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OPERATIONAL-PHASE WASTE ROCK MANAGEMENT AT CAMECO'S MCARTHUR RIVER OPERATION

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ABSTRACT

The McArthur River underground uranium mine is the world's largest high-grade uranium deposit. This mine, which is located in northern Saskatchewan and began operations in 1999, is jointly owned by Cameco Corporation (70%) and by the Areva subsidiary COGEMA Resources Inc. (30%). Early in the planning and environmental assessment stages for this project, the need for a well-articulated waste rock management plan was identified. Waste rock can prove to be one of, if not the largest long-term potential liability of any mine. Mine site decommissioning costs can be a significant part of the total liability if not properly managed. Proper management of waste rock is instrumental in developing and operating a mine using sustainable development principles. The McArthur River plan required that a process be developed to classify the various categories of waste rock with reasonable precision and that, where possible, waste rock be used for valued added purposes. The plan also requires that waste rock storage areas be designed to minimize environmental impacts. This paper summarizes the McArthur River waste rock management plan along with the benefits that have been derived from its use.

I. INTRODUCTION

The McArthur River mine is located in the southeastern portion of the Athabasca Basin in northern Saskatchewan (Figure 1). The ore body was discovered in 1988 at a depth of 500 to 600 metres below surface. Between 1993 and 1997 the ore body was further defined through underground exploration. Environmental assessment and public reviews were also completed and federal and provincial environmental approvals received. Between 1997 and 1999 construction activities took place to prepare the mine for production, including the construction of an underground ore slurry processing circuit and ancillary surface facilities. In late 1999, the mine began production using the raisebore mining method, as depicted in Figure 2, with ore slurry shipped to the Key Lake mill. As of December 31, 2003, the combined proven and probable reserve at McArthur River was 801,000 tonnes at a grade of 24.7 % for a total content of 436.5 million pounds of uranium oxide (U_3O_8) (Ref. 1).

Figure 1: General Location Map of Northern Saskatchewan

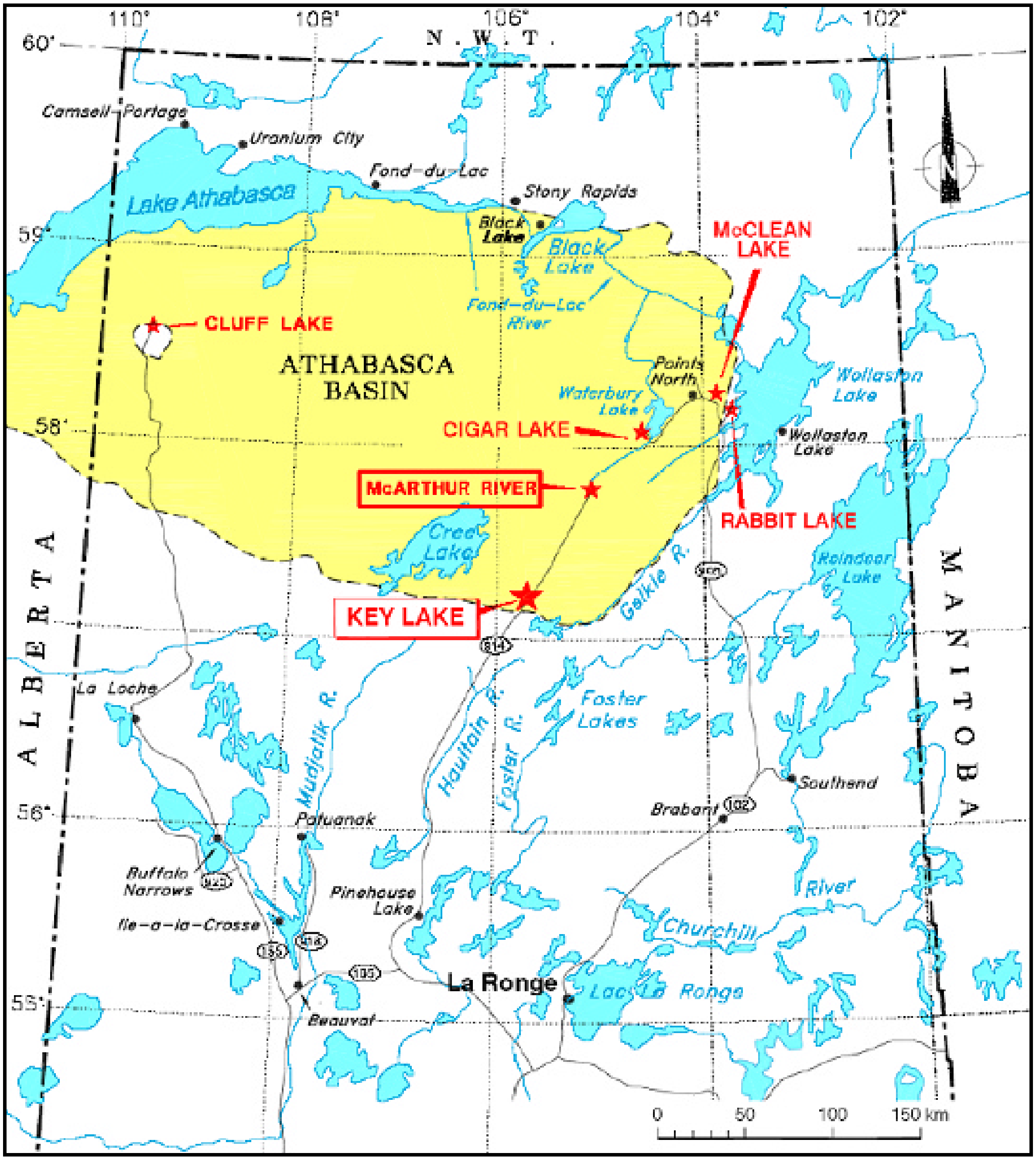
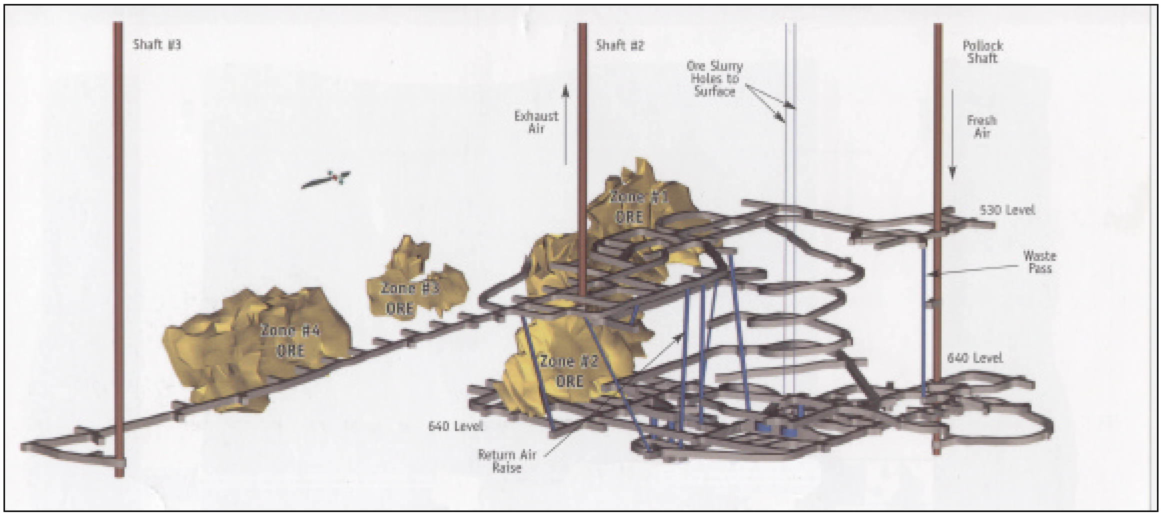
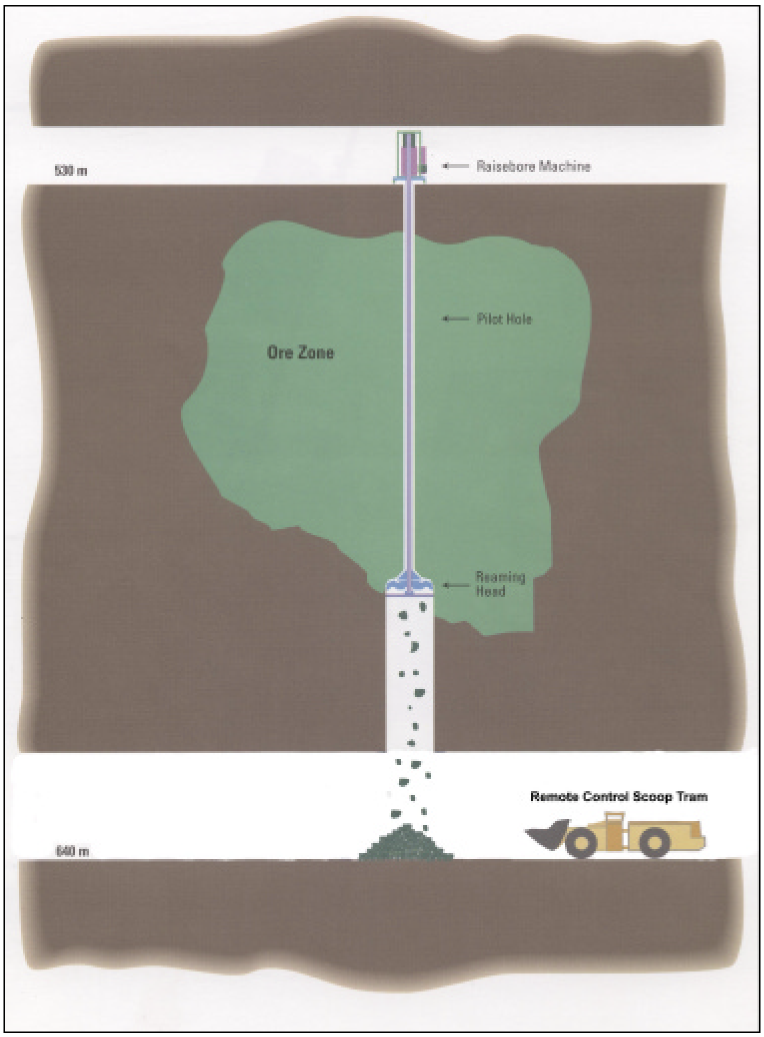


Figure 2: McArthur River Mine Development and Raise Bore Mining Method





As with all underground mines, waste rock is generated during the development and mining process. While the quantity of waste rock generated from an underground mine is generally less than for an open-pit mine of similarly sized ore body, the waste rock must still be managed. At the McArthur River mine it was recognized early on that waste rock, containing sub-economic concentrations of uranium, when coupled with the presence of sulphides could result in environmental impacts if not properly identified, handled, and stored. As such, the method of managing waste rock to minimize long-term liability was developed early in the planning and environmental assessment stage of the mine.

The waste rock management plan consists of the following components:

- Establishment of waste rock classification criteria;
- Identification of waste rock type during exploration, development, and mining;
- Storage of certain waste rock on contained pads with environmental controls; and
- Maximized usage of waste rock where possible as a valued added resource.

II. WASTE ROCK CLASSIFICATION

Classification Criteria

At the McArthur River mine, the waste rock classification system, as described in the approved McArthur River Environmental Impact Statement (Ref. 2), is based on the uranium content of the rock and it's ability to generate acidic drainage. The waste rock is segregated into three basic types – 'clean', potentially acid generating, and mineralized with uranium. The criteria for the waste rock classification at the McArthur River mine are provided in Table 1. The measurements used for this determination are the percentage of uranium oxide, the percentage of sulphur, and the ratio of neutralizing potential to acid generating potential. At other mining operations, additional classifications of waste rock have been made for waste rock containing high concentrations of arsenic and nickel. However, at the McArthur River mine, the concentration of such problematic contaminants in the waste rock are low and thus do not require specific classification and/or management.

Table 1: Waste Rock Classification Criteria

Waste Rock Classification	**% U_3O_8** [1]	**% Sulphur** [2]	**NP:AP** [3]
Clean	< 0.03	≤ 0.2	-
	< 0.03	> 0.2	> 3:1
Potentially Acid Generating (PAG)	< 0.03	> 0.2	< 3:1
Mineralized	> 0.03	-	-

1 – determined by the neutron activation, delayed neutron counting method.
2 – determined by the Horiba induction furnace method.
3 - NP:AP is the ratio of neutralizing potential to acid generating potential of the waste rock; determined by the Sobec, Schuller, Freeman and Smith method for waste rock.

Acid mine drainage has long been an environmental issue associated with waste rock storage at many mines be they base metal, gold or uranium. When sulphur minerals such as pyrite and chalcopyrite are present, oxidation during weathering and/or bacterial action can result in the production of sulphur oxides, which combine with water to form sulphuric acid. The sulphuric acid can dissolve heavy metals from the waste rock and, if not properly stored, can result in acidic drainage from the waste pile and result in environmental effects (Ref. 3).

The sulphur content of the waste rock can be a good screening tool in evaluating the acid generating potential, with sulphur contents equal to or less than 0.2 % considered clean with a low risk for acidic generation. The ratio of neutralizing potential to acid generating potential (NP:AP) is used as a decision tool when sulphur contents are above 0.2 %. Generally, waste rock having a NP:AP of 1:1 to 3:1 is considered a "grey area" where acid generation is possible despite the overall greater amount of neutralization potential. This is reflective of the variable chemical reaction rates or kinetics causing acid generation and its neutralization. However when the ratio is greater than 3:1 the waste rock is not considered a potentially acid generating (PAG) waste rock (Ref. 4).

The determination of the uranium content of the waste rock can be done through either laboratory analysis of drill samples, or through radiometric scanning. When drill core or cuttings are used, samples are collected over 3 metre intervals, representing the average length of development obtained between blasting. When radiometric scanning using a hand-held gamma meter, reading are taken 10 cm above the muck pile in a three by three grid, with a minimum of 9 readings. If the average gamma reading is equal to or greater than 1.35 μSv/hr the waste rock is considered mineralized.

When mineralized waste rock has been identified from drill samples, a minimum 3 metre buffer of non-mineralized waste rock is added to each side of the mineralized zone. This provides greater assurance that mineralized waste rock is not identified as clean or PAG.

III. WASTE ROCK IDENTIFICATION

Waste rock is generated both through underground development and production mining. The processes for identifying the type of waste expected from both activities are slightly different. In underground development, the following steps are followed to identify the waste rock:

- Geological interpretation of the development area;
- Sample collection and analysis;
- Muck pile and rock observation;
- Surface radiometric scanning;

In production mining a raise-bore machine is used to extract the uranium ore between the 640 and 530 metre levels. During this extraction process, waste rock cuttings generated from above and below the ore body, are collected under the raise using the bucket of a remotely operated load haul dump (LHD) machine. The waste rock cuttings in the bucket are then radiometrically scanned to determine their classification.

The waste rock identification process for both the development and production mining is discussed in greater detail below:

Waste Rock from Development Mining

Geological Interpretation

Through underground exploration activities, geological interpretation identified potentially acid generating and/or mineralized zones. This was accomplished through sampling and geochemical analysis of diamond drill core, visual logging, and radiometric probing. In general terms, the basement rock, located below the sandstone and surface sand overburden was interpreted to determine the types of rock expected and their geochemical characteristics.

The geological interpretation showed that most of the mine development would be located within certain types of basement rock, specifically biotite pelite gneiss with lesser amounts of calcsilicate, granitic, and quartzite rock. This type of basement rock generally contains low sulphide concentrations and has a low potential for acid generation. The interpretation also showed that less amounts of cordierite gneiss and pelite gneiss basement rock would be encountered. These types of basement rock were found to be acid generating due to its pyrite content and increased uranium mineralization due to the proximity to the ore body.

Based on this interpretation, the boundaries of the expected waste rock types were provided for mine design. This information was used as a long-term planning tool to determine the anticipated volumes of mineralized and PAG waste rock to be generated and thus require handling and storage. In addition, development plans were modified based on this interpretation to minimize areas of extensive PAG and mineralized waste rock.

Sample Collection and Analysis

While geological interpretation provides a general tool for determining the anticipated waste rock types, a more precise determination of waste rock is required prior to development activities. This is accomplished through collection and analysis of representative samples from the proposed development area in advance of excavation.

Prior to development, the McArthur River Geology Department reviews completed diamond drilling and determines whether a drilled area corresponds with the development plans. If there is a corresponding diamond drill hole, samples of the core are taken for analysis. If no suitable diamond drill sample exists, a representative sample is collected during the probe cover drilling process, where drilling into the development area takes place to determine whether there is a significant risk of a groundwater inflow. The results of the acid base accounting (i.e. determination of NP:AP ratio) and uranium assaying on the samples then form the basis for the classification of the waste rock.

Muck Pile Observation

Visual observations and radiometric scanning of the waste rock also takes place following development blasting to ensure the waste rock was correctly classified. Should sulphide or uranium bearing mineralization be observed by geological or radiation staff at the muck pile, the waste rock classification may be changed.

While waste rock may be changed from clean to PAG or mineralized, or from PAG to mineralized, under no circumstances is waste rock reclassified from PAG or mineralized to clean based upon muck pile observation. In all instances, when pre-development laboratory analysis indicate that the expected waste rock will be PAG or mineralized, the waste rock classification will not be changed to clean. This is an extra level of conservatism in some cases, but makes the system easier to administer.

Surface Radiometric Scanning

Waste rock that is produced from development mining is skipped to surface and placed into a 200 tonne waste storage bin in the head frame. The process of skipping and surface loadout of waste rock must also follow strict procedures identified in the waste management plan due to the potential for different types of waste rock to be mixed if procedures are not followed. From the storage bin, the waste rock is loaded into a haul truck and scanned with a radiometric truck scanner. The results of this scan provides another check to ensure mineralized waste rock does not report to a PAG or clean waste rock pile. As a final check, the clean and PAG waste rock placed at the pads are radiometrically scanned by a radiation or environment technician to ensure that no mineralized waste rock is present. It is fortunate that uranium-based radioactivity is so easy to monitor. The presence of a series of progeny radionuclides, all in secular equilibrium, makes it relatively easy to develop good correlation between gamma radiation levels and ore grade.

Waste Rock from Production Mining

Underground Radiometric Scanning

Unlike development mining, waste rock cuttings from the raise bore production process are only classified as either PAG or mineralized and not as clean. The reason for this is that no diamond drill or probe hole drilling is performed immediately below and above the ore body to provide samples for acid base accounting. Furthermore, due to proximity to the ore and potential for ore contamination during raise bore pilot hole development, experience has shown that only a very small percentage of the waste rock cuttings are classified as PAG following radiometric scanning.

Once the waste rock cuttings are generated, the LHD is driven to a radiometric scanner where the load is scanned and the destination for the waste rock determined. The details of the underground scanner system and the categories of the waste rock cuttings are provided in Table 2.

Table 2: Underground Radiometric Scanner and Classification System

Rock Type	**Scanner Code**	**% U_3O_8**	**Destination**
PAG	0	< 0.03 %	PAG Pads
Mineralized	1 to 2	0.03 % to 0.50 %	Mineralized Pad
Ore Blend	3	0.50 % to 2.00 %	Blend for Underground Mill Circuit
Ore	4 to 9	> 2.00 %	Underground Mill Circuit

Production waste rock classified as PAG or mineralized is skipped separately to the surface loadout bin where the same radiometric scanning process takes place for development waste rock to ensure the material reports to the correct storage pad. Raise bore cuttings that are of higher grade (0.50% U_3O_8 and above) are directed to the underground mill circuit for processing as ore or as blend material for the high-grade ore.

IV. WASTE ROCK STORAGE

There are five surface storage locations for waste rock at McArthur River. The mineralized and potentially acid generating waste rock, which has the potential for impacts to the environment if not properly stored, is placed on engineered lined storage pads for environmental containment. Table 3 provides a summary of the waste rock storage pads, capacities, and Table 4 identifies the engineered controls for minimizing environmental impacts.

Table 3: Waste Rock Storage Locations

Storage Location	**Capacity (tonnes)**
Mineralized (Pad #1)	35,000
PAG (Pad #2)	52,000
PAG (Pad #3)	39,900
PAG (Pad #4)	78,000
Clean Waste Rock Area	**

Note: ** - The clean waste rock storage area is not an engineered containment pad, therefore there is no set storage capacity for this area.

Table 4: Engineered Environmental Controls

Storage Location	Environmental Controls			
	Liner	PMP Storage	Monitoring	Runoff Control
Mineralized (Pad #1) PAG (Pad #2) PAG (Pad #3)	HDPE	Capable of Storing 469 mm of rainfall / 24 hours	15 groundwater piezometers	Dedicated capability to pump and treat at water treatment plant

The main environmental control for the mineralized and PAG waste rock storage is the requirement to store the waste rock on plastic lined pads with runoff collection. The liner material used at McArthur River is a high-density polyethylene (HDPE 60 and 80 mil).

The storage pads were also designed to contain a probable maximum precipitation (PMP) rain event of 469 mm in 24 hours. This ensures that, in the exceptionally low probability of such an extreme occurrence, all runoff will be contained. Additionally, groundwater monitoring wells have been installed around each of the waste pads to detect any possible liner leakage causing changes in groundwater quality.

V. WASTE ROCK UTILIZATION

A goal of the waste management plan is to reduce long-term storage of problematic waste rock and thus the operational and decommissioning requirements associated with it. At the McArthur River mine, efforts are made to maximize the use of the waste rock as a value-added resource while ensuring the environment is not negatively impacted.

Waste rock that has been classified as clean has been used for many purposes at the McArthur River mine site. During the surface construction activities, clean waste rock was used for road and various other construction activities. More recently, clean waste rock has been crushed and used as a capping material for the mine’s airport and the 80 km haul road between McArthur River and Key Lake.

PAG waste rock has also been used as a value added resource. Several times since the mine began production, the PAG waste rock has been crushed into aggregate. In 2003, a total of 31,000 m^3 of PAG waste rock was crushed resulting in 22,600 m^3 of coarse aggregate and 2,800 m^3 of fine aggregate being stockpiled on the PAG pads for use in underground concrete backfill, while the remainder was classified as reject and placed back on the PAG pads. The alkaline nature of the cement in the backfill, and the lack of oxidation within the concrete matrix, prevents acid generation from the PAG aggregate in the backfill.

At the McArthur River mine, the use of crushed PAG waste rock for backfill purposes has negated the requirement to obtain aggregate from difficult to find gravel pits in the area. This process results in less land disturbance, a close, easily accessible aggregate source, and significantly reduces long-term waste rock decommissioning requirements.

The greatest use of waste rock for value added purposes occurs with the mineralized waste rock. Presently, McArthur River mineralized waste rock is shipped in standard, sealed highway haul trucks with dust covers, to the Key Lake mill. At the Key Lake mill, the McArthur River mineralized waste rock, along with previously stockpiled Key Lake waste rock is fed to a semi-autogenous grinding (SAG) mill with the discharge blended with McArthur River high-grade ore slurry. This process results in a reduction of ore grade from 25% U_3O_8 to approximately 4% for milling in the Key Lake mill.

Several benefits are realized from the use of mineralized waste rock for ore grade reduction. First, the milling of ore at a 4% feed grade instead of 25% does not require significant changes to the milling process at Key Lake. In order to mill ore at a grade of 25% significant upgrades to the radiation shielding would be required to maintain a low dose to workers. Second, long term mineralized waste rock management / decommissioning requirements are significantly reduced as most of the historic Key Lake mineralized waste rock and ongoing McArthur River waste is converted to tailings. Third, the uranium content of the mineralized waste rock is recovered thereby resulting in a resource recovery and financial benefit.

A summary of the volumes of waste rock produced since production mining began is provided in Table 4, along with the associated quantities diverted for value added purposes.

Table 4: Waste Rock Quantities Generated and Used as a Value Added Resource

Rock Type	**2000**	**2001**	**2002**	**2003**	**2004**	**Inventory - as of Jan. 2005**
Quantity Produced Waste Rock (tonnes)						
Clean	178,500	0	7,700	30,200	45,200	38,800
Mineralized	89,300	71,600	53,700	36,300	67,300	20,200
PAG	11,400	52,200	1,000	9,900	4,800	133,800
Quantity Used as a Valued Resource (tonnes)						
Clean	136,700	89,000	23,700	45,900	30,400	--
Mineralized	83,300	75,100	121,500	32,500	73,600	--
PAG	9,900	4,900	8,200	11,100	10,400	--

As shown in Table 4, the actual quantities of clean and mineralized waste rock consumed over the period of 2000 to 2004 have exceeded the quantity generated. The difference between the quantity consumed and generated over this period is attributed to stored inventory of clean and mineralized waste rock produced prior to 2000 during mine development.

The current inventory of waste rock at the McArthur River mine is also provided in Table 2. There is great incentive in closely monitoring the expected and observed waste rock quantities and maintaining the volumes within the storage capacity for the designated storage pad. Should the volume of waste rock increase, without an increase in usage as a value added resource, additional storage capacity will need to be built.

VI. CONCLUSIONS

Early in the development of the McArthur River uranium mine it was identified that a waste rock management plan was required to manage its potential long-term liability. This plan was developed to ensure, with a high degree of confidence, that waste rock was appropriately classified in order to minimize environmental impact. Through geological interpretation, core sampling, muck pile observation, and radiometric scanning, waste rock generated from the mine is classified as clean, mineralized, or potentially acid generating. The mineralized and potentially acid generating waste rock are stored on waste pads designed with liners and drainage collection to ensure minimal interaction with the environment. As an additional benefit of the plan, waste rock has become a value added resource through the crushing of PAG waste rock for use as aggregate in concrete backfill and the use of mineralized waste rock as a blend material to reduce the feed grade at the Key Lake mill.

The McArthur River mine is very fortunate in that the ore is very high grade. This obviously is of great benefit in the overall economics of the development. The high grade also minimizes the size of the mine and the volume of waste rock generated in the process of extracting the asset. This compact nature allowed the mine to develop an extensive management plan that is likely fairly unique in the mining community.

When all economic ore is completely extracted many years down the road, Cameco will be left with very little waste rock liability. There will be minimal quantities in inventory, if for no other reason than the need to work within the bounds of the existing storage system, and the need to dilute the ore grade in Key Lake processing. Being able to walk away from the site with little need for ongoing control and monitoring must surely be one of the mainstays of a sustainable development.

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