



Mining the high grade McArthur River uranium deposit

B.W. Jamieson

Cameco Corporation,
Saskatoon, Saskatchewan, Canada

Abstract. The McArthur River deposit, discovered in 1988, is recognized as the world's largest, highest grade uranium deposit, with current mineable reserves containing 255 million lb U_3O_8 at an average grade of 17.33% U_3O_8 . In addition the project has resources of 228 million pounds U_3O_8 averaging 12.02% U_3O_8 . Mining this high-grade ore body presents serious challenges in controlling radiation and in dealing with high water pressures. Experience from the underground exploration programme has provided the information needed to plan the safe mining of the massive Pelite ore zone, which represents the most significant source of ore discovered during the underground drilling programme, with 220 million pounds of U_3O_8 at an average grade in excess of 17%. Non-entry mining will be used in the high-grade ore zones. Raise boring will be the primary method to safely extract the ore, with all underground development in waste rock to provide radiation shielding. Water will be controlled by grouting and perimeter freezing. The ore cuttings from the raise boring will be ground underground and pumped to surface as slurry, at an average daily production of 150 tonnes. The slurry will be transported to the Key Lake mill and diluted to 4% before processing. The annual production is projected to be 18 million lb U_3O_8 . The paper focuses on the activities undertaken since discovery, including the initiation of the raise bore mining method utilized to safely mine this high-grade ore body. Radiation protection, environmental protection and worker health and safety are discussed in terms of both design and practical implementation.

1. INTRODUCTION

1.1. Location

The McArthur River deposit is located in the eastern part of the Athabasca Basin in northern Saskatchewan, Canada (Fig. 1), and is located 80 kilometres northeast of Key Lake and 40 kilometres southwest of the Cigar Lake deposit. The site is approximately 620 kilometres north of Saskatoon, a city with a population of 220 000, and the location of Cameco's corporate office.

1.2. History

Cameco, through one of its predecessor companies, Saskatchewan Mining Development Corporation, began operating the McArthur River exploration joint venture in 1980. After several changes in joint venture partners, the project is now owned by Cameco Corporation (69.805%), and Cogema Resources Inc. (30.195%). In 1988 the ore body was discovered following eight years of systematic exploration in the area. Improvements to large-loop time-domain electromagnetic methods allowed the definition of graphite conductors in the basement fault structure which controls the location of the ore. Drilling confirmed this structure and discovered sub-economic mineralization five kilometres to the southwest of the McArthur River ore body. The recognition of favourable alteration patterns in drill holes helped guide the exploration drilling to the ore body.

Several years of core drilling from surface followed and resulted in the outlining of high-grade mineralization over 1.7 kilometres of strike length. By 1991, 60 holes were completed of which 37 holes intersected uranium mineralization at a depth of 500 to 600 metres. Based on this information a resource of 260 million pounds at an average grade of 5% U_3O_8 was estimated. Seventy per cent of the estimated resource was based on only seven drill holes, and 18% was based on a single hole which graded 43% U_3O_8 over 25 metres [1]. Following completion of the surface drilling it was decided to undertake an underground exploration programme which would provide the detailed information about the shape of the individual ore bodies.

development was developed and the Panel conducted hearings on this subject at five northern and two southern communities in December, 1992. After a favourable report from the Panel and licensing by both the federal Atomic Energy Control Board (AECB)¹ and the Province of Saskatchewan, shaft sinking commenced in the spring of 1993 [2].

Under that excavation license, horizontal development on the 530 metre level was undertaken to permit diamond drilling along a 300 metre strike length of the mineralized zone. This definition drilling increased the reserves and resources to 416 000 000 pounds U₃O₈ at an average grade of 15% [3]. A second EIS to proceed to underground production was submitted in late 1995, and the public hearings were conducted in the fall of 1996. A favourable Panel report was issued in February, 1997. Both provincial and federal government approvals were received in May, 1997.

In August 1997 all licenses and permits had been received by both federal and provincial agencies to allow the two years construction of the project to proceed. The main license issued being the 'License to Construct' by the AECB. Construction was completed within the feasibility cost estimate and on schedule.

Operating licenses were received in October, 1999 for McArthur River, and in November, 1999 for Key Lake to receive and process the high grade McArthur River ore. Production commenced, as scheduled, in early December, 1999 following the commissioning of process equipment with waste rock and low grade ore.

2. GEOLOGY

The large and high grade Saskatchewan uranium deposits occur at or close to the unconformity which separates the generally flat lying, unmetamorphosed middle Proterozoic sandstones of the Athabasca Group from folded and metamorphosed lower Proterozoic and Archean rocks beneath. At McArthur River this unconformity is at a depth of 500 to 600 metres. The mineralization at McArthur River is associated with a northeast trending, southeast dipping zone of reverse faulting along which the unconformity is displaced vertically 60 to 80 metres. This is referred to as the P2 fault. Locally the basement rocks include pelitic gneisses and significant quartzite units. Alteration is characterized by intense silicification of the sandstone with less intense clay alteration compared to other Athabasca deposits. The mineralization is largely pitchblende without the associated cobalt-nickel-arsenic minerals which are present at Key Lake and Cigar Lake [1].

Two distinctly different mineralized settings have been identified through both surface and underground diamond drilling. These mineralized zones are called Pod 1 and Pod 2 (Fig. 2).

In the first type, typified by Pod 1, mineralization occurs in sandstone and is structurally controlled by the P2 fault. It is associated with a strong (150 to 200 MPa) but fractured zone of silicified sandstone and conglomerate. This mineralization has been traced by surface drilling over a 1700 metre strike length. Significant intersections in Pod 1 grade typically 10 to 30% U₃O₈. Dip varies from 45 to 90 degrees and the ore zone width is typically 10 metres.

Shaft sinking and diamond drilling from underground revealed the presence of ground water associated with the sandstone and the conglomerate. The quantity of ground water depends locally on the nature of flow pathways, hydrostatic pressure and pathway impedance.

For Pod 1, ground water is associated with sandstone bedding planes, joints, and most significantly, faulting and brecciation related to the P2 fault (Fig. 3). These water bearing structures have generally responded well to pressure grouting techniques.

¹ Atomic Energy Control Board (AECB) was renamed Canadian Nuclear Safety Commission (CNSC) on May 31, 2000.

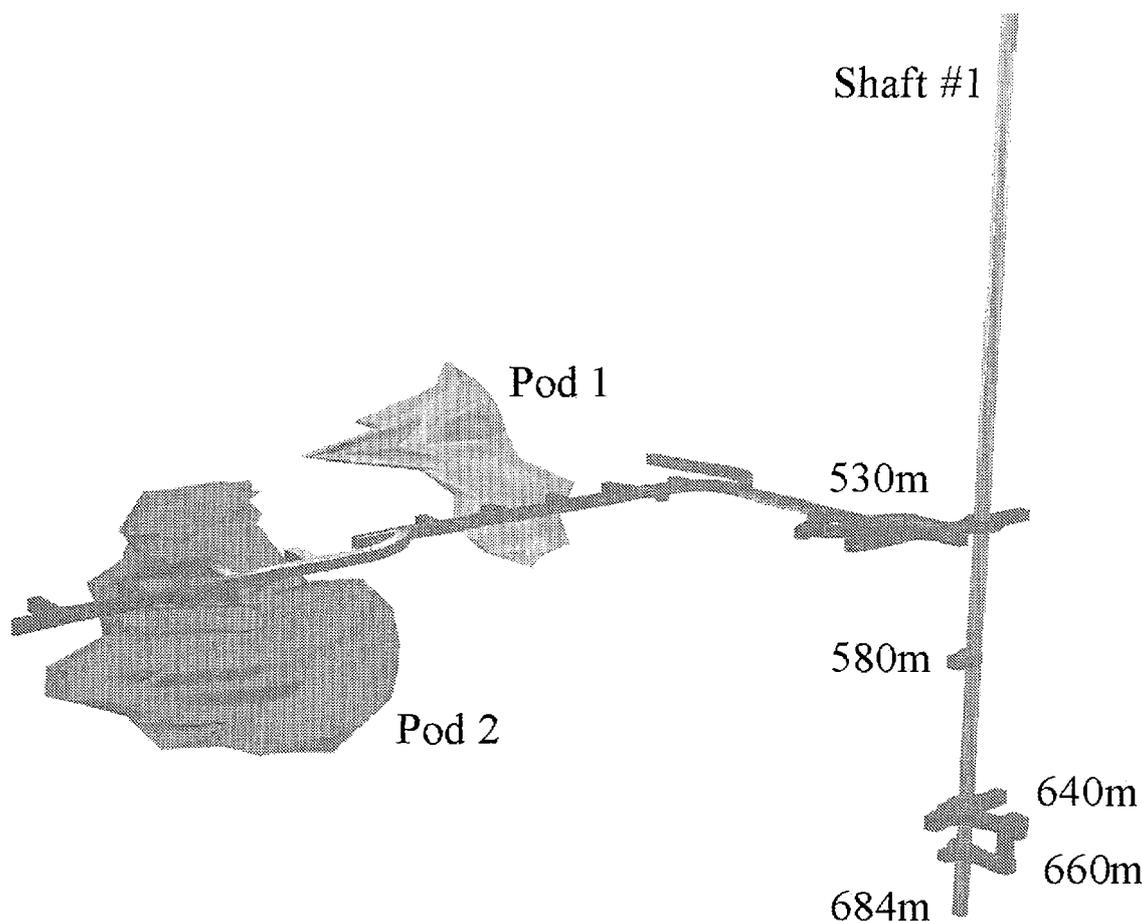


FIG. 2. Pod 1 and Pod 2.

Ground conditions are rated as good to very poor largely depending on the spatial relationship with the P2 fault. Few restrictions exist as to development placement from a stability perspective. However, mine development in sandstone and conglomerate requires extensive water control measures.

The second type of mineralized setting was identified primarily from underground diamond drilling. The large and high grade Pod 2, or Pelite ore zone is located in the basement rocks stratigraphically above a quartzite footwall unit (Fig. 4). The Pod 2 strike length is 100 metres, its height varies from 30 to 90 metres, and the width is typically 20 metres. Average *in situ* grade is greater than 20% U_3O_8 . Occasional drill intercepts with grades higher than 40% U_3O_8 were encountered over significant widths. The host rock consists of sheared and altered pelite (30 to 40 MPa) containing zones of massive and stringer pitchblende [3].

Large ground water flows associated with unconsolidated sand, clay and brecciated rock have been intercepted along the footwall of the Pod 2 ore zone. These areas have not responded well to pressure grouting techniques due to the difficulty in penetrating the fine grained clays and sands in these areas. Ground freezing was deemed necessary to consolidate this zone prior to mining. Drilling has also revealed ground water and brecciated sandstone above the ore zone. Acceptable locations for mine development for Pod 2 are therefore limited to the hanging wall basement rock and the quartzite below the mineralization.

3. UNDERGROUND EXPLORATION PROGRAMME

In July of 1994 underground development commenced to allow the detailed diamond drilling of the ore zones identified by surface drilling. This program was aimed at determining the shape, grade and continuity of the central part of the ore body, on a strike length of 300 metres.

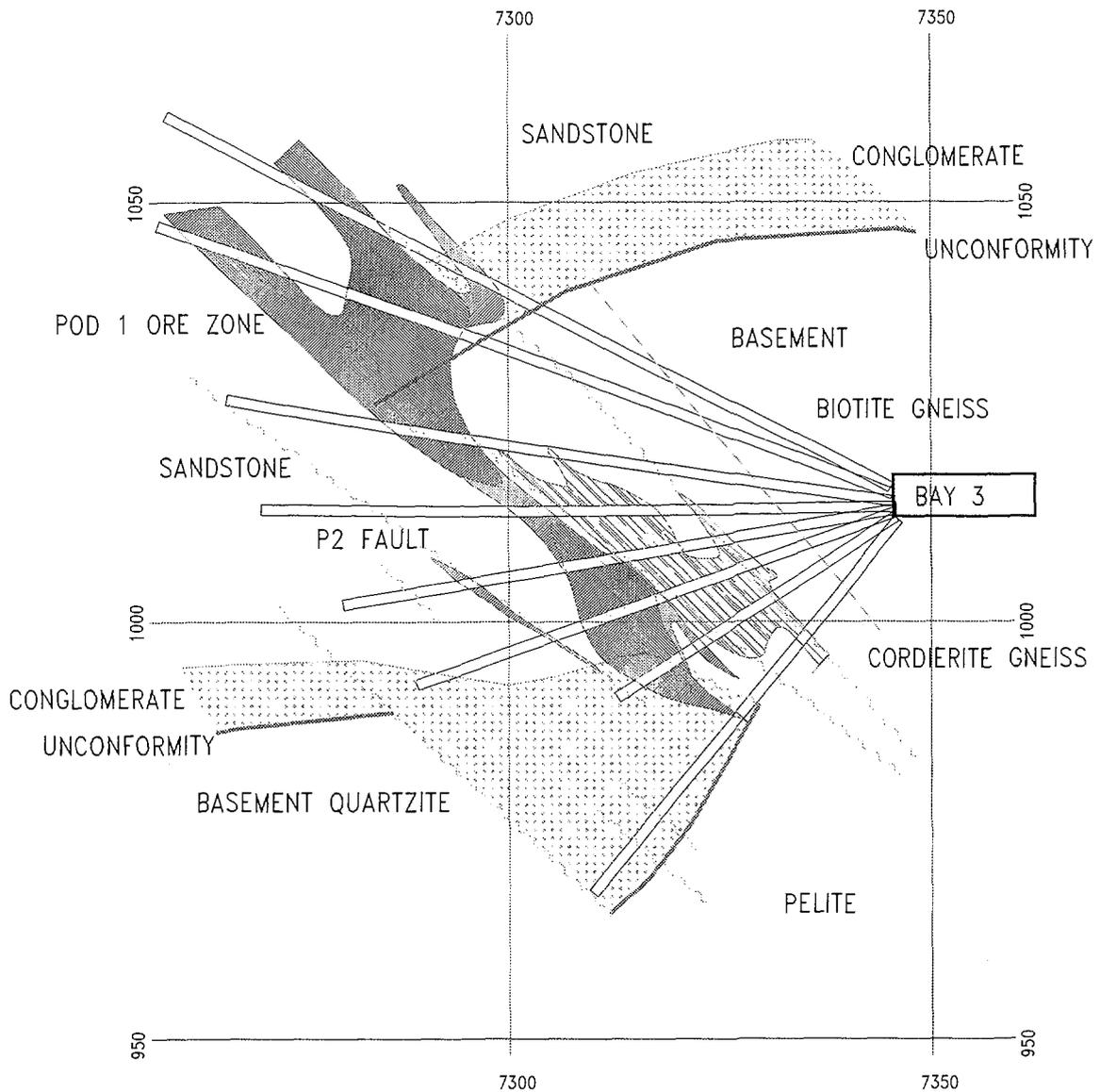


FIG. 3. Pod 1 ore at McArthur River — section looking north.

Once essential services were established for power, and the collection and pumping of mine water, development was extended to within 35 metres of the ore zone. Development then progressed southwards and parallel to the strike of the ore zone for approximately 300 metres. A total of 998 metres of development was completed by June 1996.

Diamond drill bays were created every 30 metres along strike. Diamond drilling commenced once development had adequately advanced, and holes were drilled on sections and fanned above and below the mineralized areas. Infill drilling was conducted, as encouraging results and time permitted, to define the ore zones every 10 metres along strike.

During the 1995/1996 underground drilling programme 115 holes were completed. The drilling of these holes provided both the ore geometry and grade as well as geotechnical and hydrogeological information necessary to select mining methods and design material handling systems [4]. As the high-grade ore was

encountered, extremely high levels of radon (up to 8.869 billion² Bq/m³) were found associated with the ground water. The higher levels of radon were usually associated with low water flows, however the water pressures were normally hydrostatic at a pressure of 51 Bars.

Reserves of Pod 1 and Pod 2 as identified by the underground exploration program are presented in Table 1 along with the mineral resources identified by surface exploration.

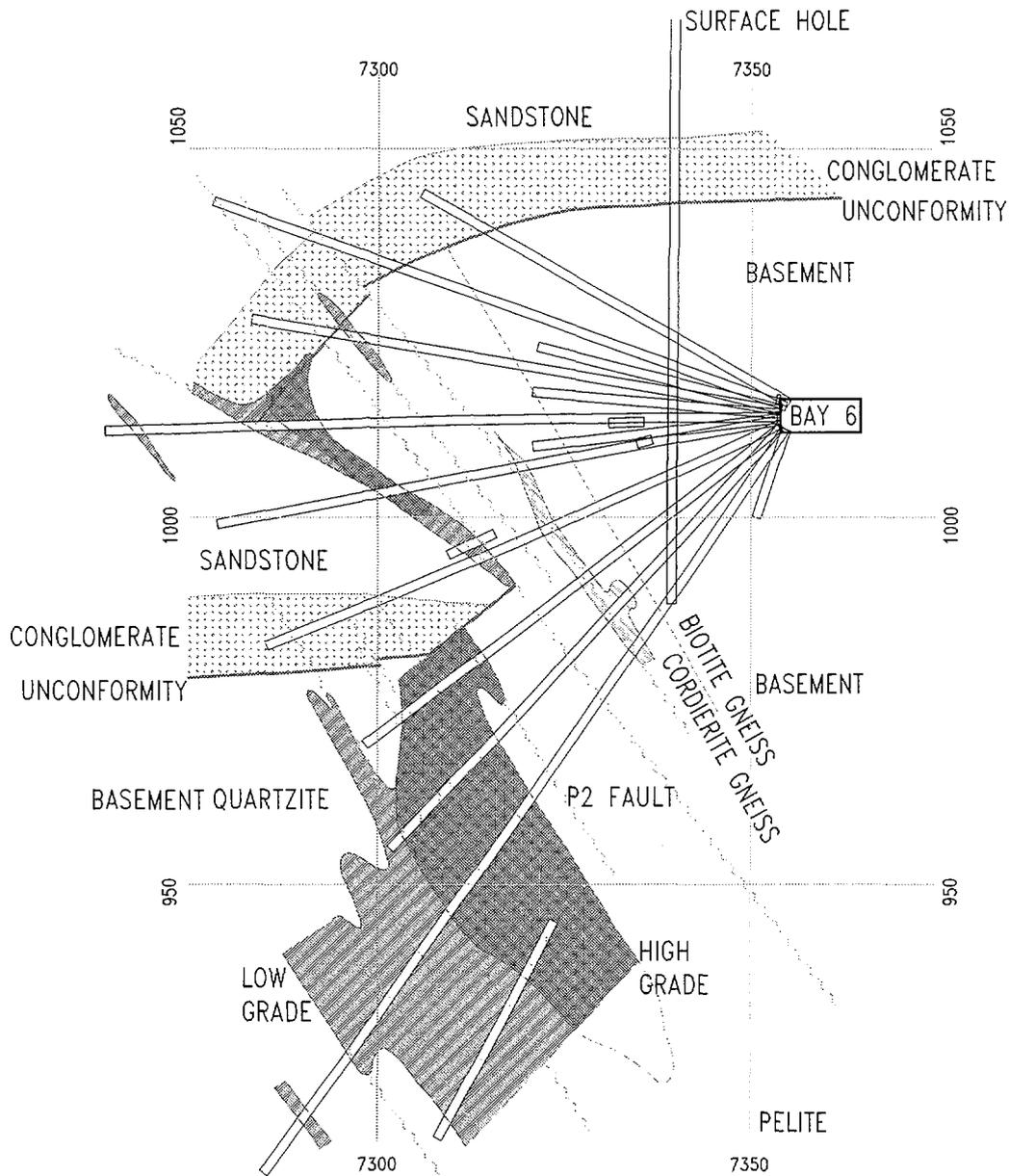


FIG. 4. Pod 2 at McArthur River — section looking north.

² One billion = 10.

TABLE I. MCARTHUR RIVER PROJECT - RESERVES AND RESOURCES

		TONNES	% U ₃ O ₈	Million Lbs. U ₃ O ₈
RESERVES (Undiluted)	Pod 1	91 000	17.46%	35.05
	Pod 2	577 000	17.3%	220.19
	TOTAL	668 000	17.33%	255.24
RESOURCES	Surface Drilled	859 000	12.0%	227.75

4. MINING METHODS

Seven potential mining methods were proposed in the EIS submitted for McArthur River, with final selection dependent upon ore grades and ground conditions. These methods are:

- (1) Raise boring
- (2) Boxhole boring
- (3) Remote boxhole stoping
- (4) Blasthole stoping, including vertical crater retreat
- (5) Remote raise bore stoping
- (6) Jet boring
- (7) Remote boxhole stoping with "Viscaria" raise mining

The preferred options for the mining of the high-grade ore are raise boring, boxhole boring, and jet boring. Raise boring was selected as the initial mining method at McArthur River and offers the following advantages:

- (a) Improved productivity when compared with boxhole boring.
- (b) Capability to extract the high strength Pod 1 ore, in contrast to jet boring.
- (c) Superior ability to limit the quantity of ore in process at any time, when compared to stoping methods.
- (d) Ease of providing excellent ventilation control, in contrast to stoping methods.

All active mine planning to date has utilized this mining method. The high grade Pod 2 ore zone is the first zone being mined. Freezing has been introduced to control ground water and occasional unconsolidated ground conditions in this area, and was implemented approximately nine months prior to mining in order to provide a frozen barrier sufficient to permit the safe extraction of the ore.

A surface freeze plant of 800 tonne capacity provides a chilled brine (-40 degrees Celsius) which circulates through a heat exchanger located on the 530 metre level. A lower pressure brine at -30 degrees Celsius is then used to circulate through freeze pipes surrounding the ore zones. Freeze holes are at two metre centres and drilled to approximately 100 metres in depth. There are 78 holes in use for the freezing of the first two mining areas of Pod 2.

4.1. Raise boring

The raise bore mining method as applied at McArthur River requires the establishment of mine openings of adequate size in surrounding non-radioactive rock both above and below the ore zone. Conventional drill and blast tunnelling methods are used to develop these openings. Standard rock bolting, screening and a 75 millimetre application of shotcrete (a cement product sprayed onto the walls and roof of underground openings) are utilized to provide long term ground support. The raise boring mining method is a four-step process (Fig. 5) [5].

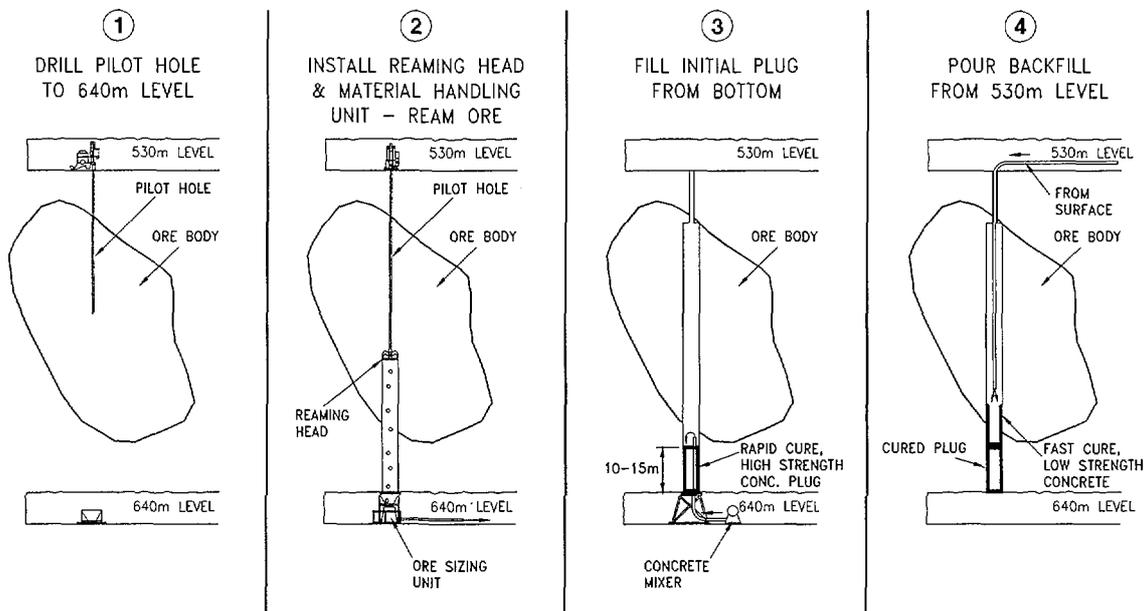


FIG. 5. Raise bore mining and backfilling sequence.

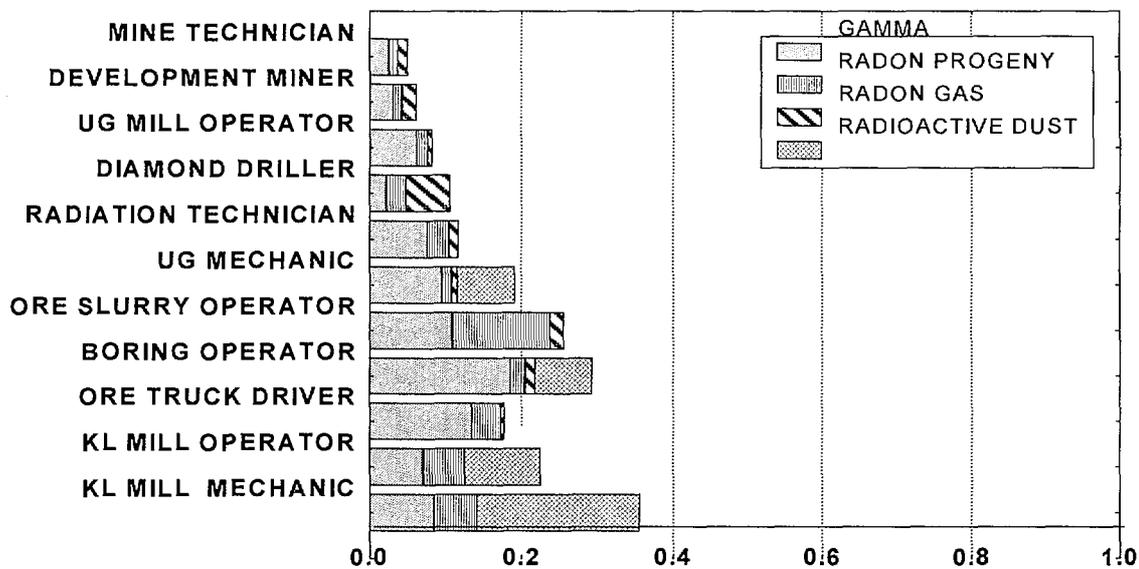
Firstly, the raise bore machine is set up in the production chamber above the ore zone. The raise bore machine then drills a 300 millimetre pilot hole from the upper chamber, through the waste rock, the ore zone and the waste rock below the ore zone and into the lower extraction chamber. These pilot holes are up to 125 metres in length.

Secondly, after breakthrough of the pilot hole into the extraction chamber, the pilot hole drill bit is removed and replaced with a reaming head.

The reaming head was initially 2.4 metres in diameter, but as geotechnical conditions have been positive in some areas, raises with a diameter of 3.0 metres are currently being utilized. Expandable reamer heads may also be developed to minimize waste dilution and to improve productivity. By applying upward thrust and rotation, the raise bore machine then reams the waste rock immediately above the extraction chamber to sink the reamer head into the rock. Reaming is then stopped, and an ore handling chute is placed beneath the raise opening. Once the installation of this ore collection chute is complete the reaming can then continue. Reamed cuttings are removed with a conventional remote control mobile mine vehicle and radiometrically scanned. Waste rock and low grade mineralized material is hoisted to surface for appropriate disposal. Higher grades of ore are processed through a screening unit. The underflow is pumped to ore surge bins located underground near the grinding circuit. All over-size ore product will be collected in a container and be transported directly to the grinding area. The raise bore reaming typically produces a fine material with few large pieces. Typically, 80% of the reamed product is less than 19 millimetres in size. Larger pieces are expected to arise from the structure and jointed nature of the ore zone, and are likely to originate within the raise during reaming of these areas, or as sloughage after the reamer head has passed.

Reaming continues upward until the top of the ore zone has been reached. At this point the reaming head is lowered to the extraction chamber and removed. The raise bore machine then raises the pilot drill rods and removes them within the upper chamber.

In the third step of the process, the bottom of the raise is then covered, and the empty raise is filled with a 5 metre rapid cure, high strength concrete plug introduced from below into the lower part of the raise. This concrete plug is designed to support the placement of the next, and much larger concrete pour.



$$\text{DOSE FRACTION} = \frac{\text{GAMMA}}{20 \text{ mSv}} + \frac{\text{RN PROGENY}}{4 \text{ WLM}} + \frac{\text{RN GAS}}{\text{ALI}} + \frac{\text{DUST}}{\text{ALI}}$$

FIG. 6. Predicted annual radiation exposures.

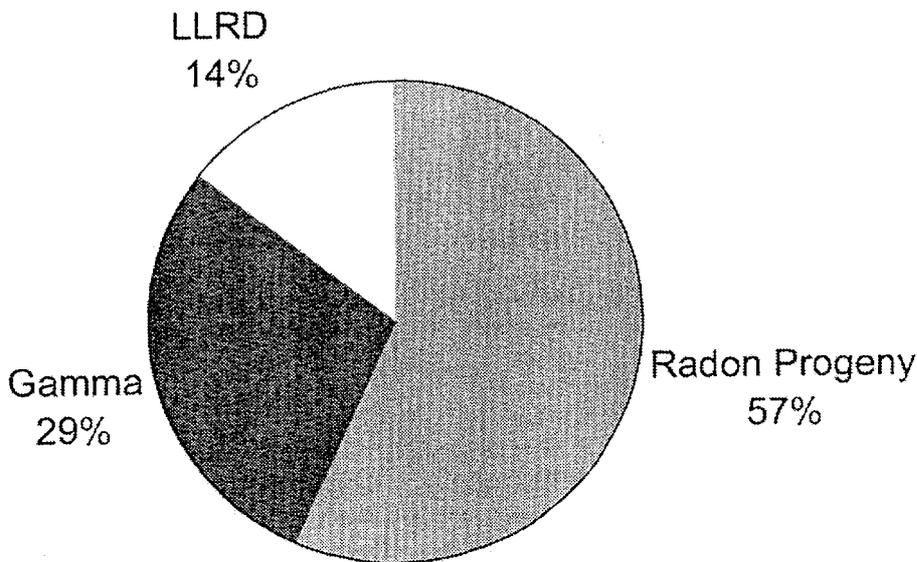


FIG. 7. Breakdown of effective dose for underground workers (first six months of 2000).

Finally, once this first concrete application has cured, the remainder of the raise is filled from the upper chamber with a lower strength, fast curing concrete.

After curing of the concrete fill, extraction of adjacent ore by repeating the sequence described above, possible. By overlapping the raises a high percentage extraction of the ore zone is achieved. After mining and filling a series of rows, the upper and lower chambers are widened to provide the ability to mine sequential rows of bored raises. The chambers above and below the completed raises are then filled with concrete to provide ground support as mining progresses with the completion of each row of bore holes.

On average, each raise will produce approximately 190 000 pounds of U_3O_8 from within initial mining areas of Pod 2, with this zone providing most of the production planned during the first years of mining. Due to the high grade of the ore, an average of only 150 tonnes is required to be mined each day [5]. A total of five raise bore machines are planned to be in operation during full production.

5. ORE PROCESSING

Once mined, the ore is transferred to a grinding circuit located underground. It was decided to process the ore to a slurry suitable to be pumped directly to surface. This eliminates the need to hoist the high-grade ore within the shaft used to move men and material and to supply fresh air.

The grinding circuit is fairly conventional and includes a semi-autogenous grinding (SAG) mill fed directly from the mining area, or from one of two ore surge tanks. The mill has been sized to grind ore that has a Bond work index of 17 kWh/t to 90% passing 300 microns. A classifying screen is operated in closed circuit with the ball mill. Classifying screen underflow, the final ground slurry, is pumped to the two underground ore thickeners. Overflows are recycled back to the SAG mill.

Thickener underflow slurry (controlled at 50% solids by weight) is pumped from the underground ore thickeners to a thickener underflow tank, which feeds the ore slurry to one of two positive displacement hoisting pumps, each of which is connected to a dedicated pipeline to convey the ore slurry directly to surface.

On surface the ore slurry is pumped through a U_3O_8 on-stream analyser. Depending on the indicated ore grade, the slurry can be placed into one of four ore storage tanks to allow for subsequent blending. When container loading begins, the ore is then re-slurried, blended, thickened to >50% solids by weight, and placed into purpose designed containers. Once all four containers are filled, washed and successfully scanned, the truck will depart for Key Lake. Each truck is designed to carry four containers and results in the transportation of 15 tonnes (21.2 m³ of slurry) of ore per trip. Approximately ten trips per day will be required to transport ore to the Key Lake mill at average grades.

At the Key Lake operation the ore will be diluted to 4 % U_3O_8 by the blending of special waste material prior to milling. All tailings will be placed in the existing Deilmann pit tailings management facility at Key Lake.

6. WASTE ROCK MANAGEMENT

Waste rock is generated both by mine development and by mining activities. The production of waste rock is minimal due to the low tonnages of ore required to be mined each day. Potentially problematic material (waste rock >0.03 % U_3O_8 or net neutralizing with acid potential: neutralizing potential ratios of 1:>3) will be hoisted conventionally via the main service shaft and stored on lined pads at McArthur River. This material will either be used for backfill underground at the mine site, or transported to Key Lake for final placement in existing, and approved storage areas.

During the development phase, 140 000 tonnes of potentially mineralized (non ore) material, and 75 000 tonnes of potentially mineralized sandstone are expected. The extensive use of cement grout will likely mediate any residual pyrite content of the rock. A total of 900 000 tonnes of inert waste rock is expected from underground development including ventilation shaft sinking. Inert waste rock will be placed on surface at approved, un-lined sites.

7. RADIATION CONTROL

The control of radiation has been the primary factor in the designs for mine and plant layout, equipment selection and the processing of the ore at McArthur River. In order to minimize exposures the following criteria were applied:

- (a) Radon gas is controlled by a dual ventilation system. A primary fresh airflow is always maintained in all active work areas, with a secondary exhaust system to remove contaminated air from particular sources.
- (b) Radon is also controlled by the freezing and grouting techniques used to control ground water.
- (c) During all mining and processing stages the ore is fully contained where practical.
- (d) Gamma radiation is controlled by utilizing the principles of shielding, distance and time. The use of heavy wall steel pipes, thick vessel walls, concrete and sometimes lead sheeting is standard practice.
- (e) Mining and ore handling and processing is accomplished remotely with computer control.
- (f) Due to the low tonnages required to be mined there is a long period between scheduled maintenance work.

A total of three shafts will be utilized to provide 455 m³/s of air a full production. Two shafts will supply fresh air (the main service shaft #1 called the Pollock shaft, and shaft #3, presently being fitted), while a third shaft exhausts mine workings (shaft #2).

Every job has been analysed for exposure time, and distance and shielding calculations have been done to ensure that radiation doses are acceptable. Design calculations have been confirmed by doing physical measurements of radiation fields around pipes filled with high-grade ore from the test mining at Cigar Lake, and at the existing Key Lake and Rabbit Lake mills. The radiation exposure calculations included estimates of exposures arising from equipment maintenance and spill cleanup.

As a result of these design criteria, the workers are well under the regulatory dose limit (Fig. 6) [3]. Actual experiences with radiation control, the treatment of radium-rich mine water, and waste rock management during the underground exploration phase has shown that the techniques used provided excellent results with very minimal exposures. This knowledge, and extensive public and regulatory review has resulted in a fairly broad based consensus that the project can be developed and meet current radiation protection and environmental objectives.

More recent experiences during production are supporting these expectations (Table 2 and Fig. 7) [6].

TABLE II. McARTHUR RIVER EXPOSURE SUMMARY FOR THE FIRST SIX MONTHS OF 2000

Job Group	Mean Effective Dose (mSv)	Maximum Effective Dose (mSv)
Surface workers	0.2	2.4
UG workers	0.6	4.2
Overall	0.4	4.2

8. MINE COMMISSIONING

The start of mining operations was dependent upon: 1) the receipt of operating licenses for both the McArthur River and the Key Lake operations; 2) the completion of construction and commissioning of all mining and process systems for the safe handling of the high grade ore; 3) the completion of necessary employee training and familiarization of these systems; and 4) the final closure of the freeze wall designed to protect the mine from water inflows.

All process facilities were first commissioned with water, and then waste rock. Only when systems operated as designed did commissioning with low grade ore commence. High grade ore commissioning (mine commissioning) was scheduled to start with the initiation of raise boring activities after closure of the perimeter freeze wall was confirmed. This confirmation was provided by temperature data recorded from 15 temperature monitoring holes placed strategically near the freeze wall. Final closure of the freeze wall was delayed due to an area of the ore zone with temperatures of 25°C. This was about 15° above ambient rock temperature and was discovered during the drilling and installation of the temperature monitoring

holes subsequent to the completion of freeze hole commissioning. The cause of this thermal increase was determined to be heat generated from the natural decay of high-grade uranium ore in this area. The result was the delaying of final freeze wall closure until November 1999.

Mining commenced in December 1999 with the raise bore mining method. In order to provide the maximum time for freeze wall growth, and increased protection from potential water inflows, initial mining was purposely limited to the eastern part of the ore zone. This area offered more competent ground conditions and was furthest from the freeze wall. As an added precaution, the immediate area identified for mining was probed with diamond drill holes and any residual water encountered was eliminated by pressure grouting with cement. These early raise bore holes were all bored at 2.4 metres in diameter and, because they were located on or near the eastern extremity of the ore zone, were limited to 50 000 to 150 000 pounds of U_3O_8 . The grade of the ore in these first raises was expected to be lower than average (8% to 10% U_3O_8) and, therefore, fitted well with the philosophy of commissioning with lower grades before progressing to higher grade material.

The actual mining of these first raise bore holes proved to be quite interesting. The design concept relied upon the raise bore machine providing control of the rate of mining. This was accomplished by limiting, if necessary, the rotation and pull force on the reamer to produce at approximately 25 tonnes per hour which matched the designed material flow of the Transportable Mining Unit (TMU) located immediately at the bottom of the raise. The design of the TMU permitted the containment of the mined material and the wet screening of the ore. Once screened, the undersize was immediately pumped to the ore surge bins which provided a buffer between mining and further underground ore processing. Oversize (+25mm) from screening was placed in a steel box for direct transfer to the grinding circuit. It was reasoned that this system design would limit exposures to employees from radon progeny, gamma and long lived radioactive dust (LLRD) due to its containment, shielding and exhaust ventilation characteristics.

Mining in the ore body had not been conducted prior to this time due to licensing constraints, therefore this was the first experience with raise bore mining in ore. What was experienced proved to be somewhat different than expected. Mining produced an excessive amount of oversize material that often would choke off the feed to the vibrating screen. As well, some unconsolidated clays encountered while mining occasionally blocked the raise itself. These conditions resulted in excessive employee intervention with the TMU in order to facilitate material flow. It was apparent that the system which was originally designed to protect employees from radiation was, in practice, exposing them to potentially higher radiation exposures and, as well, to unanticipated occupational safety hazards by working to clear obstructions.

On one occasion the material flow within the raise exceeded the processing capacity of the TMU, and the raise gradually filled with clay and rock. A minor water flow into the raise (from residual water trapped within the perimeter freeze wall) was contained by the material in the raise creating the potential for an uncontrolled run of material. This danger was recognized and precautions were taken to remove all employees from the area. A run of material did occur shortly thereafter with damaging consequences to the TMU. A subsequent review of the handling of mined material followed resulting in a new safer, and simpler design. The new design is referred to as the Ore Collection Chute (OCC) and is basically a conical chute covering the borehole with a 1.5 metre bottom opening supported on four steel legs. This design eliminated the need for employee interaction altogether as remote controlled vehicles were utilized to receive the ore cuttings and transport them to the grinding circuit.

Approvals were received from the regulatory agencies, and a test trial concluded over the following ten raises. The radiation exposure results were closely monitored and reported after each of the first three raises with satisfactory conclusions. A summary report was issued following the tenth raise indicating that the use of the OCC met expected radiation exposures to employees.

Having improved this key part of the mining cycle, work then progressed to re-establish a stationary screening facility to permit the use of the two ore surge bins which were located underground and designed to add a buffer between mining and ore processing operations.

Other mine commissioning challenges were related to the grinding and transportation of the ore. The grinding circuit initially created a product that was too coarse and resulted in the sanding of pipelines and extreme difficulty in the slurry unloading operation at the Key Lake operation. These problems led to increased maintenance activities and the potential for increased radiation exposures. After careful review the grinding circuit was modified resulting in improved grinding performance.

9. MANAGING RADIATION EXPOSURES IN AN ADAPTIVE ENVIRONMENT

All new mining operations enter the mine commissioning phase with the expectation of surprise. Sometimes these surprises are positive, and occasionally they offer new challenges. This adaptive environment is always present in a mining operation as the operators gain experience with the mining method and its effect on ground conditions, rock mechanics, the general impact on the health and safety of employees, material handling systems, and overall production expectations.

This is fundamentally different to the design of a nuclear facility where production systems can be carefully engineered to achieve the desired output. Mining operations, especially underground operations, are subject to changing conditions as dictated by the geology of the ore body and the stresses placed upon it as mining progresses. Nowhere is this more evident than in the mining of high-grade uranium at McArthur River.

The change from the TMU to the OCC as discussed above is an excellent example. The unexpected change in ground conditions ultimately forced a modified approach towards material handling. In this case the change to the OCC was carefully evaluated utilizing an established change control process and then approved by the regulatory agencies prior to implementation. The established safety systems such as dual ventilation, code of practice, and remote operation of equipment allowed the change to be made with due consideration of impacts to worker (radiation and health and safety) and the environment.

The radiation monitoring programme has two overall goals, which are dosimetry and engineering monitoring. While both types of monitoring provide important feedback of the workplace conditions, the engineering monitoring is particularly important in managing day-to-day exposures. Because of the possibility of high radiation levels at McArthur River, there has been considerable attention placed on engineering monitoring that can provide prompt feedback of the workplace conditions to the employees.

Dosimetry for radon progeny and long lived radioactive dust is done with personal alpha dosimeters (PADs), which provide an integrated exposure over the period of a month. For gamma radiation dosimetry is done with thermoluminescent dosimeters (TLDs), which are also changed on a monthly basis. At uranium mines in Canada TLDs are usually changed on a quarterly basis. However, given the potential for very high gamma fields, a tighter monitoring schedule was chosen until it could be demonstrated that other control mechanisms were working.

These other control mechanisms include engineering monitoring and administrative controls. Engineering monitoring for radon progeny is done by daily grab samples and continuous radon progeny monitors that are located in throughout the mine. The continuous radon progeny monitors take a measurement every ten minutes and are connected to a light panel system that alerts the workers of any upset conditions. There are approximately 35 of these units in use at McArthur River.

With regard to gamma radiation engineering monitoring includes routine surveys by technicians, the use of pocket gamma meters by supervisors so they can assess changing conditions, and arguably most important, workers in process areas are issued electronic direct reading dosimeters.

The direct reading dosimeters and the continuous radon progeny monitors are very important tools in controlling radiation exposures because of their ability to inform the worker directly about his or her working environment. Most workers are very receptive to these tools and have come to expect them and rely upon them.

Backing up the monitoring program is a system of administrative controls. One of these systems is what is called in the uranium mining industry in Canada a “Code of Practice”. This is a system of predefined responses to changing radiation levels. The Code of Practice helps to ensure consistent and appropriate actions are taken before a serious exposure situation develops. At McArthur River there is also a formal Radiation Work Permit system to deal with situations with the potential for high exposures. In addition, daily and weekly investigation levels have been established for gamma exposures as assessed by the electronic direct reading dosimeter results. These various administrative tools have been very important in helping the workers understand the significance of radiation monitoring results and meet dose objectives in a dynamic environment.

10. CONCLUSION

The McArthur River deposit has proven to be a major uranium discovery during the past few years. As a world class ore body, this deposit will help secure Cameco’s position as a competitive uranium producer for decades to come.

The McArthur River Joint Venture has spent approximately C\$ 450 million during the 11 years from discovery to production. While this may seem a long project lead time, it is in reality representative of the normal time investment required to bring a uranium mine into production within Canada.

The underground exploration program has proven mineable high-grade ore zones. Through well-focused engineered design and extensive project review, it has been shown that this deposit can be mined by non-entry methods, such as raise boring, to achieve the goal of high-grade ore extraction in a safe and well-engineered manner.

Radiation exposures can be effectively managed while mining high-grade uranium ores. During the first six months of production, radiation doses have remained relatively constant while production has increased considerably. As a result, the collective dose per unit production is now between 0.1 and 0.2 mSv per tonne of uranium (Fig. 8) [6].

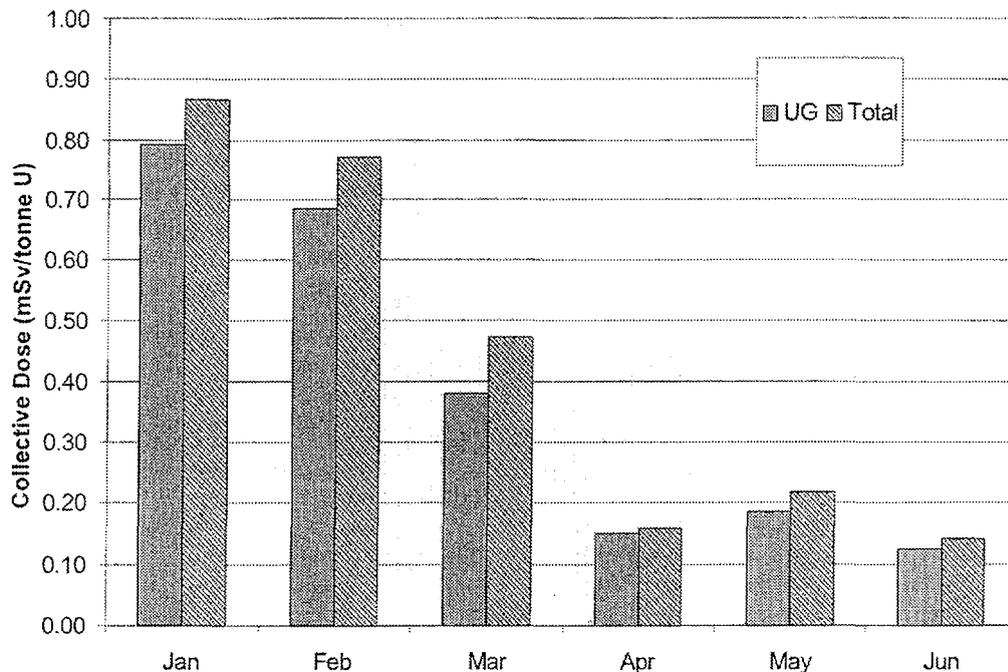


FIG. 8. McArthur River: Collective monthly dose per tonne U mined for the first six months of 2000.

Mine commissioning in high grade ore is continuing with the raise bore mining method using both 2.4 metre and 3.0 metre diameter reamers. Mining rates are increasing as productivity improvements are being made with the three raise bore machines presently in operation. The production rate of 11 million pounds of U_3O_8 per annum planned for this first mining area has been achieved. Two additional mining areas are planned to be brought into production during the next two years in order to achieve the designed annual production rate of 18 million pounds of U_3O_8 in 2002.

REFERENCES

- [1] POLLOCK, G.D., McArthur River Project, Saskatchewan, Canada. Presentation to the International Atomic Energy Agency, Technical Committee Meeting on Recent Developments in Uranium Resources, Production and Demand. Vienna, 10–13 June, (1997).
- [2] FROST, S.E., Mining Facility Construction License, Cameco McArthur River Project. Presentation to AECB, 25 June, (1997).
- [3] WITTRUP, M.B., The McArthur River Project Environmental Impact Statement, October (1995).
- [4] RICHARDSON, L., Presentation to the Pacific Northwest Metals & Minerals Conference, Spokane, Washington, 25 April, (1997).
- [5] JAMIESON, B.W., Presentation to the Pacific Northwest Metals & Minerals Conference, Spokane, Washington, 25 April, (1997).
- [6] TAKALA, J.M., Presentation at Canadian Nuclear Safety Commission and Health Canada Seminar, Ottawa, Canada, 30 August, (2000).