ENVIRONMENTAL RESTORATION OF URANIUM MINES IN CANADA: PROGRESS OVER 52 YEARS

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Abstract

In Canada, the technology for disposal of uranium mine wastes and reclamation of mines has evolved over a period of 52 years. Early practice involved dumping untreated wastes into the nearest depression or lake and leaving rock and infrastructure in place. Now, the practice is to deposit chemically-stabilized tailings, waste rock and building rubble into highly engineered waste management facilities or mine openings. Similarly the "footprint" of the mining activity has been reduced to a very small area and the site is restored as-close-as-possible to pre-mining status. This paper describes the evolution of disposal and reclamation methods and the criteria which have determined the development path followed. Remediation techniques to bring older and now unacceptable tailings deposits into satisfactory compliance with current regulations are reviewed. Some monitoring results are presented.

All of the uranium mines in Elliot Lake, Ontario, a large uranium producer since 1957, are now permanently closed. Considerable progress has been made on decommissioning the tailings areas by developing long term maintenance of water covers on some, and water treatment plants and stable soil covers on the others. The innovative methods being used to develop the water covers are described, along with the challenges remaining. Methods now under development in Saskatchewan for subaqueous deposition of paste tailings for permanent disposal in mined out open pits are also described. This method will provide for the first time, "walkaway", meaning no long term monitoring and maintenance will be required.

1. SUMMARY

The technology for the reclamation of uranium mine and waste management areas in Canada has evolved considerably over the past 52 years. The driving force for the evolution has been increasing knowledge and understanding of how best to safely and permanently store tailings and waste rock, in conjunction with stricter environmental protection regulations. Old uranium mine waste sites are being decommissioned in situ, but may require long term care and maintenance. The use of water covers is an important technique in eastern Canada to prevent intrusion, radon emission and, for the Elliot Lake tailings, acid generation. The major drawback of water covers, and any above ground disposal method, is the requirement that a long term maintenance and monitoring plan be put into effect for each site. A major public review has recently been completed, and an official decision is expected soon on the acceptance of the closure methods and the requirements for long term surveillance and maintenance.

New higher grade mines in Saskatchewan are developing waste disposal technology in mined-out pits with the pervious surround method and/or "paste" tailings technology as a method to permanently dispose of these wastes and to permit "walkaway" after a few years of monitoring. The continuous production of paste is proving to be a challenge; it is possible that the tailings will be thickened to a consistency less than that termed "paste"

Pit and underwater disposal of waste rock is also now being proposed. The use of natural lakes for the permanent disposal of uranium mine wastes is technically acceptable, but questions are being raised about water quality during deposition, and the destruction of biological habitat. As a result, the use of mined-out pits for waste disposal is increasingly favoured.
2. CANADA'S URANIUM INDUSTRY

Canada is fortunate to have an abundant supply of economic mineral deposits. On a world-wide comparative basis, Canadian uranium deposits are currently of the highest grade, contain the largest quantity of the element, and cost the lowest per unit of uranium produced.

Uranium production in Canada began in 1944 at the Port Radium operation in the Northwest Territories. The 1950's saw start of production in the Beaverlodge area in the extreme north of Saskatchewan (1953) and at numerous uranium mines (1955 to 1958) in the Elliot Lake camp in northern Ontario and in the Bancroft area in southeastern Ontario. In 1975, production from the Athabasca Basin deposits in northern Saskatchewan began at the Rabbit Lake operation. This was followed by the start up of additional Athabasca Basin operations at Cluff Lake in 1981 and at Key Lake in 1983. More Athabasca Basin operations are under execution (McClean Lake) or are planned for start up, pending regulatory approvals, before the turn of the century (Cigar Lake and McArthur River).

The Athabasca Basin deposits are, by world standards, exceptionally rich, grading up to 15 to 20% U. Prior to exploitation of these deposits the Elliot Lake camp was the largest uranium producing area in Canada, and one of the largest in the world. Although the Elliot Lake reserves are not depleted, these mines are no longer economic; uranium grades of less than 0.08 %, mainly as brannerite mineralization in pyrite-rich siliceous deposits, make production costs four to five times the current market prices. The last of the 10 Elliot Lake mines was closed in June, 1996.

Since 1944, over 280,000 tonnes of uranium have been produced in Canada. During these 52 years, significant technologies for uranium mining and milling, waste management, and environmental restoration have been developed.

Canada is the second largest country in the world with almost 10 million square kilometres (after Russia) and is sparsely populated (30 million people in total) in regions where mineral deposits are found and mining is undertaken. Most of the population of Canada lives along the Canada-United States border. Other distinct feature of the geography of Canada that affects mine reclamation, is the fact that all regions have a net positive precipitation and the surface was extensively glaciated till about 15,000 years ago.

Canada is a federal state, and the responsibility for regulation of uranium mining, processing and materials export is split between the provincial and federal governments. As of June 30, 1996, the last mine in the Elliot Lake region, the Stanleigh mine, was permanently closed. Only the province of Saskatchewan is now producing uranium, but since the grades and size of the Saskatchewan deposit are high and extensive, Canada will remain the largest producer of uranium in the world.

3. ISSUES OF URANIUM MINE CLOSURE AND RECLAMATION IN CANADA

As shown in Table 1, there are now about 200 million tonnes of uranium mine tailings and mine waste rock on the surface in Canada. Some of the waste deposits have been decommissioned (and now being monitored), some are actively being closed out, some abandoned, and some waste disposal areas are active.
Table 1. Uranium Mine Wastes in Canada

<table>
<thead>
<tr>
<th>Area</th>
<th># of mines</th>
<th>Tonnes (10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest Territories</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Saskatchewan*</td>
<td>6</td>
<td>28</td>
</tr>
<tr>
<td>Southern Ontario</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Northern Ontario</td>
<td>11</td>
<td>165</td>
</tr>
<tr>
<td>TOTAL</td>
<td>22</td>
<td>200</td>
</tr>
</tbody>
</table>

* in addition, 4 new mines under development

As with uranium mines everywhere, the principle issues are radioactivity, dispersion and water contamination. In some remote localities, the public access is less of a concern than elsewhere; at the same time ingestion of contaminants by plant and animal species is an issue. On the other hand, casual access to former mine sites by native population who use the land for hunting and fishing, provides added impetus for reclamation in remote regions.

Acid generation in some uranium tailings and waste rock is particularly problematic; acidic waters will mobilize radionuclides - principally thorium and uranium and toxic levels of metals and non metals. In the uranium mines of the Elliot Lake district of Ontario, 3 to 5% pyrite was found in the quartzite conglomerate deposits. The uranium mineralization of these deposits is composed of both easy to leach uraninite (U_3O_8) and difficult to leach brannerite ((U,Ca,Fe,Y,Th)_3Ti_5O_16). Very strong acid (100 g/l H_2SO_4) was used to extract the uranium from the brannerite, and in doing so all natural mineral alkalinity was destroyed. If Elliot lake uranium tailings are left exposed, they generate acid from pyrite oxidation and mobilize metals such as thorium, uranium, iron and aluminum.

Faced with technical and regulatory challenges, uranium mining companies and their expert consultants have teamed up to provide innovative and breakthrough techniques for minimizing the impacts on the environment - mainly the aqueous environment, and in minimizing the chance of exposure to ionizing radiation. Paradoxically the most important technique to minimize contaminant dispersion is the use of water saturation and water covers to immobilize contaminants. An important advance in the hydrological isolation of contaminants has been the development and implementation of the pervious (or porous) surround technique that permits the permanent disposal of wastes below grade and below the water table. This technique has recently been refined to include the use of thickened slurry tailings technology.

Old, inactive mines generally mined low grade (0.1 % to 0.3% uranium) deposits. Casual exposure to wastes from these mines resulted in low radiation and toxic element exposure. However, new mines have grades of uranium as much as 100 times higher than old mines and contain significant concentrations of heavy metals and arsenic. Therefore, more stringent, and hence more costly, disposal technologies needed to be developed.

In discussions about proposals for new uranium mines, the three stakeholders (industry, regulators and public) want these new uranium mines to provide for "walkaway" when the
mining ends. For this to be realized, tailings, waste rock and building rubble will be disposed below surface in mines, mainly mined-out open pits.

However, significant technical and economic challenges remain for abandoned uranium mine/mill and inactive sites in Canada.

4. REGULATORY ENVIRONMENT

The Atomic Energy Control Board, an independent agency of the Government of Canada, is responsible for matters related to nuclear energy and radioactive materials through the Uranium and Thorium regulations. Regulation R-90 deals with mine decommissioning and site reclamation. Although Canada regulates uranium mines, the provinces are the principal landowners. Therefore, closed uranium mines ultimately will revert to the provinces, or once again become "crown land". The provincial environmental agencies are the chief regulators of water quality from all mine sites, including uranium facilities. The net effect is that both provinces and the federal government are responsible for regulating operating and closed uranium mines.

Although the regulators contend that long term control and monitoring is not a desirable strategy, permanent, "walkaway" management of uranium tailings is only becoming reasonably possible at mines currently operating or planned. It is clear to most stakeholders that, because of costs and physical barriers, there is no other place to dispose of uranium mine wastes at old mines than leaving them where they are. Therefore, interim controls and a monitoring program for the transition phase will be needed. The time of the transition phase will depend on site-specific characteristics.

Canadian regulation objectives are:

* to minimize future burdens;
* to protect the environment, taking into account social and economic factors;
* to minimize the need for long term institutional controls;
* to ensure that risks to health and environment meet current standards; and
* to not prohibit the future use of natural resources contained in mine wastes.

What this in effect means is that, site specific reclamation scenarios are developed.

The Canadian Environmental Assessment Act (CEAA) of 1995 provides for public hearings on development projects, where public financial resources are implicated, and where "significant" concern is raised by the general public. Public hearings on the closure and reclamation of the Elliot Lake tailings areas started in November 1995 under a precursor to CEAA, the Environmental Assessment and Review Process (EARP). The EARP expert panel submitted it's report in June 1996. Public hearings on the Cigar Lake and McArthur River uranium projects in Saskatchewan began in June 1996. These reviews are providing the opportunity for significant public input into management of uranium mining and wastes in Canada.
5. REVIEW OF WASTE MANAGEMENT AND MINE RECLAMATION METHODS

A chronological and a site by site review of Canadian uranium tailings management methods will illustrate the trend towards better methods of safely and permanently storing or disposing wastes, in conjunction with stricter environmental protection regulations.

The Port Radium operation on the east shore of Great Bear Lake was opened in 1933 by Eldorado Gold Mines Limited to produce a pitchblende gravity concentrate from which radium was extracted and refined. Tailings were deposited near the mill, underwater in Great Bear lake. The plummeting price of radium forced closure of this operation in 1941. It was reopened for uranium production in 1944; the operator was then Eldorado Mining and Refining Limited, a federal government corporation. This was Canada's first uranium producer. Gravity concentration continued as the sole treatment method until 1952, and tailings continued to be dumped into Great Bear. In 1952, along side the gravity circuit, an acid leach plant commenced operation, and with its development the old tailings were rendered economic as a source of uranium. Tailings were reclaimed by dredging and, in a 1:1 ratio with the gravity circuit tailings, constituted the leach circuit feed. Tailings from the leaching plant were placed in nearby surface depressions. This operation was shut down in 1960.

In the late 1970's, the Port Radium mine was reopened by a precious metal mining company and the remaining silver reserves were recovered. The mine was closed and the site cleaned up in 1986. Building rubble was placed underground and mixed in with tailings. A soil and rock cover was placed over the tailings. Periodic site visits have been made to the site since closure by the national regulator, the AECB.

In 1953, the second Canadian uranium mine and mill commenced operation at Beaverlodge on the north shore of Beaverlodge Lake, 10 km. east of Uranium City. A total of 8 mines fed the mill over 29 years of operation; production ceased in 1982. The process had involved sulphuric acid leaching of a small amount of pyrite flotation concentrate and alkaline carbonate leaching of the much larger amount of flotation tailings. Eleven million tonnes of tailings were produced by the Beaverlodge mill. About 5 million tonnes were used as mine backfill and placed underground. The other 6 million tonnes of tailings were deposited in nearby natural lakes, with the coarser sands forming a beach.

The Beaverlodge site was decommissioned over the years 1982 to 1985. The mill tailings were reclaimed by maintaining a water cover and covering a relatively small beach with clean rock. Incidental spillage over the 29 years of operation was cleaned up and deposited underground by dumping into shafts and ventilation raises. Waste rock, being of low contamination source was recontoured in situ and all buildings were demolished and buried in situ, or dumped down shafts and ventilation raises. Over the past 11 years, the site has been monitored.

Since the completion of reclamation in 1985, the Beaverlodge site has been monitored and the principle focus has been on water quality. As shown in Figures 1 and 2, the uranium and dissolved solids concentration have declined as predicted, and can be seen to meet water quality objectives in a few years.
However, as shown in Figure 3, the dissolved radium concentrations are increasing with time. A possible explanation for this phenomena is the lowering of sulphate levels in the surface waters.
Mining and milling commenced in 1955 at Gunnar Mines, 25 kilometres southwest of Uranium City on the north shore of Lake Athabasca. A sulphuric acid leach plant operated until 1964. After 1960 a mine backfill plant directed approximately 40% of the tailings underground. The remaining unneutralized tailings, which are not acid generating, were deposited into Mudford Lake, which is now called the Gunnar Main Tailings site. The Mudford Lake basin eventually filled and the tailings flowed north through two small lakes into Langley Bay of Lake Athabasca. The Gunnar site was the subject of an extensive field investigation by the National Uranium Tailings Program in 1985. The tailings and waste rock were measured to have low impact on the local environment, but can be classified as abandoned at the present time.

A custom built mill for Beaverlodge district ores was operated from 1957 to 1960 by Lorado Uranium Mines Limited at a site about 10 kilometres southwest of Uranium City on the west shore of Nero Lake. This was also an acid leach plant. The acid for leaching was made from pyrite, part of which was recovered from the uranium ores. The tailings were still sufficiently pyritic to be acid generating. Tailings were deposited at pH 2 directly into Nero Lake. This site is yet to be reclaimed.

The Rayrock mine, 450 kilometres north west of Uranium City, was a small tonnage uranium mine that produced under 100,000 tonnes of tailings from 1957 to 1959. Since that time the site had been essentially abandoned. Concerns raised by native population who from time to time use the mine area for hunting and fishing trips, led an agency of the Government of Canada (Indian and Northern Affairs) to develop and implement a site remediation plan. This was put into effect this year at a cost of $2.5 million. The very large cost of this remediation for such a small amount of wastes is mainly due to the cost of mobilization of workers and
equipment to the site. Five options for reclamation of tailings at the Rayrock site were considered and costed:

1. Do Nothing
2. Cover and Freeze - $3.5 million
3. Soil Cover - $3.8 million
4. Reprocess - >$25 million
5. Lake Disposal - $2.5 million

In the end a less costly version ($2.5 million) of the soil cover option was chosen scheduled for completion by November 1996. The main objective of this option as is evident from Table 2 is to reduce dispersion of wastes and gamma exposure rate.

Table 2
Effects of Mining and Reclamation on Direct Radiation at Rayrock

<table>
<thead>
<tr>
<th>Dates</th>
<th>Mean Exposure Rate μR/hr</th>
<th>Mean Dose Rate μSv/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>pre 1997</td>
<td>Pre Mining</td>
<td>15</td>
</tr>
<tr>
<td>1959-1995</td>
<td>Post Mining, Pre-reclamation</td>
<td>144</td>
</tr>
<tr>
<td>Oct 1996</td>
<td>Rehabilitated</td>
<td>34</td>
</tr>
<tr>
<td>Post 1997</td>
<td>Post rehabilitation</td>
<td>36</td>
</tr>
</tbody>
</table>

Production in the Bancroft area began in 1957 at the Bicroft and Faraday Mines, both of which used acid leaching. Mining and milling took place at the Faraday mine from 1957 - 1963 and 1977 - 1982, (later renamed Madawaska). Tailings were deposited in surface depressions and dewatered by decant structures. These tailings have been reclaimed in situ with a simple soil cover, and both direct radiation and water quality are being monitored annually. Since both these mines are near small towns and vacation homes, they are being monitored for intrusion. Some results of water monitoring are shown in Table 3.

Table 3
Water Monitoring Downstream of Madawaska Mine

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ra²²⁶(Bq/l)</td>
<td></td>
<td></td>
<td>0.007</td>
<td>.05</td>
</tr>
<tr>
<td>U μg/l</td>
<td>45</td>
<td>41</td>
<td>33</td>
<td>43</td>
</tr>
</tbody>
</table>
Also in 1957, production commenced at the Elliot Lake camp with the start up of the Quirke mill. Additional plants subsequently came into operation (Nordic, Denison, Panel, Stanrock, etc) until eventually 10 mines were running at or near Elliot Lake. A strong acid leach was used to extract uranium from uraninite and brannerite. Tailings were and are strong acid generators because of residual pyrite as noted above. Tailings were typically stored in surface depressions behind embankments, on areas of relatively impervious rock. The ore grade was low at approximately 0.1% U₃O₈, but the deposits contain 0.03% Th₂³₂ and a wide assembly of rare earths that might be economically extracted from tailings in the future. Therefore, leaving the tailings in a position of possible future exploitation was a consideration in the choice of the tailings storage method and, recently of tailings closure options. The selected options for the Elliot Lake sites are water covers for the major tailings areas and in situ management for Stanrock. Permanent water covers are being established by engineering low permeability dams and providing for a continuous feed of fresh water upstream. Reclamation is under way at 4 sites and is well nearing completion. Four other sites have still to be reclaimed.

A summary of reclaimed uranium mine waste sites is given in Table 4.

Table 4
Reclaimed Uranium Mines Sites in Canada

<table>
<thead>
<tr>
<th>Site</th>
<th>Years 19-</th>
<th>Tailings t (10⁶)</th>
<th>Action</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tailings</td>
<td>Waste Rock</td>
</tr>
<tr>
<td>Bancroft</td>
<td>57-63</td>
<td>2.4</td>
<td>In situ, soil cover</td>
<td>In tailings</td>
</tr>
<tr>
<td></td>
<td>77-82</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agnew Lake</td>
<td>77-83</td>
<td>0.4</td>
<td>In situ, soil cover</td>
<td>waste with</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>precipitates</td>
</tr>
<tr>
<td>Port Radium</td>
<td>33-60</td>
<td>0.9</td>
<td>Soil, rock cover</td>
<td>In situ</td>
</tr>
<tr>
<td>Rayrock</td>
<td>57-59</td>
<td>0.1</td>
<td>Soil cover</td>
<td>In situ</td>
</tr>
<tr>
<td>Spanish American</td>
<td>58-59</td>
<td>0.5</td>
<td>Underwater</td>
<td>None</td>
</tr>
<tr>
<td>Beaverlodge</td>
<td>53-82</td>
<td>6.0</td>
<td>Underwater</td>
<td>In situ</td>
</tr>
</tbody>
</table>

The four uranium mine sites in Canada that can be classified as "abandoned" are shown in Table 5. These wastes are in remote locations and present little potential for future impact on the environment, but are nevertheless a concern to some members of the public and to the regulators of uranium mines.
Table 5
"ABANDONED" URANIUM MINE WASTES IN CANADA

<table>
<thead>
<tr>
<th>Site</th>
<th>Years</th>
<th>Tailings $t \times 10^6$</th>
<th>Issues</th>
<th>Tailings</th>
<th>Waste Rock</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gunnar</td>
<td>55-64</td>
<td>4.4</td>
<td>dispersion, direct $\gamma$ radiation</td>
<td>acid, uranium</td>
<td>yes(*)</td>
<td></td>
</tr>
<tr>
<td>Lorado</td>
<td>59-63</td>
<td>0.6</td>
<td>acid, $\gamma$ radiation</td>
<td>none</td>
<td>yes(*)</td>
<td></td>
</tr>
<tr>
<td>Rayrock</td>
<td>57-59</td>
<td>0.1</td>
<td>dispersion direct radiation</td>
<td>little</td>
<td>State</td>
<td></td>
</tr>
</tbody>
</table>

* Company with limited assets

A list of "inactive" mine waste sites in Canada is shown in Table 6. The property owner is currently developing reclamation plans for these sites. It is expected that an in-situ reclamation strategy will be employed.

Table 6
"INACTIVE" URANIUM MINE WASTE SITES

<table>
<thead>
<tr>
<th>Site</th>
<th>Years</th>
<th>Tailings $t \times 10^6$</th>
<th>Issues</th>
<th>Tailings</th>
<th>Waste Rock</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nordic</td>
<td>57-68</td>
<td>12</td>
<td>Acid</td>
<td>Roads, embankments</td>
<td>yes**</td>
<td></td>
</tr>
<tr>
<td>Lacnor</td>
<td>57-60</td>
<td>2.7</td>
<td>Acid</td>
<td>none</td>
<td>yes**</td>
<td></td>
</tr>
<tr>
<td>Pronto</td>
<td>55-60</td>
<td>2.1</td>
<td>Acid, copper tails on top</td>
<td>none</td>
<td>yes**</td>
<td></td>
</tr>
</tbody>
</table>

** Unlicensed properties

Four sites in the Elliot Lake are currently being reclaimed, following extensive public review of the company proposals. These sites are listed in Table 7. The results of the expert panel review are now public, and the in-situ reclamation proposals are being recommended. The expert review Panel had the following recommendations:
water covers are the best options for 3 sites;  
elevated water table, for the Stanrock site;  
in the short term, containment for the long term must be demonstrated;  
in the intermediate term, the containment must be verified;  
care and maintenance with hard financial assurance is needed; and  
curiosity driven research (mainly biological) is needed.

Table 7
URANIUM MINE WASTE SITES RECLAIMED OR CURRENTLY BEING RECLAIMED

<table>
<thead>
<tr>
<th>Site</th>
<th>Years</th>
<th>Hectares</th>
<th>Tailings t (10⁶)</th>
<th>Issues and Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tailings</td>
</tr>
<tr>
<td>Panel</td>
<td>58-61</td>
<td>123</td>
<td>16</td>
<td>Acid - underwater</td>
</tr>
<tr>
<td></td>
<td>79-83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quirke</td>
<td>56-61</td>
<td>192</td>
<td>46</td>
<td>Acid - water covers</td>
</tr>
<tr>
<td></td>
<td>68-83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denison</td>
<td>57-83</td>
<td>271</td>
<td>64</td>
<td>Acid - water covers</td>
</tr>
<tr>
<td>Stanrock</td>
<td>57-64</td>
<td>7.5</td>
<td>6</td>
<td>Acid - elevated water table</td>
</tr>
</tbody>
</table>

The concept of water covers over uranium tailings has had and continues to have extensive research conducted on it. The Quirke tailings as shown in Figure 4 has a "rice paddy" profile. Therefore water will pass across the surface and permeate through the tailings.

Processing the relatively high grade Athabasca Basin ores was first done at the Rabbit Lake operation, which started up in June 1975. The Rabbit Lake mill initially used sulphuric acid for leaching and ammonia for solvent extraction (SX) stripping and uranium precipitation. From 1975 to 1985 neutralized tailings were deposited in a conventional manner in an on-surface tailings pond. This facility consists of two earth-filled dams constructed across an elongated valley between two north-south trending ridges. To process higher grade ores scheduled for exploitation beginning in 1985, the Rabbit Lake milling process was modified to strong acid stripping and hydrogen peroxide precipitation of uranium. To hold the tailings from these higher grade ores the pervious surround tailings disposal method was developed. Tailings are placed in the mined-out Rabbit Lake pit inside a pervious envelope of sand and coarse crushed rock. Tailings water flows out of the tailings through the pervious surround and is collected and pumped to a treatment plant.

After shutdown, groundwater in the area will short-circuit around the tailings because the resistance to flow of water is very high in the consolidated tailing and negligible in the coarse
rock of the pervious surround. Groundwater contamination is thus avoided. Considerable experimenting has been done over the last 10 years to find the optimum method of transferring tailings into this tailings management facility. Originally, tailings were dewatered by filters prior to placement in the facility. This was altered to partial filtration and then to direct placement of unfiltered tailings slurry. Presently, injection of tailings slurry below the consolidated tailings surface is being tested and evaluated.

Cluff Lake, the second Athabasca Basin operation, started up in 1981. For the first two years, Cluff Lake processed high grade "D Zone" ore. Tailings from this ore were temporarily stored in concrete vaults, and later reprocessed to recover gold. The reprocessed tailings were diluted with neutralized tailings from the lower grade ores then being processed. Tailings are placed in surface impoundment with low permeability embankments. Equipment to thicken tailings to a paste prior to deposition has been commissioned, but operating challenges remain.

The third Athabasca Basin operation, Key Lake, began producing in 1983. The mill uses sulphuric acid for leaching and ammonia for SX stripping and uranium precipitation, and produces an ammonium sulphate byproduct. Until November 1995, neutralized tailings were placed in clay-lined surface impoundment surrounded by engineered dams on all four sides. Since then, thickened tailings have been placed in the mined-out Deilmann pit using the pervious surround system. Key Lake is exploring the possibility of reprocessing the tailings in the surface facility to extract nickel and cobalt. After processing, the reprocessed tailings would be placed in the Deilmann Tailings Management Facility (TMF).

Although both the Key Lake and Rabbit Lake tailings facilities have operated more or less the way they were designed, residual frozen tailings from winter operations have been recognized as an issue requiring solution. Frozen tailings that could thaw in a matter of years and facilitate continuing pore water release and possible disruption of surface covers.
The latest concept in tailings disposal in Saskatchewan is subaqueous deposition of paste tailings by "tremie" piping into open pits as shown in Figure 5. This innovative method will combine the advantages of the pervious surround method with subaqueous paste deposition, thereby minimizing segregation, freezing, dusting and radiation exposure.

Figure 5
Pit Disposal of Thickened Tailings

A tailings "paste" or thickened slurry is to be made by thickening tailings in the mill to 40% solids or more in a specially designed thickener and possibly with the assistance of filters. No chemical agents to alter tailings rheology are predicted to be needed. Two concepts are being considered for the final decommissioning of the tailings basin: water covers and a soil/wetlands cover. The choice will depend on the local hydrology, the availability of clean fill and the actual state of consolidation of the tailings deposited under water. Two major technological barriers need to be overcome to ensure success in the paste tailings deposition under water: abrasion in the paste pumps caused by extreme pressures, and the dispersion of pastes under water. The abrasion problem appears to have been overcome by the use of ceramic pump parts. The dispersion of paste underwater is expected to be complicated by the fact that the paste does not easily disperse, and will form a series of shallow cones as the dispersion location is changed. A new system of monitoring will need to be developed once the underwater paste system starts operating in the near future.

6. CONCLUSIONS:

Uranium mine waste disposal technology has evolved considerably in Canada in the last 52 years. For low grade uranium ores (< 0.3% U) where the environmental issues have been intrusion and acid generation, the use of engineered water covers is now the primary closure method. Where water covers are not possible or uneconomical, dry soil covers or elevated water tables are preferred methods.
For high grade deposits (0.3% to 15%U), the evolution over the last 15 years has been:

Concrete vaults → Surface impoundment (Cluff Lake)

Surface impoundment → Pit disposal with porous surround (Rabbit Lake)

Subareal → Pit disposal with thickened tailings (Key Lake)

Pit disposal → Pit disposal with paste or thickened tailings (JEB/McLean/Cigar)

By using the thickened tailings- paste/pit disposal concept, true "walkaway" is expected to be achieved in 10 to 15 years after mine closure. This concept may be adapted for special situations in the base metal industry where:

- acid generation is a concern;
- a mined-out pit is available; and
- the hydrology of the pit is subject to water level control (no underground mines connecting).

REFERENCES


