METHODS OF EVALUATING ORE PROCESSING AND EFFLUENT TREATMENT FOR CIGAR LAKE ORE AT THE RABBIT LAKE MILL

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Abstract. Cigar Lake is the second-largest, high grade uranium orebody in the world. Mineable reserves for Cigar Lake Phase 1 are estimated at 191 million pounds U_3O_8 with a grade of 25.6% U_3O_8. Subject to regulatory approval, Cameco intends to process the majority of ore from Cigar Lake in the Rabbit Lake mill. Cameco initiated a programme to study the processing of Cigar Lake ore and the treatment of the resulting waste streams. Laboratory and follow-up pilot scale ore leaching tests with Cigar Lake ore samples were performed. Tailings and effluents were generated from the products of the pilot scale leach tests. Mill process tailings were blended with ground waste rock. Using these materials, geotechnical and geochemical properties, including long term tailings pore water characteristics, will be evaluated. In addition, proposed changes to the mill waste treatment operations were developed to deal with increased levels of arsenic and radium in the waste streams. This paper describes the methods and techniques Cameco used in this programme.

1. INTRODUCTION

The Cigar Lake orebody is located in the Athabasca Basin in northern Saskatchewan, about 660 km north of Saskatoon, see Figure 1. The Cigar Lake project, currently operated by Cigar Lake Mining Corporation, is owned by Cameco Corporation (50.025%), Cogema Resources Inc. (37.100%), Idemitsu Uranium Exploration Canada Ltd. (7.875%) and TEPCO Resources Inc. (5.000%). Upon the joint venture decision to proceed with development, Cameco will assume the role of operator at the Cigar Lake minesite.

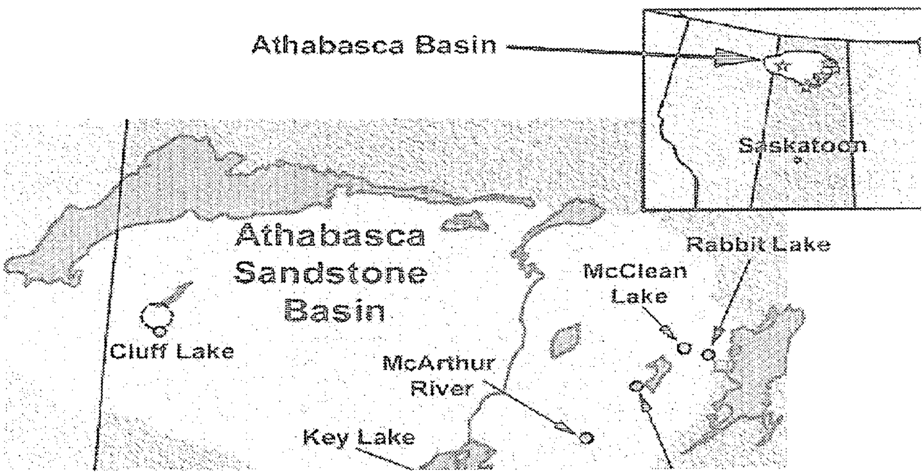

FIG. 1. Project location map.

Subject to regulatory approval, Cameco intends to process 57% of the Cigar Lake ore in the Rabbit Lake mill. (Processing of the rest of the ore is proposed for the McClean Lake mill, subject to regulatory approval). The Rabbit Lake operation is 90 km northeast of Cigar Lake, see Figure 1. The Rabbit Lake project is 100% owned and operated by Cameco. It is planned to mine and grind the ore at the Cigar Lake site and truck ore slurry to Rabbit Lake for processing.

The Cigar Lake ore is high grade, with the Phase 1 mineable reserve averaging 25.6% U_3O_8. The ore also contains significant quantities of arsenic and nickel, with the Phase 1 ore expected to average 3.0% As and 1.5% Ni. The scheme for processing Cigar Lake ore in the Rabbit Lake mill must include methods to prevent contamination of mill effluent discharge by As and Ni in particular, but other metals also. For the Rabbit Lake operation, the present Saskatchewan Environment and Resource Management waste water quality limits include the following criteria:

Substance	Maximum Monthly Arithmetic Mean Concentration	Maximum Grab or Composite Sample Concentration
Arsenic (mg/L)	0.5	1.0
Copper (mg/L)	0.3	0.6
Lead (mg/L)	0.2	0.4
Nickel (mg/L)	0.5	1.0
Zinc (mg/L)	0.5	1.0
Uranium (mg/L)	2.5	5.0
Total Ra-226 (Bq/L)	0.37	1.1
Total Suspended Solids (mg/L)	25.0	50.0
Total Cyanide (mg/L)	1.0	2.0
Th-230 (Bq/L)	1.85	3.7
Pb-210 (Bq/L)	0.92	1.84
Un-ionized Ammonia (mg/L)	0.5	1.0

2. LABORATORY SCALE LEACHING TESTS

Prior to the tests undertaken by Cameco in this programme, the process design for leaching Cigar Lake ore used autoclaves. Cameco has operated uranium leach autoclaves at the Key Lake mill since 1983. Since capital and operating costs for autoclaves are relatively high, it was decided to see if the Cigar Lake ore could be leached in pachucas.

The laboratory scale testing was begun in late 1997 at the Key Lake metallurgical laboratory. Pachuca leaching was tested using specially-designed leach vessels which were developed in the late 1970s by Eldorado Nuclear R&D to enable a bench scale simulation of the operation of the 5.5 metre diameter by 17 metre tall leach pachucas at the Beaverlodge mill. These laboratory leach vessels are essentially low pressure autoclaves with automatic temperature control, continuous oxygen addition at a controlled pressure, and large, slow-moving mixing blades to simulate the relatively mild agitation in pachucas. See Figures 2 and 3.

Because there was no Cigar Lake ore sample available, the first laboratory scoping tests used a hand picked, high grade (28% U_3O_8) ore sample from the A-zone stockpile at Rabbit Lake. Leach conditions kept constant were: 35% solids, 450 kg/t sulphuric acid addition, and 60°C temperature. Three tests were run at 150,200 and 250 kPa, equivalent to pachucas 11, 15 and 19 metres tall. Results were very promising:

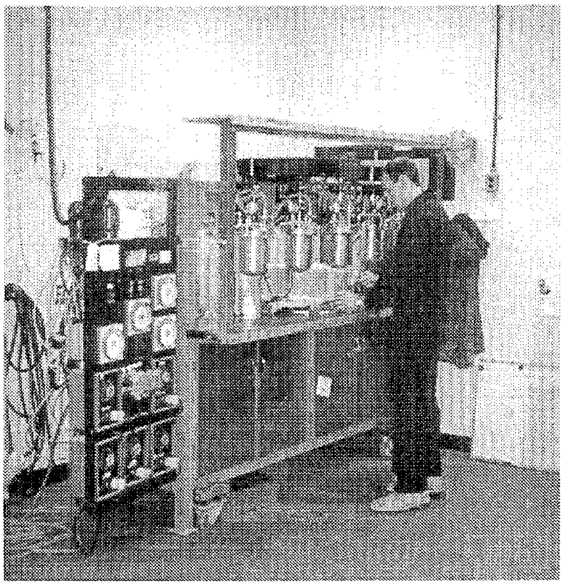

FIG. 2. Pachuca leach test apparatus.

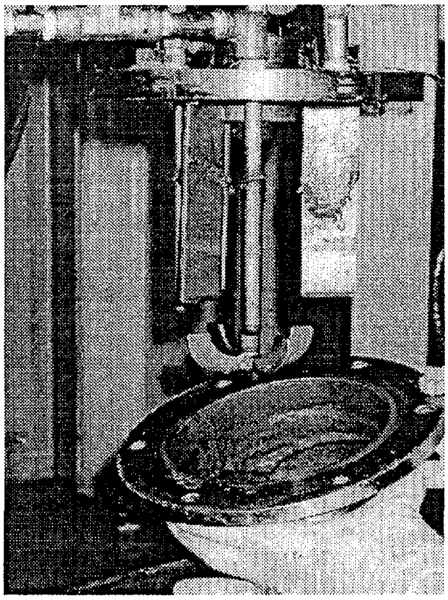

FIG. 3. Test apparatus internals.

Pressure, kPa	% U_3O_8 Extraction at 20 h	% U_3O_8 Extraction at 40 h
150	79.5	99.8
200	93.2	99.7
250	94.7	96.2

Follow-up tests to confirm these results with a Cigar Lake ore sample (28.4% U_3O_8) were done in early 1998. In these tests the leach feed slurry density was maintained at 35% solids, while sulphuric acid addition, temperature and pressure were all varied. Leach pressure was kept below 150 kPa, since higher pressures gave no apparent benefit. The success of pachuca leaching was indeed confirmed by the results:

Acid Addition kg/t	Temperature °C	Pressure kPa	Leach time h	U_3O_8 Extraction %
450	53	150	20	99.83
450	56	150	30	99.83
450	57	150	40	99.84
450	65	100	40	99.80
450	56	75	40	99.82
350	53	150	40	99.52
250	57	150	40	94.92
350	65	75	40	99.58
250	56	75	40	85.17
350	50	75	40	95.24
350	40	75	40	99.58

In each of these laboratory tests, all the sulphuric acid was added in a single dose at the start of the leach. In contrast, in full scale operation sulphuric acid would be added continuously to maintain a target free acidity; in fact, slurry conductivity (directly proportional to free acidity) is sensed and controlled. To simulate acid addition in full scale operation, two more bench scale tests were performed with the free acidity controlled to 100 g/L at the start of the leach, gradually reducing to 20 g/L at the end.

Acid addition kg/t	Temperature °C	Pressure kPa	Leach time h	U_3O_8 Extraction %
304	60	75	36	99.11
310	45	75	36	97.87

The encouraging results of the laboratory scale leaching tests justified continuing on to pilot scale tests.

Small tailings samples were made using the products from the leaching tests. Leach residues from individual tests were mixed together into one sample, then slurried and neutralized with lime. Undiluted tailings were prepared by mixing the neutralized residue slurry with gypsum solids and solids from solvent extraction raffinate neutralized in the Rabbit Lake mill. Combining a portion of the undiluted tailings with ground till or ground waste rock, both from the Rabbit Lake site, provided the final diluted tailings samples. The purpose of this dilution was to lower the tailings grade and improve geotechnical properties — final settled density, for example.

A great deal of experience in splitting and blending tailings slurry samples was obtained generating these laboratory scale diluted tailings samples. This experience was invaluable later in preparing the larger pilot scale tailings sample. It was expected that the solute concentrations in the till-diluted tailings samples would be lower than in the waste rock-diluted tailings samples because of the presumed absorptive properties of the clays in the till. In fact, there was no significant difference found. Both till-diluted and waste rock-diluted tailings had improved geotechnical properties. The Rabbit Lake site has waste rock already mined. However, till for tailings dilution would have to be mined, with a potential for increased environmental impact. Thus the till-dilution option was dropped in favour of waste rock-dilution.

It was also observed that the geotechnical properties (e.g., solids settling rate, final settled density) of the undiluted tailings sample were not optimal for subaerial or subaqueous deposition in the Rabbit Lake in-pit tailings management facility. Geotechnical properties of undiluted tailings were considered potentially effective for deep injection into the previously deposited tailings.

3. PILOT SCALE LEACHING TESTS

In mid-1998 Cameco asked Cigar Lake Mining Corporation to supply a sample of Cigar Lake Phase 1 ore sufficient for pilot scale testing. A drilling programme was initiated and completed by October 1998. 575 kg of drill core were collected and stored in bags. Of the 212 individual bagged samples, 89 were ore and 123 were waste. Each individual bagged sample was dried, crushed and assayed. A pilot plant composite sample was mixed from selected individual samples to approximate as closely as possible the expected average composition of the Cigar Lake Phase 1 ore. The resulting pilot plant composite sample closely matched expected ore composition:

	% U_3O_8	% As	% Ni	% Fe
Expected Cigar Lake Phase 1 Ore	25.6	3.0	1.5	6.0
Pilot Plant Composite	24.6	2.7	1.8	4.6

The pilot plant consisted of a grinding, classification and thickening circuit, a leach feed conditioning tank, and a pilot pachuca. Grinding equipment included a 0.6 m^3 feed hopper with a vibratory pan discharge, a variable speed feed conveyor, and a 41 cm diameter by 41 cm long ball mill. Classification was provided by a vibrating screen with 500 micrometer openings. Thickening after grinding was performed in a single 91 cm diameter by 91 cm deep thickener. Leach feed conditioning was done in a 76 cm diameter by 122 cm tall polyethylene tank. Various pumps, piping and ventilation hoods and fans were fitted as required. See Figures 4 and 5.

The pilot pachuca was fabricated at Rabbit Lake. Figure 6 provides details of its design. Based on the laboratory scale leach tests, the slurry depth in the pilot pachuca was set at 11 metres. Pilot pachuca instrumentation included ORP and conductivity probes to permit control of oxidizing potential and conductivity (i.e., free acidity). A thermocouple placed in the top overflow lateral enabled leaching temperature control. An oxygen gas flowmeter and totalizer was installed to determine instantaneous flow rate and total consumption.

In outline, the pilot pachuca leach test procedure was as follows:

- 110 kg of ore were ground and thickened
- Ore slurry was pumped into the leach feed conditioning tank and the initial addition of sulphuric acid was made
- The conditioned ore slurry was pumped into the pilot pachuca
- Oxygen gas flow was set at the operating level; this was taken as time zero for the leach test
- Slurry temperature was increased as rapidly as possible, then held at 50°–60°C
- Leaching was continued for 40 hours
- Pilot pachuca contents were pumped into the conditioning tank, flocculated, and allowed to settle

— The clear pregnant aqueous solution was collected from the top of the tank and stored for later use

— To simulate CCD washing, acidified wash water (pH~2) was added to the tank, the slurry remixed and allowed to settle, and the supernatant solution was drawn off; this was done five times to simulate the Rabbit Lake CCD circuit

— The washed leach residue solids were collected and stored for later use

Two pilot pachuca leach tests were performed. In the first, U_3O_8 extraction was 99.7%. This extraction was reached after just 16 hours of leaching. In the second, U_3O_8 extraction was 99.8%. Once again, this extraction was reached after just 16 hours of leaching.

Once metallurgical tests were completed the test products were used to prepare tailings samples.

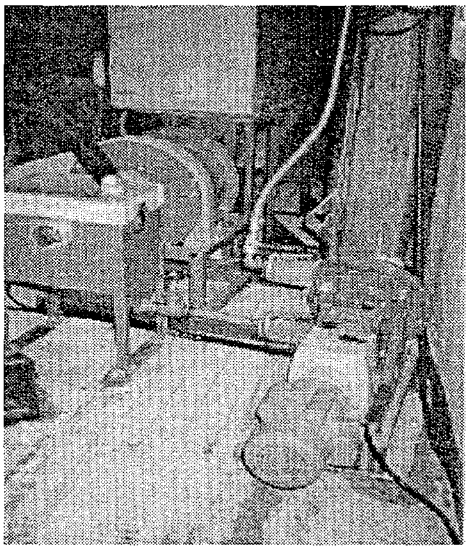

FIG. 4. Pilot plant ball mill, pump box and classification screen feed pump.

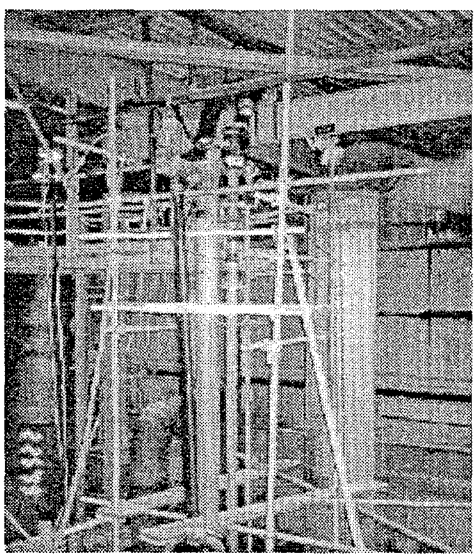

FIG. 5. Top and upper section of the pilot plant pachuca

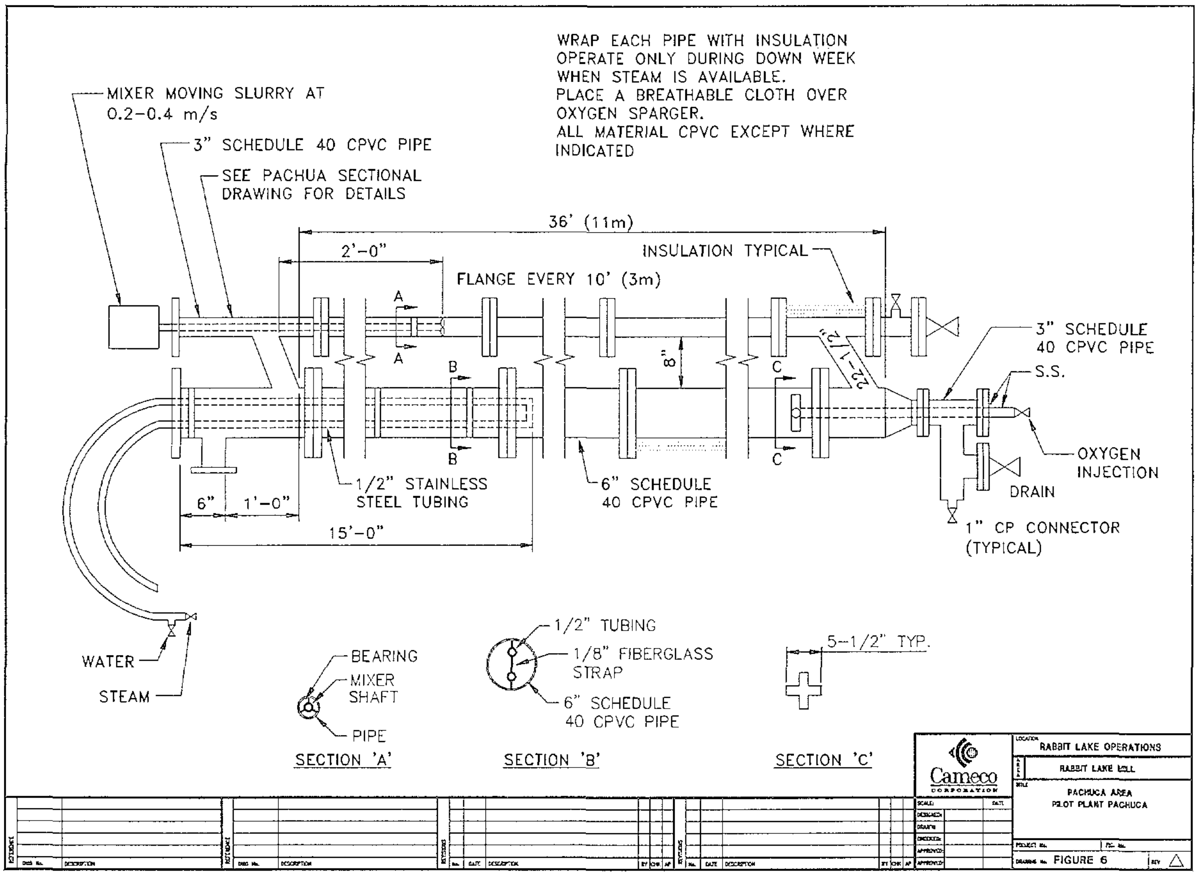

FIG. 6. Rabbit Lake operations, Rabbit Lake mill, Pachuca area, Pilot Plant Pachuca

4. ENHANCED ARSENIC PRECIPITATE STABILITY

The anticipated scheme for processing Cigar Lake Phase 1 ore in the Rabbit Lake mill is shown in Figure 7. Arsenic leached from the ore will be removed from solution by precipitation with lime in the solution neutralization pachucas. Presently, the Rabbit Lake solution neutralization circuit operates with the following pH profile:

Solution Neutralization Pachuca	pH
1	6.5
2	8.5
3	10.0

A large number of laboratory tests were completed to determine the optimum pH profile for obtaining stable arsenic precipitates while maintaining acceptable solution concentrations of all major species, in particular U_3O_8, As and Ni. A balance had to be attained: a higher pH would give lower dissolved Ni and U_3O_8 but higher As; a lower pH would give higher dissolved Ni and U_3O_8 but lower As. The literature indicated that the stability of the arsenic precipitate would be enhanced by precipitating basic ferric arsenates, and that their formation is favoured by precipitating at a relatively low pH. The precipitation tests confirmed this; 95.0% and 99.8% of the dissolved arsenic was precipitated at pH 2 and 3, respectively.

Increasing pH further, to between 8 and 9, provided an eight-fold decrease in dissolved arsenic relative to pH 3. However, increasing pH even further appeared to cause the dissolution of the basic ferric arsenates; pH 11.3 gave a ten-fold increase in dissolved arsenic. Equally importantly, it was found that at pH 8.5 the solution concentrations of U_3O_8 and Ni were within acceptable levels. Based on these results, an adjustment in the pH profile of the solution neutralization pachucas has been proposed:

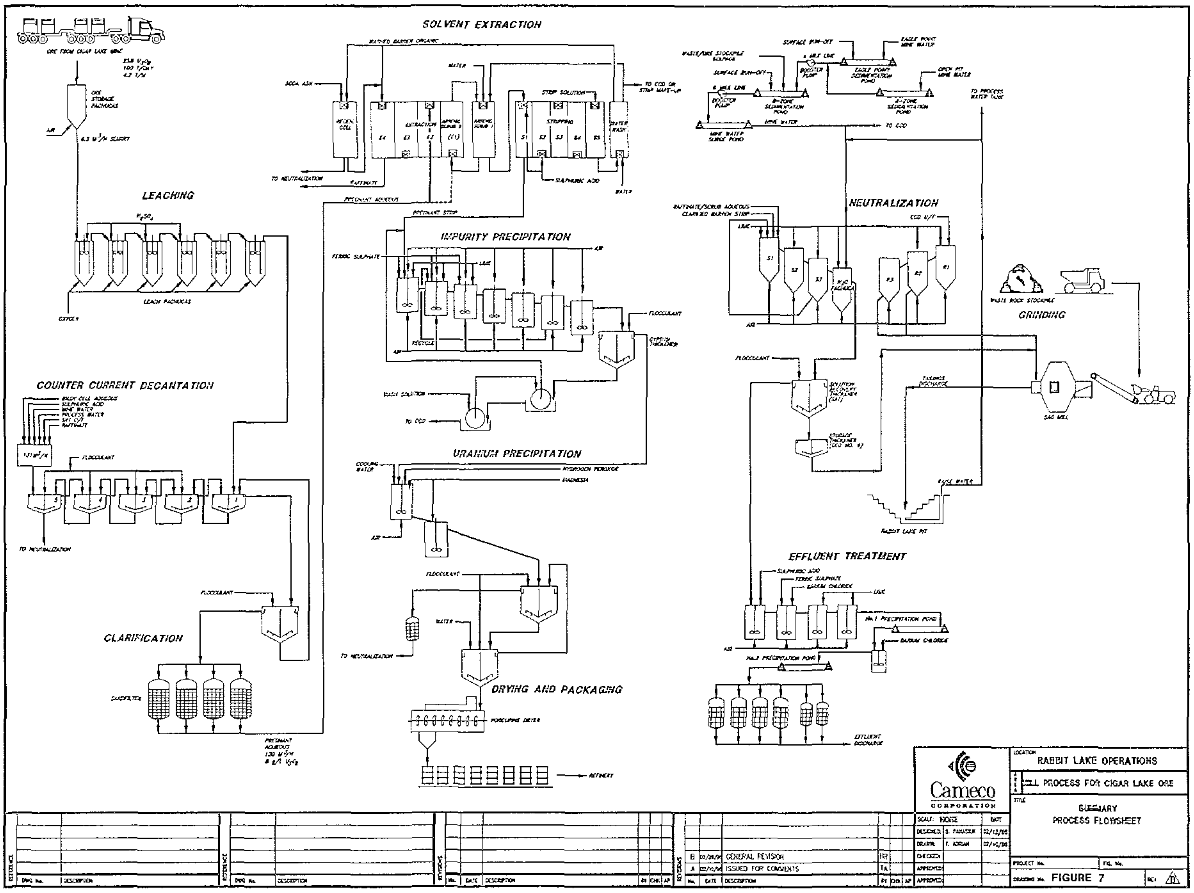

FIG. 7. Rabbit Lake operations, mill process for Cigar Lake ore, summary process flowsheet

Solution Neutralization Pachuca	pH
1	2.0
2	3.0
3	8.5

It was decided that the residue neutralization pachuca profile should mirror the solution neutralization pachuca profile. In the residue neutralization pachucas, lime is added for pH control only in the first two pachucas. The pH in the final pachuca matches that of the second pachuca. The following profile has been proposed:

Residue Neutralization Pachuca	PH
1	3.0
2	8.5
3	8.5

5. ENHANCED RADIUM PRECIPITATION

It was noted in early leach residue neutralization trials that the dissolved radium (Ra-226) concentration was increasing as the slurry pH was increased from less than 2 to 8.5. This situation had to be corrected to prevent unacceptably high dissolved Ra-226 levels in the tailings pore water. The standard method of removing radium from solution is to add barium chloride solution and thus precipitate barium-radium sulphate. However, "conventional wisdom" held that barium chloride addition is only effective in clear solutions, and ineffective in slurries. Nevertheless, it was decided to test barium chloride addition to the acidic leach residue slurry as the first step in the residue neutralization process. Happily, the tests showed that addition of 25 to 50 grams of barium chloride per cubic metre of slurry, followed by neutralization to the above proposed pH profile, was effective in reducing the dissolved Ra-226 concentration to below acceptable levels.

6. TAILINGS PREPARATION

Tailings samples were needed to provide geochemical and geotechnical data to enable evaluation of three proposed tailings deposition concepts: subaerial, subaqueous and deep injection.

The tailings samples prepared were comprised of:

- Neutralized leach residue
- Neutralized raffinate solids (i.e., solution recovery thickener underflow; see Fig. 7)
- Gypsum thickener underflow solids (see Fig. 7)
- Ground waste rock

The first three constituents were mixed in the ratios dictated by pilot test results combined with historical operating data from the Rabbit Lake mill. Undiluted tailings made from these constituents were mixed with ground Rabbit Lake waste rock to give diluted tailings. The waste rock addition rate diluted the tailings to an equivalent 4% U_3O_8 ore grade.

Neutralized leach residue was prepared by mixing together the leach residue slurries from the two pilot pachuca leach tests, adding barium chloride, and neutralizing with milk of lime to the above proposed pH profile.

To prepare neutralized raffinate solids, the combined pregnant aqueous solution from the two pilot pachuca leach tests was subjected to solvent extraction to produce the required raffinate. The raffinate was then neutralized with milk of lime to the above proposed pH profile and the resultant slurry of precipitated solids was thickened.

During a period when the Rabbit Lake mill was processing ore with high As:U_3O_8 and Ni:U_3O_8 ratios (indeed, higher ratios than those expected when processing Cigar Lake ore), gypsum thickener U/F solids were collected from the mill circuit. These were subjected to a wash simulating the mill CCD circuit wash.

Waste rock slurry for tailings dilution was prepared in the pilot plant grinding, classification and thickening circuit.

The pilot plant waste rock-diluted tailings sample was mixed according to the following "recipe":

Neutralized Leach Residue, weight %	Neutralized Raffinate Solids, weight %	Gypsum Thickener U/F Solids, weight %	Ground Waste Rock, weight %
7.5	20.5	12.0	60.0

The pilot plant undiluted tailings sample was mixed according to this "recipe":

Neutralized Leach Residue, weight %	Neutralized Raffinate Solids, weight %	Gypsum Thickener U/F Solids, weight %	Ground Waste Rock, weight %
18.8	51.2	30.0	0.0

Completed tailings slurry samples, diluted and undiluted, were thickened, packaged, and shipped to consultants for geochemical (e.g., solids assays, initial and aged porewater assays) and geotechnical (e.g., grain size distribution, specific gravity of particles, settled density, hydraulic conductivity) testing.

7. RECOMMENDATIONS

In principle, the methods and techniques described for evaluating ore processing and effluent treatment could be adapted for other uranium ores. The exact methods and techniques would have to be tailored for the specific unique properties of the ore in question. For example, arsenic and nickel might not be of concern, but other metals such as vanadium, selenium or molybdenum could well pose ore processing and effluent treatment challenges.

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