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Canadian Uranium Mines and Mills
Evolution of Regulatory Expectations and Requirements for Effluent Treatment

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ABSTRACT

The regulation of uranium mining in Canada has changed over time as our understanding and concern for impacts on both human and non-human biota has evolved. Since the mid-1970s and early 1980s, new uranium mine and mill developments have been the subject of environmental assessments to assess and determine the significance of environmental effects throughout the project life cycle including the post-decommissioning phase. Water treatment systems have subsequently been improved to limit potential effects by reducing the concentration of radiological and non-radiological contaminants in the effluent discharge and the total loadings to the environment.

This paper examines current regulatory requirements and expectations and how these impact uranium mining/milling practices. It also reviews current water management and effluent treatment practices and performance. Finally, it examines the issues and challenges for existing effluent treatment systems and identifies factors to be considered in optimizing current facilities and future facility designs.

I. INTRODUCTION

While the earliest uranium mines and mills in Canada operated with limited understanding of potential environmental impacts, increased knowledge, public concern and regulatory controls have led to significant changes in the management and treatment of mine and mill effluents.

By the mid-1970s, all new mine developments were subject to Environmental Assessments (EA) including panel hearings under harmonized provincial and federal EA processes. The EAs and subsequent licensing processes resulted in the implementation of improved water management and effluent treatment systems.

Prior to 2000, while the Atomic Energy Control Board (AECB) (now the Canadian Nuclear Safety Commission) was involved in environmental assessments and the review of environmental protection programs and results, its mandate for environmental protection was not explicitly stated in the relevant act and regulations in force at the time.

The enactment of the *Nuclear Safety and Control Act* (NSCA) and its associated regulations in May 2000, clearly mandated the role of the Canadian Nuclear Safety Commission (CNSC) and the obligations of proponents for environmental protection.

For example, NSCA paragraph 9(a)(i) states that the objects of the Commission are to regulate the production and use of nuclear substances to prevent unreasonable risk to the environment. NSCA paragraph 24(4)(b) prohibits the issuance of a licence unless in the opinion of the Commission the applicant will make adequate provisions for the protection of the environment in carrying on the licensed activity. Adequate provision is further expanded upon in paragraph 12(1)(f) of the *General Nuclear Safety and Control Regulations* to include a requirement for the licensee to take all reasonable precautions to control the release of radioactive nuclear substances or hazardous substances into the environment.

Other recent changes to federal legislation, namely the enactment of the *Metal Mining Effluent Regulations* and the *Canadian Environmental Assessment Act* (CEAA), and the associated application of Ecological Risk Assessments (ERA), have further defined regulatory expectations and requirements concerning water management and effluent treatment practices and performance at uranium mines and mills.

While effluent discharge limits are generally based on existing water quality objectives established at both provincial and federal levels, the recent application of ERAs has shown that releases of a few currently unregulated contaminants may harm non-human biota. For example, the potential for chronic molybdenum effects on reproduction in wildlife with aquatic diets and selenium teratogenicity and potential effects on reproduction in fish and waterfowl have been identified[1,2,3]. In addition, the *Priority Substance List* (PSL) 2 assessment of radionuclide releases from nuclear facilities, completed in support of the *Canadian Environmental Protection Act,* identified uranium as an element of concern.

As a result of these findings, the CNSC has been requiring licensees to review and modify their proposed and existing processes and treatment facilities to effectively control and minimize the environmental releases of these contaminants.

II. WATER MANAGEMENT

The sources of water potentially requiring treatment that are generated at operating uranium mines and mills may include pit dewatering, underground groundwater inflow, mine process water, runoff from waste-rock piles and facility aprons, mill process water (i.e., raffinate, scrubbing solutions, barren strip solutions, tailings process water), raise waters or seepage waters from tailings management facilities and domestic water. The sources, quantity, and quality of water to be handled and treated are site specific as some sites only have operating mines (i.e., McArthur River Mine, Cigar Lake), some have only mills and dewatering operations at mined-out pits and tailings management facilities (i.e., Key Lake, McClean Lake) and one site (Rabbit Lake) currently has both an operating mine and mill with the associated mine water and tailings management facilities.

The quantity and quality of water to be treated is affected by local hydrology, the selected mining and milling methods, and the characteristics of the ore, waste rock and tailings that are produced at each site.

At each site, various approaches are used to reduce the volumes of water requiring treatment and release. The interception and diversion of natural ground and surface water that would otherwise report to flooded pits or tailings management facilities has been effectively used to prevent the contamination of water and the need for treatment. For example, at the McClean Lake minesite, some 1.6 million m^3/yr of groundwater is pumped from dewatering wells surrounding the in-pit tailings management facility and discharged as uncontaminated water to the environment. Similarly, at the recently shutdown Cluff Lake mine, diversion ditches at the perimeter of the above ground tailings management facility effectively divert surface water that would otherwise report to the tailings area and become contaminated.

In underground mines, shafts have been lined and grouted to limit the amount of water that could enter the mine shafts. The uncontaminated groundwater collected from water rings has also been segregated and handled separately to allow for direct effluent discharge or use as clean process water. At uranium mills (Key Lake, Rabbit Lake and McClean Lake), some minewater is used as mill process water, thereby reducing the use of uncontaminated surface water. The recycling of mill process water further helps to reduce water and reagent consumption.

III. EFFLUENT TREATMENT PRACTICES

While the earlier effluent treatment systems used lime and sulphuric acid for pH adjustment and barium chloride for Radium-226 removal, current effluent treatment systems may be required to remove additional contaminants.

Effluent treatment systems at the operating uranium mines and mills rely primarily on chemical precipitation and separation to remove contaminants of concern. Lime is used extensively to neutralize the highly acidic mill process water and to precipitate metal hydroxides. Barium chloride is used to produce a co-precipitate of radium-barium sulphate with ferric sulphate also used as an adsorbent to facilitate floc formation.

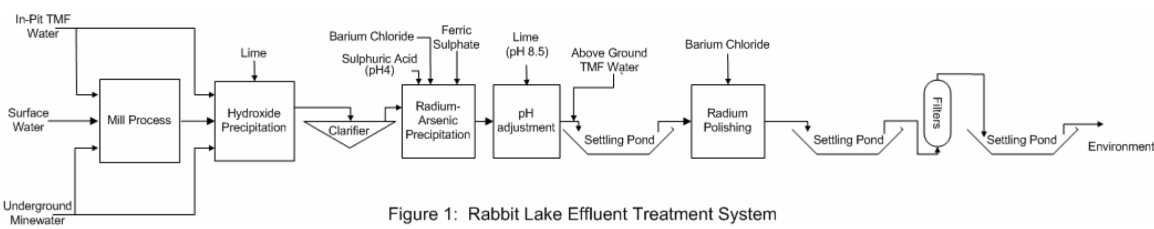

Figure 1: Rabbit Lake Effluent Treatment System

The effluent treatment systems at uranium mines developed in the mid-1970s and early 1980s (i.e. Rabbit Lake and Cluff Lake) include reaction tanks for reagent addition and chemical precipitation followed by large settling ponds with secondary effluent polishing. As shown on Figure 1, Rabbit Lake uses sand filters after the final settling pond effluent polishing system. Both facilities operate with continuous effluent release to the environment. The large settling ponds provide significant retention and settling times to remove suspended solids and provide buffering capacity to handle minor process upsets and changes in feed water quality. The large footprint of the settling ponds, the potential for groundwater contamination from the settling ponds and the potential for release of unacceptable water from a continuous release operation were some of the concerns that lead to further changes to the effluent treatment systems.

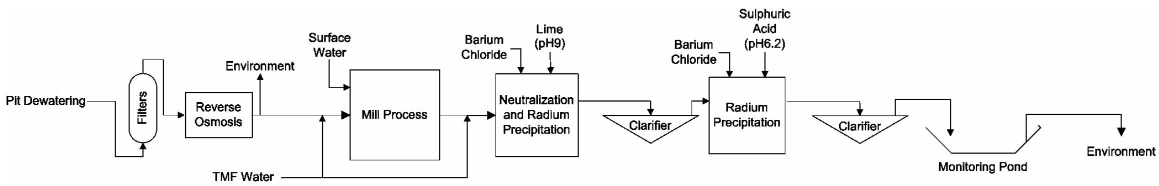

Figure 2: Key Lake Effluent Treatment System

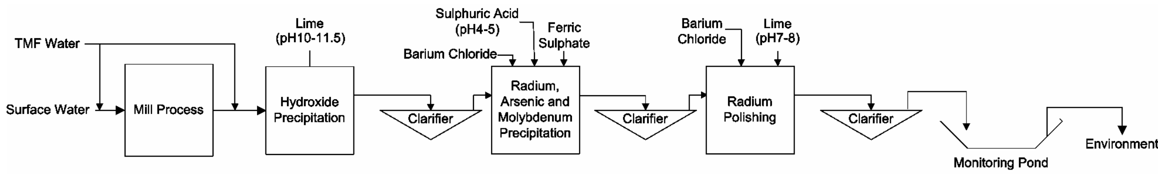

Figure 3: McClean Lake Mill Effluent Treatment System

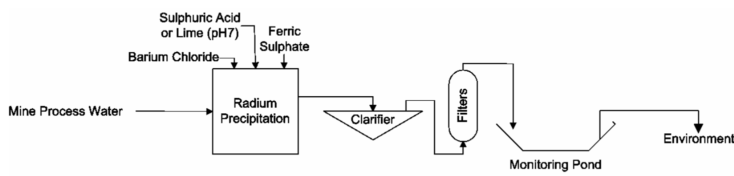

Figure 4: McArthur River Effluent Treatment System

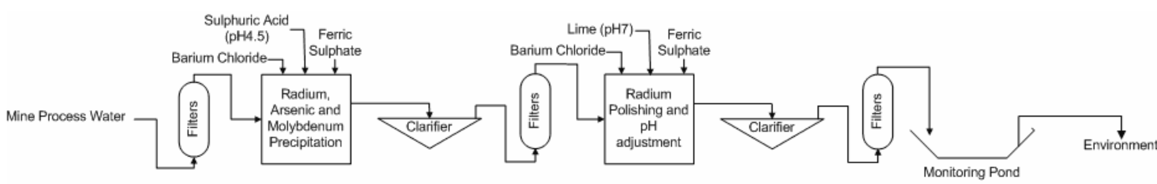

Figure 5: Cigar Lake Effluent Treatment System (Under Construction)

As shown in Figures 2 to 5, the more recent mine/mill developments (Key Lake, McClean Lake, McArthur River and Cigar Lake) apply similar reagent addition and chemical precipitation processes, however, precipitate removal is achieved by the use of clarifiers and/or filters. Treated water is transferred to monitoring ponds for analysis to confirm acceptable water quality prior to batch release to the environment. At the McClean Lake, McArthur River and Cigar Lake facilities sand filters are used to remove fine suspended particulate from the effluent treatment clarifier overflow. At the Key Lake operation, sand filters are not used and suspended particulate removal relies on the use of clarifiers only.

Of note is the McClean Lake operation, which has three separate treatment and clarification stages for the control of arsenic, pH and radium. This multistage process has an appreciable effect on the ability and flexibility of the effluent treatment system to remove various contaminants. This was recently demonstrated when minor process changes lead to significant reductions in molybdenum concentrations in effluent.

While reverse osmosis and ion exchange technology have been applied in a few circumstances, their application has remained rather limited. At the Key Lake operation, reverse osmosis technology has been effectively applied to treat contaminated groundwater intercepted around flooded pits. However, reverse osmosis technology requires pre-treatment of the feedwater and appears to be limited in application because of concerns with membrane fouling. Ion exchange processes have been previously used at certain mills (e.g., Stanleigh Mine in Ontario) to extract uranium from the pregnant solution, and previously at Key Lake for radium removal.

IV. EFFLUENT TREATMENT PERFORMANCE

Table 1: Regulatory Limits and Effluent Concentrations at Operating Uranium Mines and Mills in Canada

Parameter (Note 1)	SSWQO for protection of aquatic life	Ontario PWQO	Canadian Guideline for the Protection of Aquatic Life or as noted	Metal Mine Effluent Regulations	Mineral Industry Environmental Protection	Mean Effluent Concentrations at Operating Uranium Mines and Mills for the first ten months of 2004 (Note 6)				
						McClean Lake	Rabbit Lake	Key Lake	McArthur River	Cigar Lake
As	0.05	0.1	0.005	0.5	0.5	0.019	0.010	0.008	0.002	0.001
Cu	0.01	0.005	0.002-0.004	0.3	0.3	0.004	0.002	0.007	0.001	0.002
Mo	--	0.040	0.073			0.54	5.7	1.3	1.9	0.039
Ni	Note 2	0.025	0.025-0.150	0.5	0.5	0.028	0.016	0.028	0.002	0.005
Pb	0.020	Note 3	0.001-0.007	0.2	0.2	0.001	0.002	0.010	0.002	0.002
Ra^{226} (Bq/L)	0.11	1		0.37	0.37	0.026	0.015	0.061	0.039	0.010
Th^{230} (Bq/L)					1.85	0.024	0.168	0.223	0.010	0.010
Pb^{210} (Bq/L)					0.92	0.082	0.080	0.048	0.027	0.038
Se	0.01	0.100	0.001 (Note 4)							0.001
U	--	0.005	0.011-0.120 (Note 5)		2.5	0.075	0.334	0.012	0.022	0.030
Zn	0.05	0.030	0.030	0.5	0.5	0.005	0.006	0.008	0.007	0.010
TSS				15		1.2	1.4	2.2	1	1.5
pH			6.5-9.0	6.0-9.5		7.5	7.0	6.4	7.1	7.4
Volume (m^3)						1322152	3073591	991154	2632430	143669

PWQO = Provincial Water Quality Objective
SSWQO = Saskatchewan Surface Water Quality Objective
Note 1: (mg/L) unless otherwise shown.
Note 2: Nickel values are hardness related; values are 25 μg/L when [Hardness] <100 mg/L and 100 μg/L when [Hardness] >100 mg/L at the site in question.
Note 3: Interim PWQO for lead is still hardness related but more restrictive. 1μg/L when [Hardness] <30 mg/L, 3 μg/L when [Hardness] >30 mg/L and < 80 mg/L, and 5 μg/L when [Hardness] >80 mg/L.
Note 4: Canadian Guideline for the Protection of Aquatic Life (Freshwater) for pH = 8 at 10^oC.
Note 5: CNSC recommended values for total U in mg/L. High value is for hard water (>100 mg/L $CaCO_3$).
Note 6: November 2004 Monthly Environment Reports for McClean Lake, Rabbit Lake, Key Lake, McArthur River and Cigar Lake.

Table 1 presents the contaminant concentrations in effluent for the first ten months of 2004 for the four operating uranium mines and mills, which are all located in northern Saskatchewan. The table also includes federal and Saskatchewan mine effluent discharge limits. The surface water quality objectives for Ontario and Saskatchewan, and the *Canadian Environment Quality Guidelines* (EQG) have also been included for comparison and to highlight a few other contaminants of interest. Of note is that effluent releases from all the operating uranium mines and mills are significantly below the federal and provincial effluent discharge limits for regulated elements. Furthermore, the effluent concentrations for these same elements are below the current *Saskatchewan Surface Water Quality Objectives* (SSWQO). All of the operating mines have demonstrated a commitment and ability to meet and exceed regulatory expectations for these regulated elements.

As noted in the introduction, recent environmental assessments have identified molybdenum, selenium and uranium as contaminants of concern. As shown in Table 1, some provincial and federal water quality objectives and guidelines have been established for these elements as a result of environmental concerns. The table also shows that for molybdenum in particular, the effluent concentrations are significantly above the EQG. While no new effluent limits have been established, through the environmental assessment and licensing processes, licensees are being requested to review and modify their water treatment systems to reduce effluent concentrations of uranium and molybdenum.

For example, during the recently completed environmental assessment for the Cigar Lake uranium mine project, concerns of potential impacts from molybdenum to ruminants and aquatic mammals lead to modifications to the proposed effluent treatment system to allow for the effective removal of molybdenum[3]. In another case, in 2003, as a condition to the CNSC operating licence for Rabbit Lake, Cameco Corporation committed to conduct a detailed study and to implement modifications to the effluent treatment circuits to lower the uranium level in the final effluent. Molybdenum is also being reviewed. Some minor process changes have lead to some reduction in uranium concentrations (January to October 2004 mean concentration of 334 ug/L vs 450 ug/L in 2003), however, further process changes are being investigated for implementation in the coming year or two [4, 5].

The McArthur River and Key Lake facilities are also conducting further studies with respect to molybdenum while the McClean Lake operation has evaluated and implemented changes to its effluent treatment system to reduce molybdenum concentrations in effluent. The McClean Lake operation effectively reduced the molybdenum concentration in its mill effluent from a mean of 4.0 mg/L in 2003 to a mean of 0.54 mg/L for the first ten months of 2004. This reduction was achieved by lowering the pH level to approximately 4.5 in the second effluent treatment stage and adding more ferric sulphate to precipitate the molybdenum as ferrimolybdenite. No physical changes to the existing effluent treatment system were required.

V. ISSUES FOR CONSIDERATION

While several improvements have been or are in the process of being implemented to reduce the concentration of certain elements, several issues and opportunities may need further consideration.

A review of the monthly environmental reports for the various facilities indicates that the concentration of contaminants in the mine waters and mill process waters are affected by the ore characteristics. As such, it is becoming increasingly important to better characterize the ore being processed to better predict and respond to changes in milling and effluent treatment process requirements. Furthermore, optimization and increased robustness in effluent treatment systems is necessary to allow for increased flexibility to accommodate changes in ore characteristics or mine/milling processes. At the McClean Lake operation, the rapid implementation of process changes to reduce molybdenum concentrations demonstrated that the process could be easily adapted to further reduce the molybdenum concentration in the effluent.

While chemical precipitation provides for a relatively simple method for removal of various contaminants, it also leads to significant consumption of reagents and loadings of these reagents to the environment. Even though the effluent discharge limits for sulphate and chloride remain very high, efforts to reduce the loadings of these contaminants to the environment should be considered. Furthermore, the precipitates produced in the effluent treatment systems have not been fully characterized and their long-term stability has not been fully demonstrated. As such, the potential remobilization of contaminants needs to be further examined and addressed.

Recent experience has demonstrated the pH dependency of treatment processes for different contaminants[5,6]. While some elements precipitate at elevated pH, others such as molybdenum require treatment at reduced pH levels. Some of the current treatment processes do not provide the flexibility for multistage treatment and would require additional reaction and clarification stages to deal with other contaminants.

Treatment options other than chemical precipitation should be further examined to reduce chemical consumption and loadings to the environment. These options may also lead to more stable waste forms.

While not a regulatory concern, the potential to economically recover certain elements from the effluent stream may also be worth considering when evaluating various milling and treatment options. The revenue generated could then be used to offset effluent treatment costs. For example, in 2003, the total uranium inflow to the Rabbit Lake effluent treatment system was approximately 20 tonnes. At an assumed spot price of \$55/kg U_3O_8 (21 U.S.\$/lb), the uranium which might be recovered from the effluent could be worth upwards of \$1M. The Rabbit Lake operation is examining ion exchange technology to recover uranium from the mine waters produced at the minesite[5]. The recovery of other elements such as molybdenum may also be worthy of consideration.

In the area of source management, while the various mines and mills have undertaken various efforts to reduce or control the quantity and quality of water requiring treatment, opportunities for further reduction in water consumption, contaminated water production and increased recycle should be carefully examined. Improvements in water segregation and diversion, changes to milling processes and increased recycling might some day lead to a near-zero effluent discharge mine and/or mill site. The efforts underway at the Cigar Lake uranium mine to maximize the recycling of water used in the underground mining and milling processes may pave the way to such a realization.

In any event, the regulatory bodies will continue to encourage the operators of uranium mines and mills to examine every reasonable opportunity to reduce their potential impact on the environment. While the operators have demonstrated their ability to maintain contaminant concentrations of regulated elements well below effluent discharge quality limits and in many cases below surface water quality objectives and guidelines, a continuing commitment to environmental protection and pollution prevention is encouraged to further reduce loadings to the environment.

VI. CONCLUSIONS

As the current knowledge gaps in ERAs are filled, and new issues arise from scientific and environmental monitoring information, it is anticipated that regulatory expectations and requirements for effluent treatment systems and releases will continue to evolve.

The CNSC encourages operators of uranium mines and mills to further optimize mining and milling operations, water management and treatment practices to reduce waste water generation and reduce contaminant loadings to the environment. While minimizing any potential environmental impacts, this should also allow operators to effectively respond to changing regulatory expectations and requirements and minimize potential decommissioning liabilities.

While maintaining an overall pollution prevention approach in accordance with the NSCA and federal government policy, the CNSC will continue to strive to maintain regulatory fairness in its decision-making process taking into consideration risk, scientific uncertainty and public concerns.

VII. REFERENCES

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