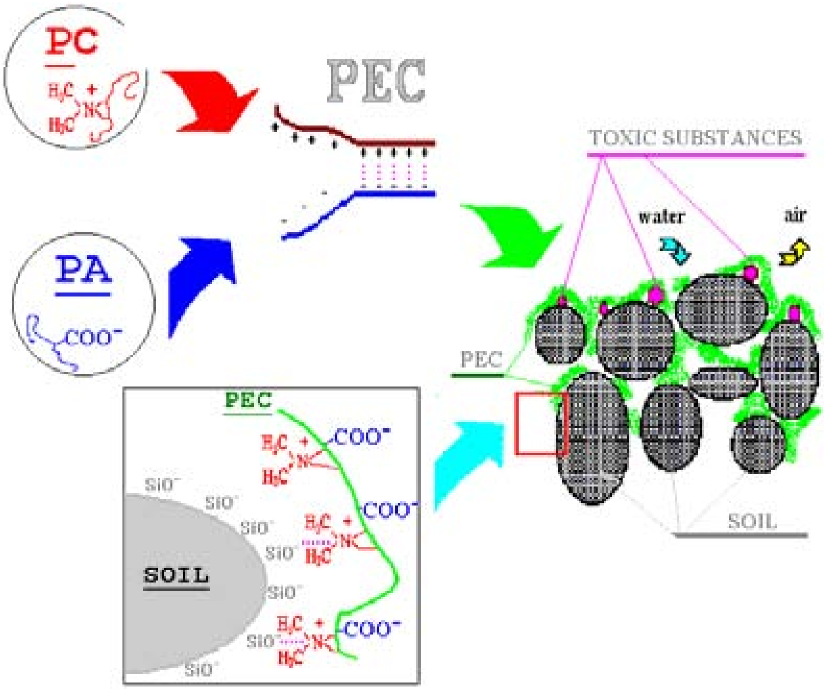
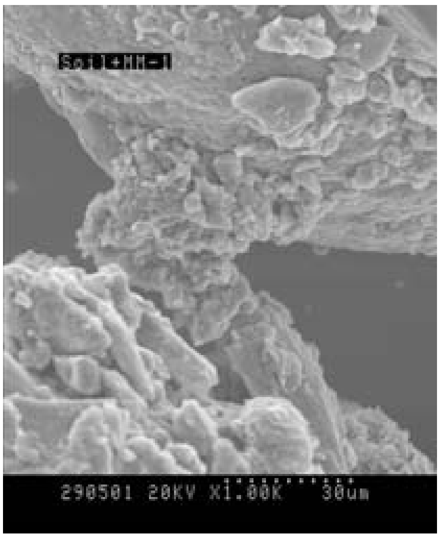


FIG. 53.



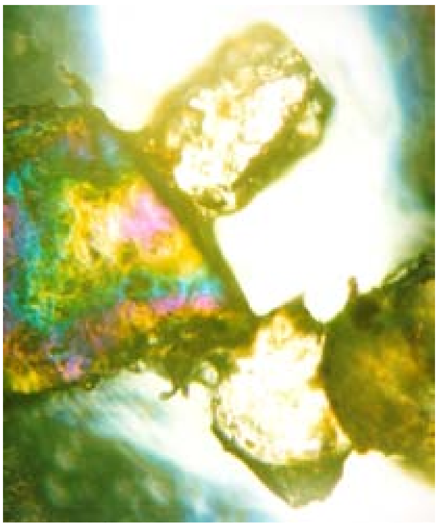


FIG. 54.

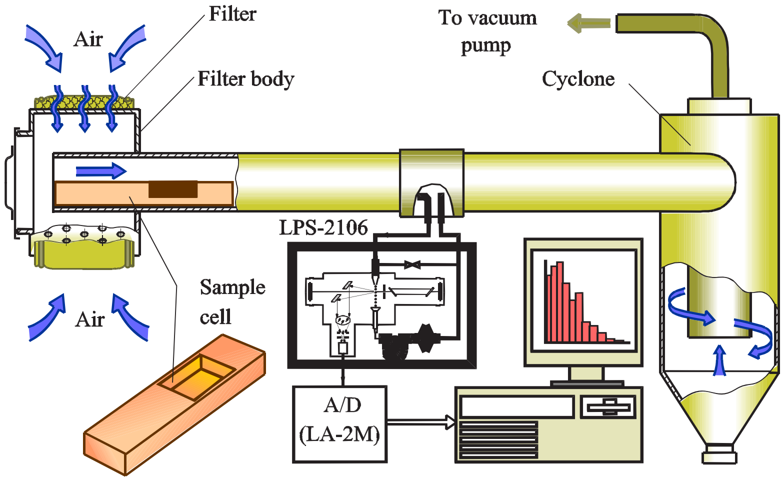


FIG. 55.

FIG. 56.

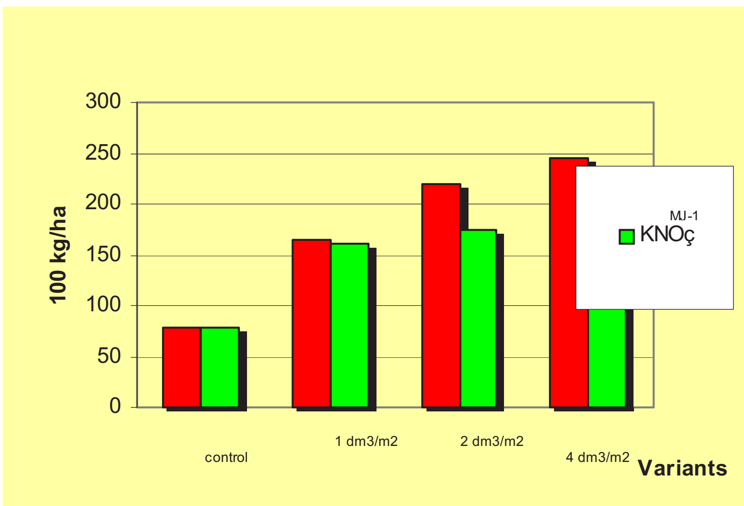


FIG. 57.

DECOMMISSIONING/CLOSEOUT OF URANIUM MILLING FACILITIES IN UKRAINE: CURRENT STATE, LEGISLATIVE BASES, LICENSING PROCESS

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Mining and processing of uranium ore has been done in Ukraine since 1948 by the manufacturing enterprise “Prydneprovskyy chemical plant” (ME “PChZ”) in Dneprodzerzhynsk and by the state enterprise “East ore mining and processing plant” (SE “VostGOK”) in Zheltie Vody.

The “PChZ” construction activity on processing the uranium-containing minerals was conducted in special secrecy and without taking into account the basic requirements on radiation safety and environmental protection. On the “PChZ” uranium concentrate was received by processing slag, which remained after the resmelting of iron and uranium containing ores in the blast furnace No. 6 of the metallurgical factory. Since 1963, only processing uranium ores produced uranium concentrate. The production of uranium at “PChZ” was stopped in 1991.

The “PChZ” tailing pits are located on two sites:

- On the Dneprodzerzhynsk site — tailing pits “West”, “Central Yar”, “Southeast” and “Dneprovskoe” (Fig. 1);
- On the Sukhachevskaya site — tailing pits “Sukhachevskoe” 1st and 2nd section, “Storehouse C”, “radioactive waste storage facility No. 602” (Lanthanum fraction) and “DP-6” (blast furnace No. 6).

The state of most of the “PChZ” tailing pits does not meet the modern requirements of environmental protection. Clay quarries and ravines, which are located on the slopes of the Dnepr River valley near the “PChZ” site, were used for these tailing pits. The bottom and the walls of these tailing pits did not have any specially created geochemical or filtration barriers, except for the second section of the “Sukhachevskoe” tailing pit. It should be noted that these tailing pits are located within the unloading zone of underground waters in the direction of the Dnepr River.

According to expert conclusions, the “Dneprovskoe” tailing pit is most dangerous in terms of environmental contamination because of its closeness to the Dnepr River, the presence of radioactive leakage through groundwater and the possibility of an emergency situation due to the destruction of the barrier dams.

“D” tailing pit was exploited from 1954 to 1968. It is created by building a closed contour of the barrier dike, which consists of a two-layer and three-layer embankment, poured out using the dry method with further compression. The filtration barriers both in the body of dam and in the bottom of the bowl are absent. The body of the dike consists of very heterogeneous material, beginning with wastes of the by-product coke industry (carbonaceous slag, sands) and building debris (fragments of bricks, cement dust) to fine sands and loess loam and clay sand. The variety of materials composing the dike determines the wide limits of changes of their physical, mechanical and filtration properties.

Presently, 5.6 million tonnes of waste from uranium ore processing are stored in this tailing pit. It occupies an area of more than 70 thousand m^2. The average density of tailing material is 1.76 g/cm^3, porosity 56%, and degree of pore saturation by water 99%.

Considerable fluctuations of radionuclide-specific activity are typical for the stratum of tailing materials. This is connected with the quality of uranium ore processing, a complicated structure of the stratum and the presence of free gravitational water, which determines the adsorption ability of wastes, intensity of leaching and speed of radionuclide migration.

The radon flow density from the tailing pit surface has values lower than background levels for local soils: 0.001–0.008 $Bq{\cdot}m^{-2}{\cdot}s^{-1}$. The concentration of radon decay products in the surface air ranges from 0.21 to 2.48 $Bq{\cdot}m^{-3}$.

Total ***a***-activity of tailing materials varies from 23 051 to 604 950 Bq kg^{-1}, total β-activity — from 9250 to 201 650 Bq kg^{-1}.

When stacking of tailing material was finished from 1976 to 1980, on top of them, non-radioactive wastes of chemical (phosphogypsum) and by-product coke (carbonaceous slag) plants were placed (Fig.2). Phosphogypsum covers the tailing surface with a layer of 0.5–2.5 m in the northwest area and 8.2–13.5 m in the central and eastern

TABLE 21. CHARACTERISTICS OF URANIUM TAILING PITS IN UKRAINE

Tailing pits	Operation period	Occupied area 10^3 m^2	Mass of waste 10^6 t	General activity TBq
West	1951–1954	60	0.77	181
Central Yar	1949–1954	24	0.22	103.6
Southeast	1956–1980	36	0.33	66.7
D (Dneprovskoe)	1954–1968	73	12	1 400
№ 602 (Lanthanum fraction)	1965–1988	0.6	0.0066	130
DP № 6	1982–1982	2.0	0.04	330
Sukhachevskoe, 1st section	1968–1983	160	15.4	684.5
Sukhachevskoe, 2nd section	1983–1993	390	7.4	296
Storehouse C	1960–1991	330	0.3	444
KBZ	1964–1991	548	19.3	999
Scherbakovskoe	1959–	2250	43.2	2220

areas. The carbonaceous slag dumps cover part of the tailing surface with a 5 to 26 m layer in the north and northeastern side.

It is especially dangerous that tailing materials are in the water-saturated state. The degree of pore volume filled by water varies from 82 to 100% and is on average 99%. Most of the tailing material has free water, which forms a man-caused, water-bearing horizon. As a result of radionuclide migration from the tailing materials in natural soils under the tailing pit, a zone of radioactive contamination on average 3.0 m thick has formed. This zone is characterized by an exposure rate of more than 0.6 μSv per hour and a high specific activity of radionuclides, on average 11–102% from initial specific activity in the tailing materials.

Chemical and radionuclide composition of underground waters is characterized by the considerable exceeding of background levels for natural waters. Concentrations of most chemical and radioactive components are 10 to 100 times higher than those acceptable. This gives evidence of the passing processes of leaching out chemical compounds and radionuclides from tailing materials and their migration into the surface water of the Konoplyanka and Dnepr rivers.

Expert estimations show that in the years of high water from “PChZ” territories, 2–3 10^{11} Bq of ($U^{238+234}$) activity can be released into the Dnepr River annually, while in the case of an accident (erosion of dikes etc.), this release can be ten times higher. Only during floods that form on the Konoplyanka river as often as one time every four years, total activity of 0.3 GBq of uranium can be released into the Dnepr river for the year, which is equivalent to 23 kg of uranium. Once in a hundred years, the quantity of uranium release can reach up to 60 kg.

Presently, the only uranium mining and processing facility in Ukraine is the state enterprise “East ore mining and processing plant” (SE “VostGOK”) in Zheltie Vody. Processing of uranium ore and production of uranium concentrate is conducted at the hydrometallurgical plant. The extraction of uranium ore is conducted by an underground method in the Smolyno and Ingul'sky mines.

Stocking of uranium processing waste is done in two tailing pits: “Strip mine of brown ironstone” (KBZh) and “Scherbakovsko”.

The “KBZh” tailing pit is located 2 km north from the outskirts of Zheltie Vody. A worked out strip mine of brown ironstone, consisting of a small bowl 10–15 m deep and a large bowl 60–65 m deep is used as a tailing pit without special filtration barriers.

Stocking of uranium processing waste was done in a period from 1964 to 1982 by means of the hydro-filling method. Presently with the purpose of dust suppression, an insulating layer covers most of the tailing pit surface, and on the residuary part, the pond is used for reserve capacity.

The “Scherbakovskoe” tailing pit is located 1.5 km south of Zheltie Vody within the Scherbakovskaya gully. It consists of two sections — “old” and “new”. The “old” section of the “Scherbakovskoe” tailing pit is 1.6 km long and 0.6 km wide and occupies an area of 984 000 m^2, with useful volume being about $5.47 \cdot 10^3$ m^3. Its exploitation began in 1959, and since 1980, it has been used for reserve capacity. The "new" section is located in the western, lower part of the gully. Its area is 1518 thousand m^2 and its useful volume $25.84 \cdot 10^6$ m^3. It has been exploited since 1979, using special filtration barriers.

Research conducted for assessing the influencing of uranium mining activity and processing facilities on the environment shows that the content of dissolved uranium in the water of the Zheltaya river on its part flowing through the uranium mining and processing region is ten times higher.

Despite the hypothetical and conservative scenario of water use from the Zheltaya river (the population in not supplied with water from the river, and the radiological influence is only due to such radionuclides as ^{238}U, ^{234}U and ^{210}Po), the conducted calculations show that in the case of the scenario realization, the quota of annual dose limit (50 μSv) due to the critical type of water use in accordance with the Radiation Safety Standard of Ukraine (NRBU-97) requirements will be exceeded by 2 to 5 times. Taking into account the exposure to other radionuclides and other existing migration routes up the food chains (fishing, watering crops, supplying water for cattle, presence of water meadows), scenario effective doses will be even higher.

In the SE "VostGOK", uranium mining was carried out using the method of in situ leaching at the "Devladovo" site (1969–1983) and the "Bratskoe" site (1971–1989).

The uranium ore deposits were leached within the Buchak water-bearing horizon. This horizon occupies a significant portion of the deposit; and its groundwaters discharge to the Dnipro Ternovskaya valley.

By 1983, the "Devladovo" site was worked out and closed down in accordance with the law. The affected lands were recultivated and transferred to general land tenure. As a result of leaching conducted during exploitation of the mine, the underground water is contaminated with residual acid solutions containing natural radionuclides. The legislation in force at that time did not foresee renewal of the initial state of underground waters.

The main source of contamination of the underground waters were the leaching solutions with typical concentrations of 10 g/l sulfuric acid and 2 g/l nitric acid. During the operation period, 200 000 tonnes of sulfate ion (as sulfuric acid) and 18 600 tonnes of nitrate (as nitric acid) were pumped into the horizon. Artificial contamination from the leaching covers the whole area of the former site in the direction of underground water movement from east to west at the monitored area.

The underground waters of the Buchak water-bearing horizon have naturally high concentrations of sulfates and total dissolved solids (TDS) and, for that reason, were not used for drinking water prior to the development of the orebody.

The major contributors to radioactive contamination are U_{total}, ^{210}Pb and ^{210}Po. The measured concentrations are within the following ranges: U_{total} from 2.45 to 885 Bq/l, ^{210}Pb from 0.22 to 14.9 Bq/l and ^{210}Po from 0.018 to 0.72 Bq/l.

The legislative basis of regulating uranium mining and processing activity

During the past 9 years, laws that regulate activity in the field of nuclear energy use and provision of radiation safety were passed in Ukraine. The following laws regulate legal frameworks of uranium mining and processing activities:

About the use of nuclear energy and radiation safety (1995) — is fundamental in the nuclear legislation of Ukraine. It establishes the priority of human and environmental safety, the rights and duties of citizens in the field of nuclear energy use, regulates the activities related to operating nuclear installations and sources of ionizing radiation, and also establishes legal frameworks of Ukraine's international obligations regarding the use of nuclear energy.

About mining and processing of uranium ores (1997) — regulates the legal relations in mining and processing of uranium ores and the use of processing products as raw material for receiving nuclear material, determines the features of the activity of uranium facilities, protection of personnel, population and the environment from exposure to ionizing radiation, and also aspects of social protection of uranium facility personnel as well as the population due to influence of ionizing radiation.

About protection of humans from the influence of ionizing radiation (1998) — focuses on the protection of life, health and property of people from the negative influence of ionizing radiation, which results from practical activity or in the case of a radiation accident, by implementation of warning and rescuing measures and compensation of damage.

About permissive activity in the field of nuclear energy use (2001) – determines legal and organizational principles of permissive activity in the field of nuclear energy use and also general points of regulating public relations, which arise during its realization, as an exception from the general regulations established by the Law of Ukraine "About entrepreneurship".

Uranium ore mining and processing are subject to government regulation by means of licensing. The State committee of natural resources of Ukraine is the specially authorized state structure for licensing of uranium ore mining.

Uranium ore mining must be carried out in accordance with the “Licensing procedure of economic activity in uranium ore mining”.

In accordance with the requirements of the Law of Ukraine “About permissive activity in the field of nuclear energy use” and government decree “About the licensing procedure of separate types of activity in the field of nuclear energy use”, the State Nuclear Regulatory Committee of Ukraine is the specially authorized state body on licensing activity in uranium ore processing.

The licensing procedure of activity in uranium ore processing is established in “Order of licensing of separate types of activity in the field of nuclear energy use” approved by the Cabinet of Ministers of Ukraine in 2000 № 1782.

Activities on processing of uranium ores include planning, placing, construction, introduction to operation, operation, reconstruction, temporal stopping (preservation), re-profiling and liquidation.

Activity on processing of uranium ores must be carried out in accordance with the requirements of standards and rules on nuclear and radiation safety “Conditions and rules of conducting activity on processing of uranium ores” (НП 306.4.03/2.044-2001).

Main documents that an applicant must produce for the receipt of a license on uranium ore processing are:

- A report on the safety analysis of activities in processing uranium ore (requirements to this report are laid down in the normative document “Requirements to the report on safety analysis of conducting activities in processing uranium ore”, НП 306.5.03/2.045-2001);
- Conclusions of the State expertise on radiation safety of the processing uranium ore project;
- A programme of radioactive waste management;
- A programme of quality assurance, developed in accordance with ISO 9000 standards;
- A report on the safety analysis during realization of activity on uranium ores processing (the requirements to the report are established in the safety standard “Requirement to the safety analysis report of conducting of activity on uranium ores processing”;
- Conclusions of State expert evaluation on radiation safety of uranium ores processing project;
- Radioactive waste handling programme;
- Quality assurance programme developed in accordance with the ISO 9000 standards.

In 2003, the State programme on converting radiation-dangerous objects of “PChZ” to the ecologically safe state and providing protection of the population from the influence of ionizing radiation for the years 2005–2014 was approved by the Government of Ukraine. The programme includes:

- Factors of negative environmental impact of uranium objects are defined;
- Preliminary estimation of soil, water and air contamination is done, and calculations of exposure doses of the population living in the area of the influence of uranium objects are described;
- Measures on development of a complex radiological monitoring system are proposed;
- Priorities in implementing of decommissioning measures are defined;
- Cost estimation of liquidation, re-profiling and preservation of uranium objects that stopped their activity is fulfilled.

In the first stage of this programme, the following should be conducted: full-scale inspection of radiation-dangerous objects, development of a unified database for assessment of the impact of uranium objects on the environment and prognosis of radionuclide migration processes in the environment in order to avoid emergency situations and optimize the sanation projects for tailing pits, and in addition, conducting priority actions for avoiding emergency situations and decreasing the tailing pit's impact on the population and environment.

The State enterprise "Barrier" was created for implementation of programme measures. In 2003, SE "Barrier" received a license for conducting liquidation activities on "PChZ" tailing pits. Activities on uranium object liquidation must be conducted in accordance with projects that should pass the State expertise on radiation safety.

Priority is given to dismantling pipelines (Fig.3) because of the possible unauthorized use of pipes contaminated by radionuclides with a considerable concentration of radioactive deposits on the walls.

After ending uranium processing activities at the "PKHZ" site on technological trestles (3–15 m high), technological pipelines have remained a total length of about 5 km; their diameter is different (25–200 mm). The pipeline is divided into three zones 1845, 1760 and 875 m long, respectively. The total weight of all pipes is about 46.6 t.

Accepted project decisions on the organization of activities, in particular, while cutting pipe sealing in the cutting line with a layer of building suds able to sorb both gaseous and mechanical products of cutting, sucking out the air from the cutting line, preventing cutting products from getting into the working zone or the environment.

The procedure of handling waste, which appears during dismantling, includes the following operations:

— Collection of thermal insulation materials, fastening elements of pipes, filters of vacuum cleaners in polyethylene bags, with further placement in a container;
— Sorting of the dismantled fragments of pipelines, depending on the dose rate of gamma-radiation on conditionally clean, low-active and middle-active, with their placement in the proper container;
— Registration of container content, their pressurization, and transporting to the temporal storing site;
— Temporal storing of container with waste from dismantling at a specially equipped site.

Waste volume:

— Thermal insulation materials, which are removed in the process of dismantling pipelines — 6.5 m^3;
— Removable filters of filter-ventilating equipment — 125 pieces;
— Fastening elements of pipes — 2.3 t;
— Waste of building suds, disposable individual protection means — 250 kg.

The individual effective dose of personnel exposure for 125 working shifts will make: for a dosimetrist — 8.24 mSv; for a fitter — 12.11 mSv; for the machinist of build faucet, assembling tower, driver of car — 8.97 mSv; for the fitter assistant — 7.28 mSv.

During implementation of the project, working conditions of the personnel will improve, radioactive contamination of the "PChZ" site and adjoining territories will decrease, and the probability of radiation accidents and their consequences will decrease.

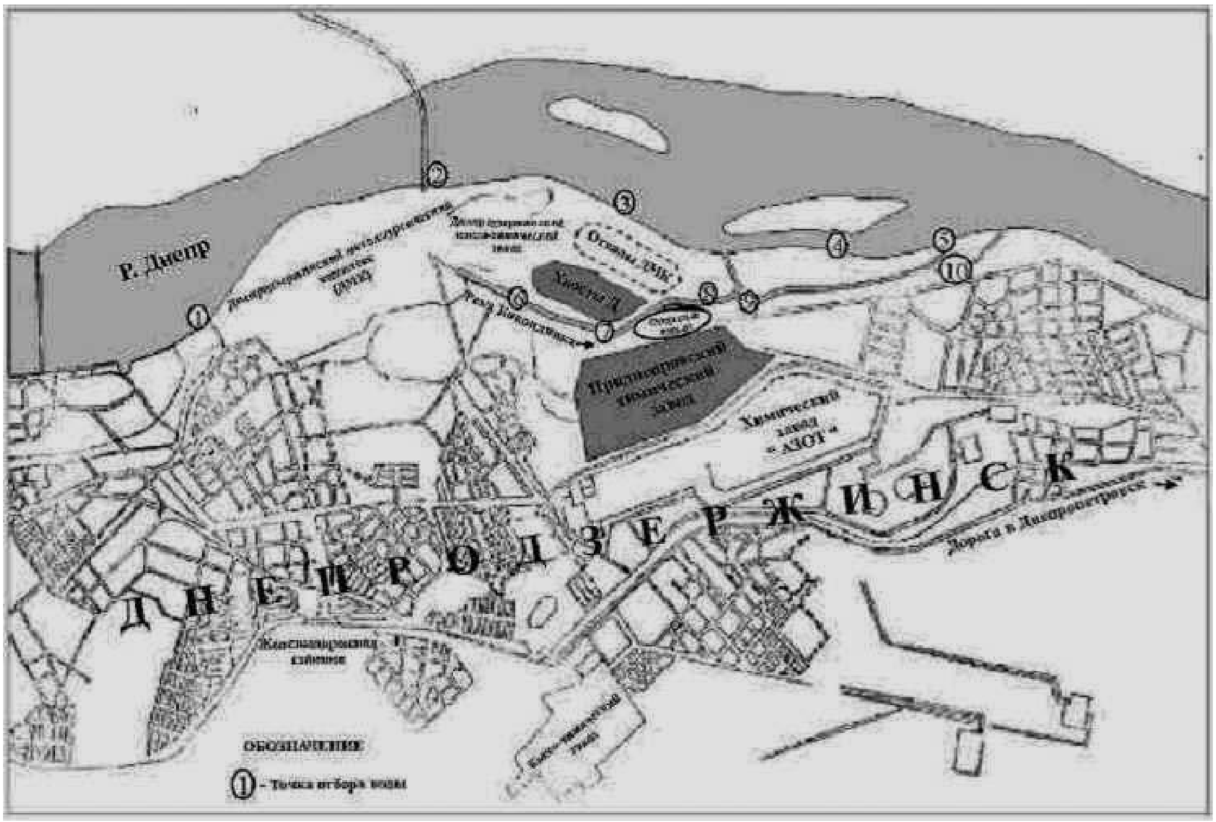

FIG. 58. Location of the "PChZ" tailing pits on the Dneprodzerzhynsk site.

FIG. 59. Tailing pit "D" (Dneprovskoe).

FIG. 60. Technological pipelines of the "PChZ".

GROUND AND SURFACE WATER RESTORATION TECHNOLOGIES*

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Abstract

The paper presents new technologies, demonstrated successful at full-scale mine/mill/nuclear fuel cycle sites in the United States of America for more effectively re-creating the host conditions that form uranium bearing minerals. Treatment of contaminated waters have been successful in open pit lakes and in groundwater units. Sediment stabilization has been shown to be critical to success, with a key mediator of successful stabilization comprising the timing and amount of iron sulfides formed with the heavy metal contaminant precipitates. This technology builds on a knowledge base of more than 250 sites where similar encapsulation and mineralization technology was employed for other contaminants such as chromium, heavy metals, sulfate and chlorinated solvents.

* Only an abstract is given here as the full paper was not available.