THE MCARTHUR RIVER PROJECT
HIGH GRADE URANIUM MINING

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ABSTRACT

The McArthur River deposit, discovered in 1988, is recognized as the world's largest, highest grade uranium deposit, with reserves and resources of 416 million lb U_30_8 at an average grade of 15% U_3O_8. Underground diamond drilling along 300 metres of the 1.7 Km strike length has proven more than six times the uranium expected from surface drilling interpretation. Hence, there is excellent potential for additional reserves.

The deposit is in northern Saskatchewan, on the eastern edge of the Athabasca Basin, northeast of the Key Lake mine. The ore is approximately 550 metres underground, associated with a major thrust fault, which has caused fracturing of the footwall Athabasca sandstone and gives the potential for significant water flows near the ore body.

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 154 million pounds of U_3O_8 at an average grade in excess of 19%.

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 crushed and ground underground and pumped to surface as a slurry, at an average daily production of 125 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 environmental assessment panel recommended in February, 1997, that the project be approved. Both provincial and federal government approvals were received in May, 1997. The licensing of various details of the construction by the Atomic Energy Control Board and by the Province of Saskatchewan is proceeding.

The presentation will focus on the activities undertaken since discovery, including the methods to be utilized to safely mine this high-grade ore body. Radiation protection, environmental protection and worker health and safety will be discussed in terms of both design and practical implementation.

The project is estimated to cost C$450,000,000 and require two years of development. Production is anticipated to start in the fall of 1999.

INTRODUCTION

The McArthur River project is the world's largest known high grade uranium deposit. It is presently being developed to allow the start of production in late 1999. Located in northern Saskatchewan, Canada, the deposit is estimated to contain 416 million pounds of U_3O_8 with an average grade of 15%. Provincial and federal government approvals were received in May 1997, and regulatory construction licenses and permits have been issued or are in the process of being approved.

Cameco Corporation owns 56% and is the operator of McArthur River. Cameco presently operates and owns two-thirds of the world's two largest, highest grade and lowest cost producing uranium mines at Key Lake and Rabbit Lake also located in northern Saskatchewan. Together these two operations will produce 26 million pounds of U_3O_8 in 1997. This represents about one third of the total western world's production.

Within the next five years, reserves at both Key Lake and Rabbit Lake will be depleted. Nevertheless, Cameco's future is secured by its controlling interest in the McArthur River deposit and in the near-by high grade Cigar Lake deposit.

The uranium grades at McArthur River are roughly ten times those at Key Lake and Rabbit Lake and a hundred times higher than average grades elsewhere in the world.[1]

Planned production from McArthur River underground mine is 18 million pounds of U_3O_8 per year. The ore will be transported 80 kilometres by road to be milled at the existing Key Lake operation.[2]

The successful mining of the McArthur River deposit , however, will not be accomplished without technical challenge. Not only is the high grade of the uranium ore challenging, but solutions must also be found to deal with ground water at very high pressures, and ground conditions which vary substantially from excellent to wholly unconsolidated clays and gravels. The protection of workers and the environment has been the first priority in the design and development of the project.

This paper will present a brief history of the McArthur River project, a description of the geology and the results of the underground exploration program, followed by a summary of the proposed mining methods, radiation control procedures and ore processing facilities.

LOCATION

The McArthur River deposit is located in the eastern part of the Athabasca Basin in northern Saskatchewan, Canada (see Figure 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 200,000, and the location of Cameco's corporate office.

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 (55.844%), Uranerz Exploration and Mining Limited (27.922%), and Cogema Resources Inc. (16.234%). 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 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 sixty holes were completed of which thirty-seven 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 eighteen per cent was based on a single hole which graded 43% U_3O_8 over 25 metres.[3] Following completion of the surface drilling it was decided to undertake an underground exploration program which would provide the detailed information about the shape of the individual ore bodies.

The project was referred to the Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan, in February, 1991. Scoping meetings were held in nine northern and three southern communities in early 1992 to get public input into the guidelines for the environmental impact statement (EIS). The guidelines were issued later that year, after a public review of the draft. Environmental studies had already been started to develop the information necessary for the EIS. An EIS for underground 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) and the Province of Saskatchewan, shaft sinking commenced in the spring of 1993.[4]

Under the current 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 U_3O_8 at an average grade of 15%.[5] 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. The licensing of various details of the construction by the AECB and the Province of Saskatchewan is proceeding.

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.[6]

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 (see Figure 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% U_3O_8. 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 (see Figure 3). These water bearing structures have generally responded well to pressure grouting techniques. 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 (see Figure 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 *insitu* 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.[7]

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 has been 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.

UNDERGROUND EXPLORATION PROGRAM

In July of 1995 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.

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 (see Figure 5).

During the 1995/1996 underground drilling program 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.[8] As the high grade ore was encountered, extremely high levels of radon (up to 8.869 billion Bq/m^3) 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.

Diamond drill bays were developed at right angles to the main drift and, therefore, created difficulties in designing a ventilation system which would ensure the capture of all air-borne contaminants. After some trial and error, plastic curtains and various sizes of flexible ventilation exhaust ducting were utilized to create a one pass ventilation flow within these drill bays. This worked extremely well and prevented the contamination of working areas further down wind of the drillers. This careful design of ventilation systems and the diligent application of an appropriate code of practice resulted in the underground drill program being completed without any radiation excursions (see Figure 6).

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.

Table 1 McARTHUR RIVER PROJECT - RESERVES AND RESOURCES

		TONNES	% U_3O_8	Million Lbs. U_3O_8
RESERVES	Pod 1	79,000	20.1%	35.05
(undiluted)	Pod 2	318,000	21.9%	153.69
	TOTAL	**397,000**	**21.6%**	**188.74**
RESOURCES	**Surface Drilled**	**859,000**	**12.0%**	**227.75**
TOTAL (Reserves and Resources)		**1,256,000**	**15.0%**	**416.49**

MINING METHODS

The controlling factors for mining method selection at McArthur River were:

- The high grade of the reserve.
- The wide range of ground conditions present, and limitations of acceptable locations for mine development.
- The presence of significant ground water, mostly encountered within the sandstone and conglomerate geological units.

All mining methods requiring the workers to enter the mining area were immediately eliminated. Non-entry mining methods were required due to the high radiation level of the ore.[9] Other methods were eliminated if not compatible with grouting or freezing techniques for ground water control. Strict adherence to the principles of limiting the time of exposure, maximizing the distance between the workers and the ore, and placing shielding between the workers and the ore were necessary in order to limit worker gamma radiation exposures.

Radon gas released from the ore and ground water adjacent to the ore meant excellent ventilation practices were required. The need to capture radon gas at its source has also affected mining method selection.

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 remote boxhole stoping. Raise boring has been selected as the initial mining method at McArthur River and offers the following advantages:

- Improved productivity when compared with boxhole boring.

- Capability to extract the high strength Pod 1 ore, in contrast to jet boring.
- Superior ability to limit the quantity of ore in process at any time, when compared to stoping methods.
- Ease of providing excellent ventilation control, in contrast to stoping methods.

All mine planning to date has utilized this mining method. The high grade Pod 2 ore zone will be the first zone to be mined. Freezing will be required to control ground water and occasional unconsolidated ground conditions in this area, and must be 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 will provide a chilled brine (-40 degrees Celsius) which will be circulated through a heat exchanger located on the 530 metre level. A lower pressure brine at -30 degrees Celsius will then be used to circulate through freeze pipes surrounding the ore zones. Freeze holes will be at two metre centres and drilled to approximately 100 metres in depth. The 85 holes needed for the freezing of the first two mining areas of Pod 2 are planned to be drilled during 1998 to allow the freezing to start in early 1999.

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 will be 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) will be used to provide long term ground support. The raise boring mining method is a four step process (see Figure 7).[10]

1) The raise bore machine is first 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 will be up to 125 metres in length.
2) After break through of the pilot hole into the extraction chamber, the pilot hole drill bit is removed and replaced with a reaming head. The reaming head will initially be 2.4 metres in diameter, but may, if geotechnical conditions permit, be increased to a diameter of 3.0 metres. Expandable reamer heads may also be utilized 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. This barren waste rock is removed with a conventional mobile mine vehicle and hoisted to surface for appropriate disposal. Prior to the reaming head entering the ore, reaming is stopped, and an ore handling infrastructure is placed beneath the raise opening. Reaming then recommences with all reamed ore product passing through a sizing screen and crusher. The underflow will be pumped to the ore grinding area underground. All over-size ore product will be collected in a closed container and be transported to the same grinding area. The raise bore reaming typically produces a fine material with few large pieces. Tests conducted at Rabbit Lake‘s Eagle Point mine showed that 91.4 % 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 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.

3) The bottom of the raise is then covered, and the empty raise is filled with a rapid cure, high strength concrete 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.

4) Once this first 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, is 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.

BOXHOLE BORING

The boxhole boring method only requires the lower mining chamber. The machine pushes the reamer upwards through the ore, adding stabilizers to the drill rods as mining progresses. The ore falls down the raise to a chute above the boxhole machine, and is then diverted to the sizing screen and crusher. All further ore processing is as described for the raise boring method. The method is shown in Figure 8 with an expandable reamer head being utilized to improve productivity.

REMOTE BOXHOLE STOPING

This mining method combines the productivity improvements offered by stoping with the control and containment provided by boxhole boring. The raise is reamed as described in the boxhole boring method. Once completed, blast holes are drilled from the security of production drill drifts placed lateral to the raise, and above the mining chamber. These blast holes intersect the raise, and are loaded with explosive and blasted, as required, to provide broken ore to the boxhole boring unit. The reamer head is kept within the lower section of the raise and functions to control the size and regulate ore flow to the sizing screen and the crusher below (see Figure 9).

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 125 tonnes is required to be mined each day.[10] The total time necessary to mine and fill a raise is expected to be about 10-11 days. During this time the raise bore machine will likely be reaming in ore for one day. A total of four raise bore machines are planned to be in operation during full production.

WASTE ROCK MANAGEMENT

Waste rock will be generated both by mine development and by mining activities. The production of waste rock will be 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.

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:

- Radon gas is controlled by a dual ventilation system. A primary fresh air flow is always maintained in all active work areas, with a secondary exhaust system to remove contaminated air from particular sources.
- Radon is also controlled by the freezing and grouting techniques used to control ground water.
- During all mining and processing stages the ore is fully contained.
- 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.
- Mining and ore handling and processing will be accomplished remotely with computer control.
- 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 m^3/s of air a full production. Two shafts will supply fresh air (the main service shaft #1, and shaft #2), while a third shaft will exhaust mine workings.

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 clean-up.

As a result of these design criteria, the predicted annual doses for the workers are well under the regulatory dose limit (see Figure 10).[11]

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.

ORE PROCESSING

Once mined, the ore is screened and/or crushed prior to being pumped 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 ball mill fed from a crushed ore surge tank. The mill has been sized to grind ore that has a Bond work index of 17 kWh/t to 80% passing 200 microns.[12] 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 mill.

Thickener underflow slurry (controlled at 50% solids by weight) is pumped from the underground ore thickeners to an agitated thickener underflow tank, which feeds the ore slurry hoisting pumps.

The two ore slurry hoisting pumps are positive displacement type, and are each 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 is placed into one of four ore storage tanks. When container loading begins, the ore is then re-slurried for grade blending, thickened to 50% solids 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 18 tonnes (21.2 m^3 of slurry) of ore per trip. Approximately eight 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.

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 will have spent approximately C$450 million during the eleven 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.

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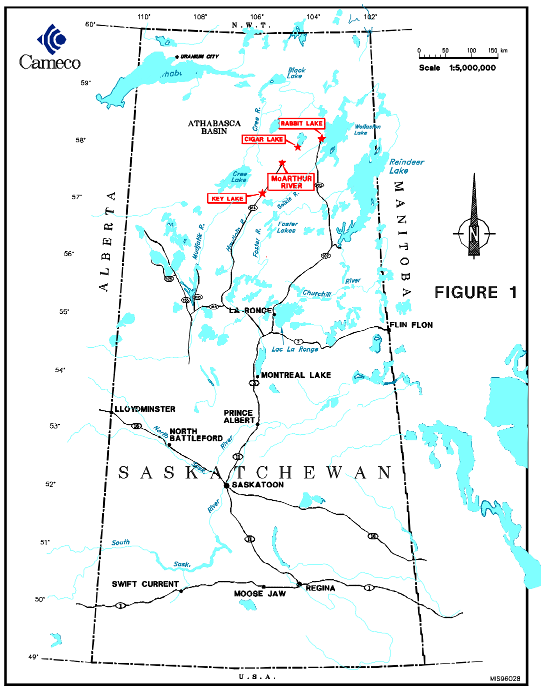
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FLIN FLON
MONTREAL LAKE
LLOYDMINSTER
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FIGURE 1

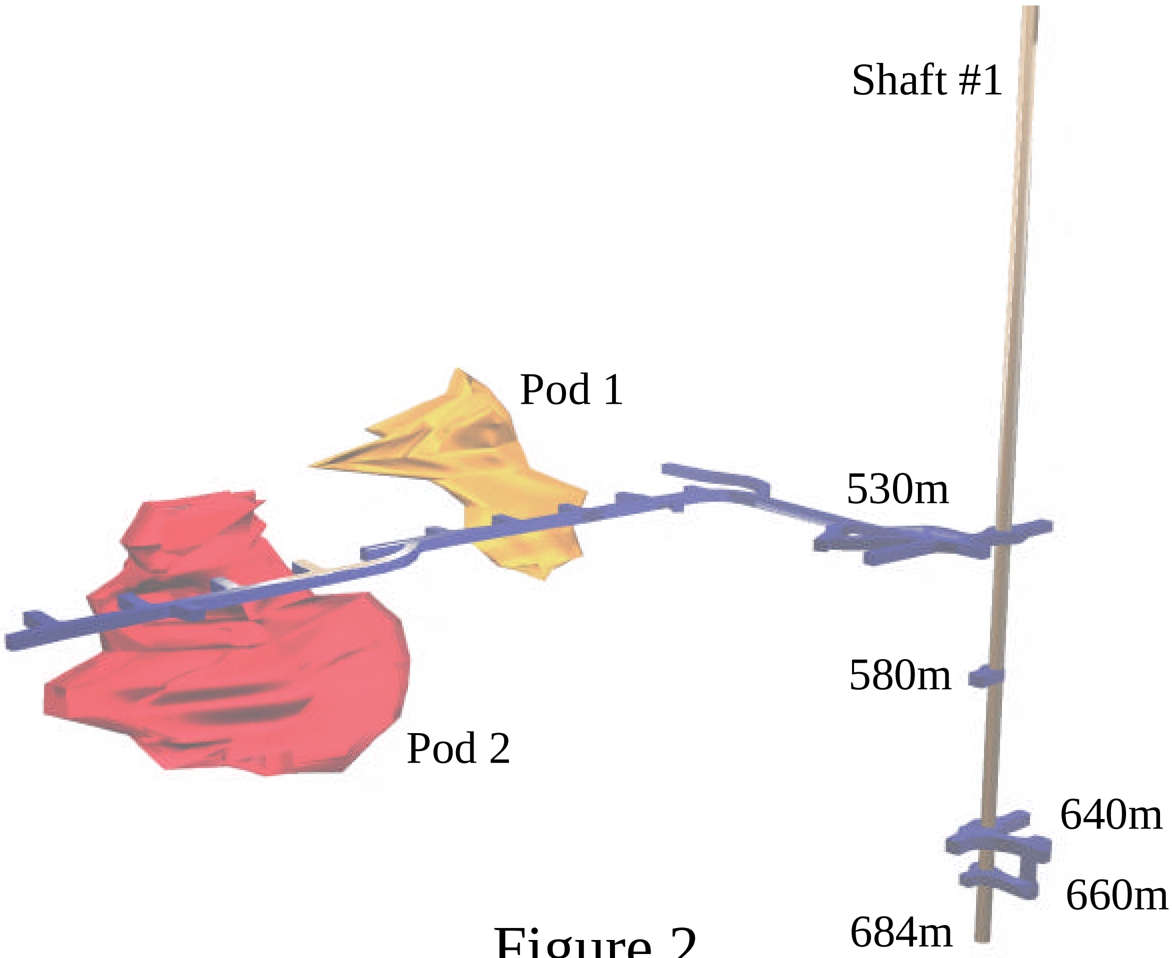


Figure 2

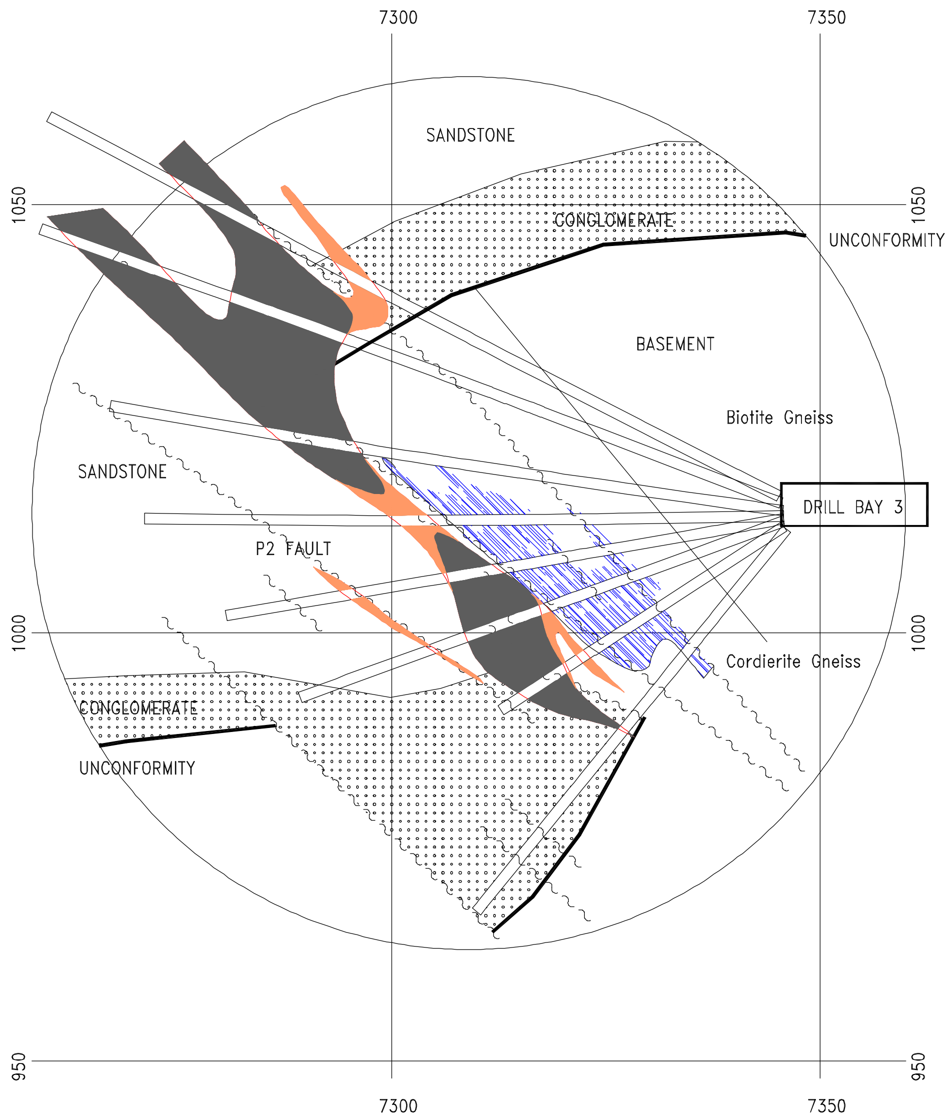


Figure 3 - Pod 1 Ore : Section Looking North

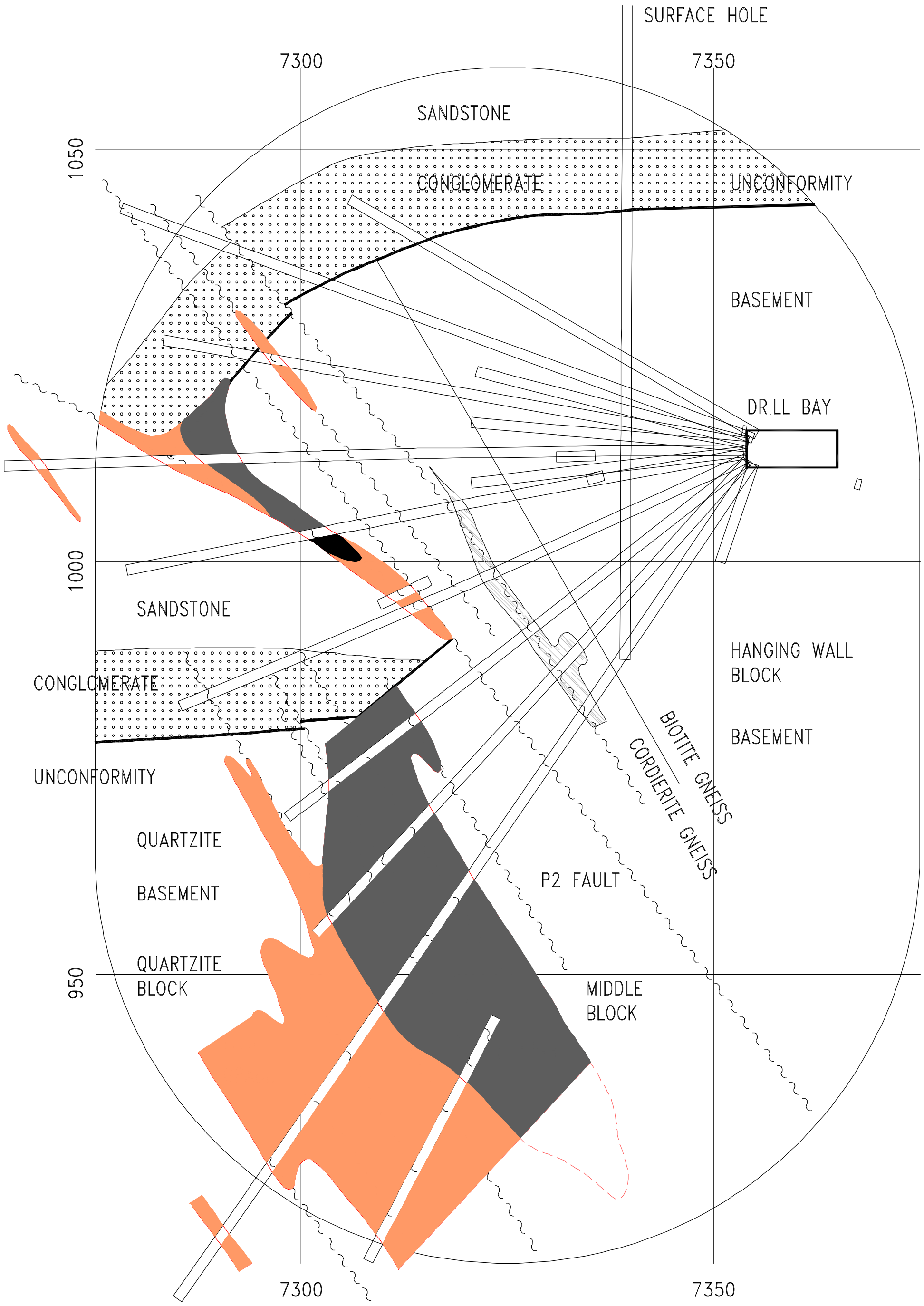
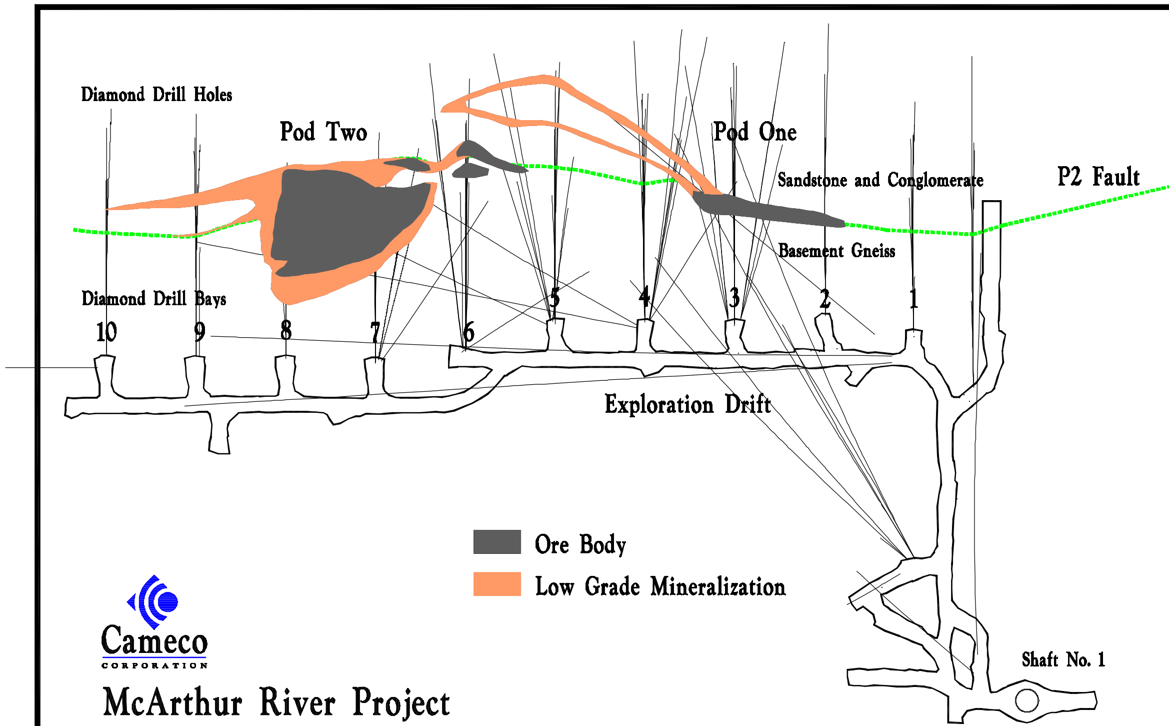


Figure 4 - Pod 2 Ore : Section Looking North

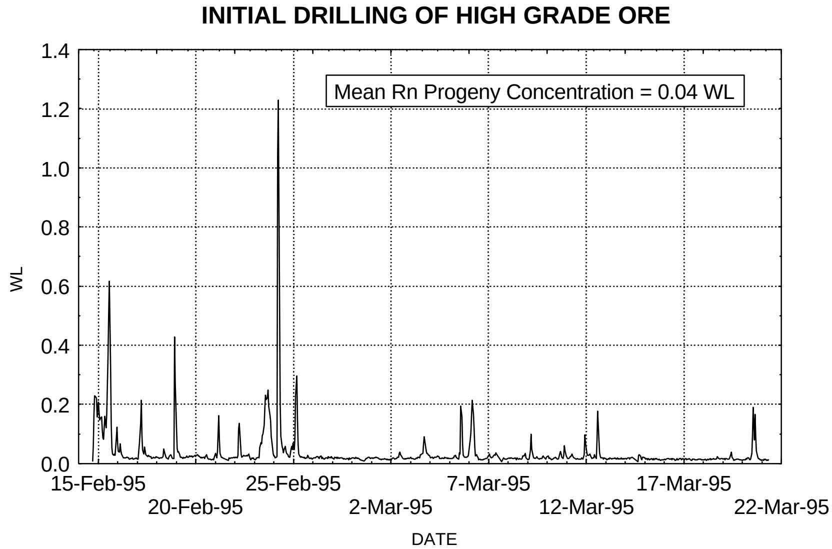


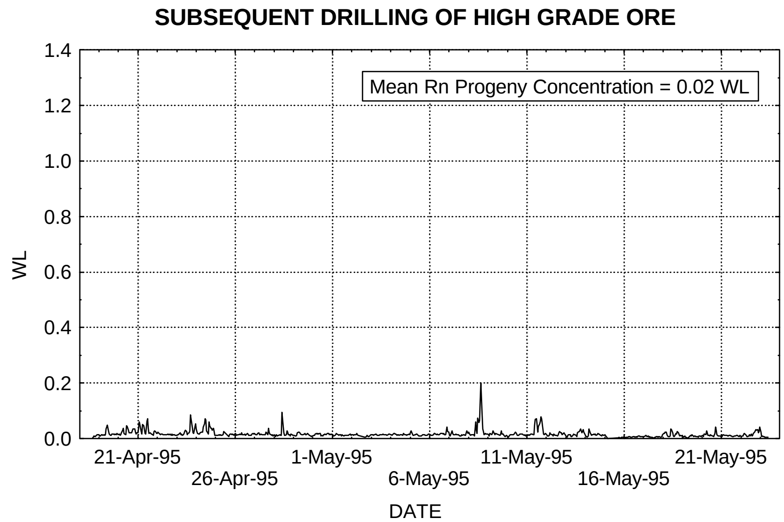
McArthur River Project

530 Level Exploration Drift

Figure 5

Figure 6: Continuous Rn Progeny Sampling Results





McARTHUR RIVER PROJECT
RAISE BORE MINING AND BACKFILLING SEQUENCE

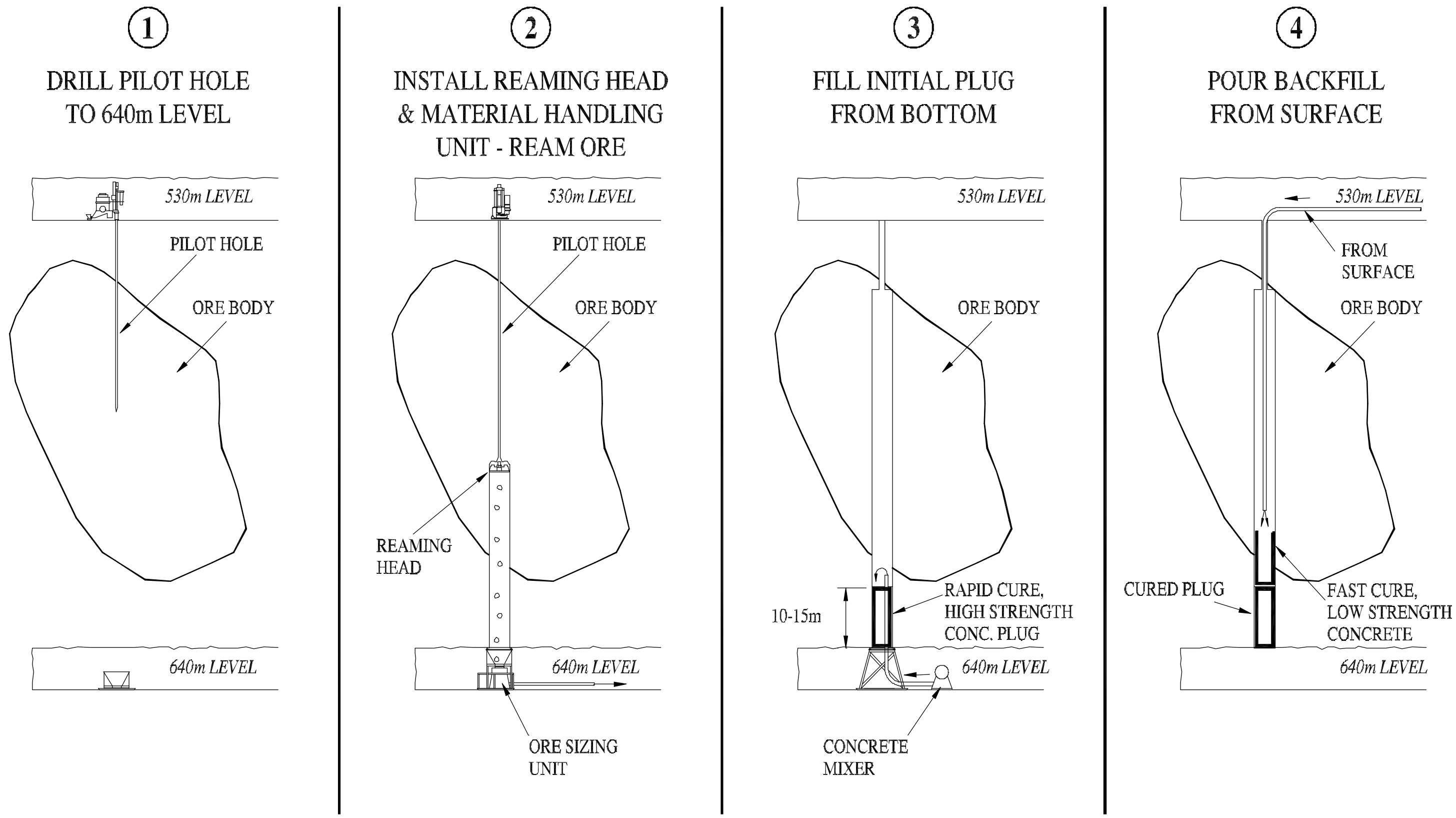
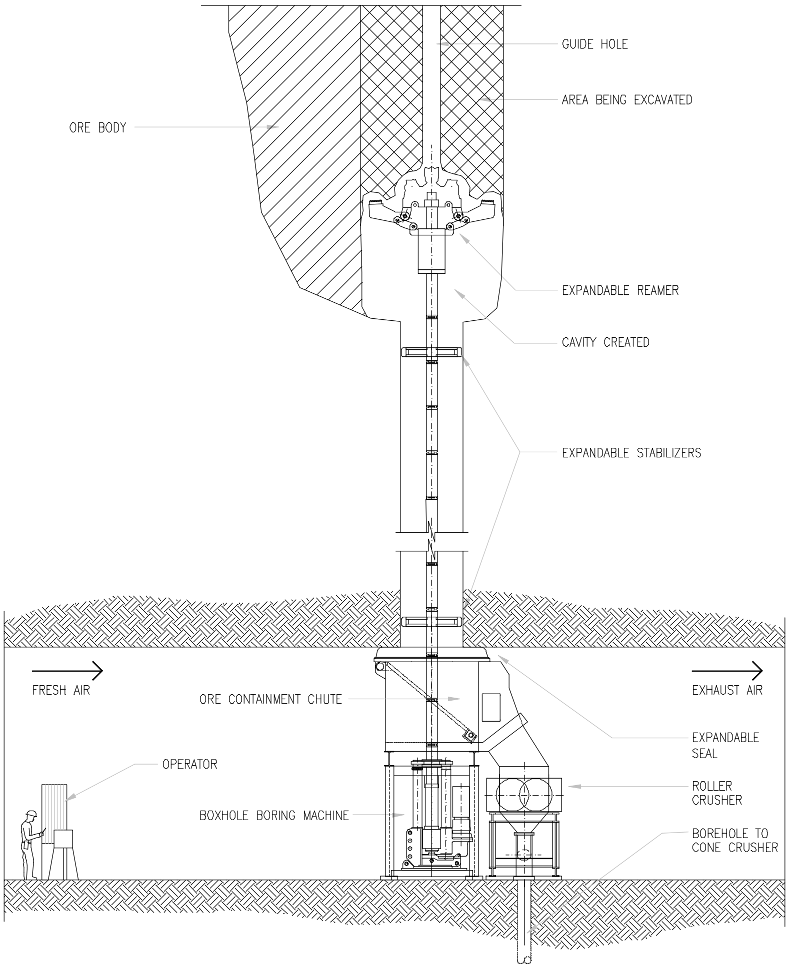
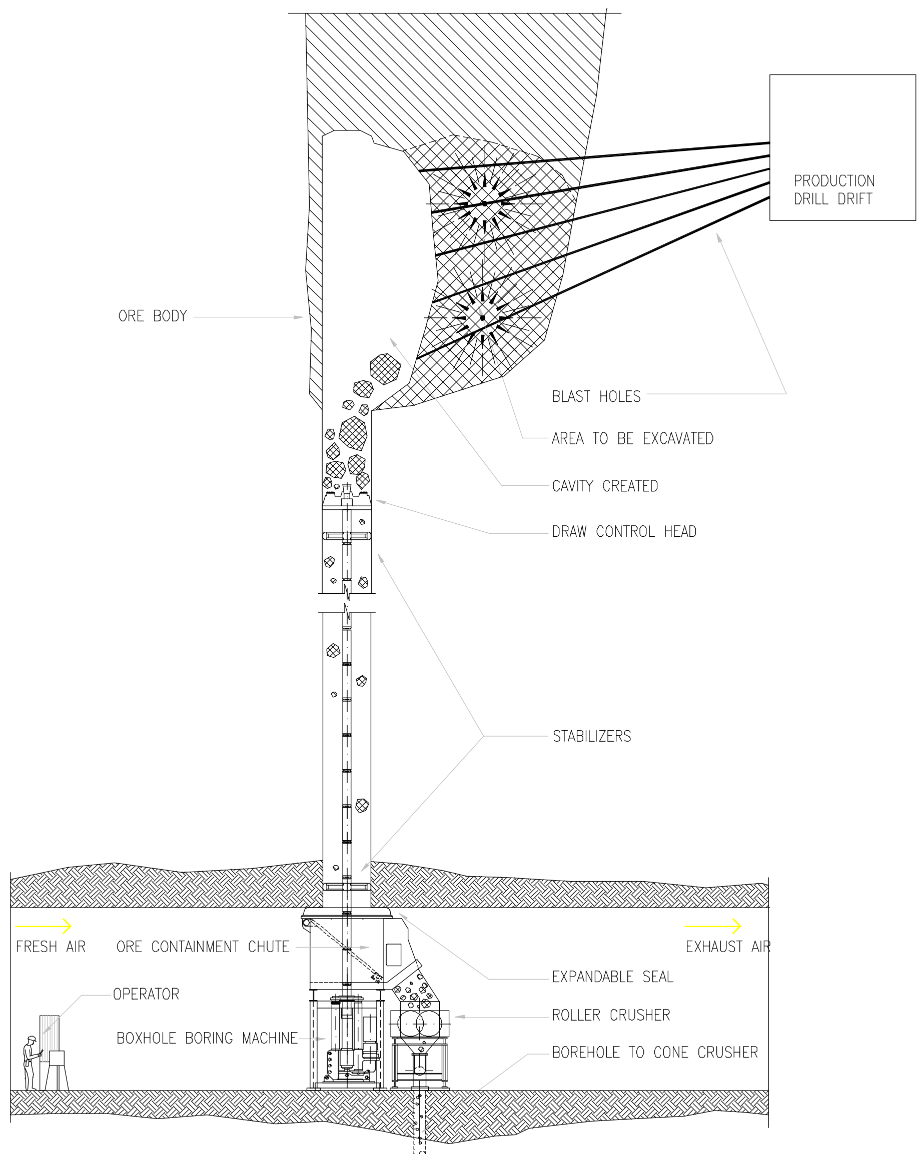


FIGURE: 7



McArthur River Project

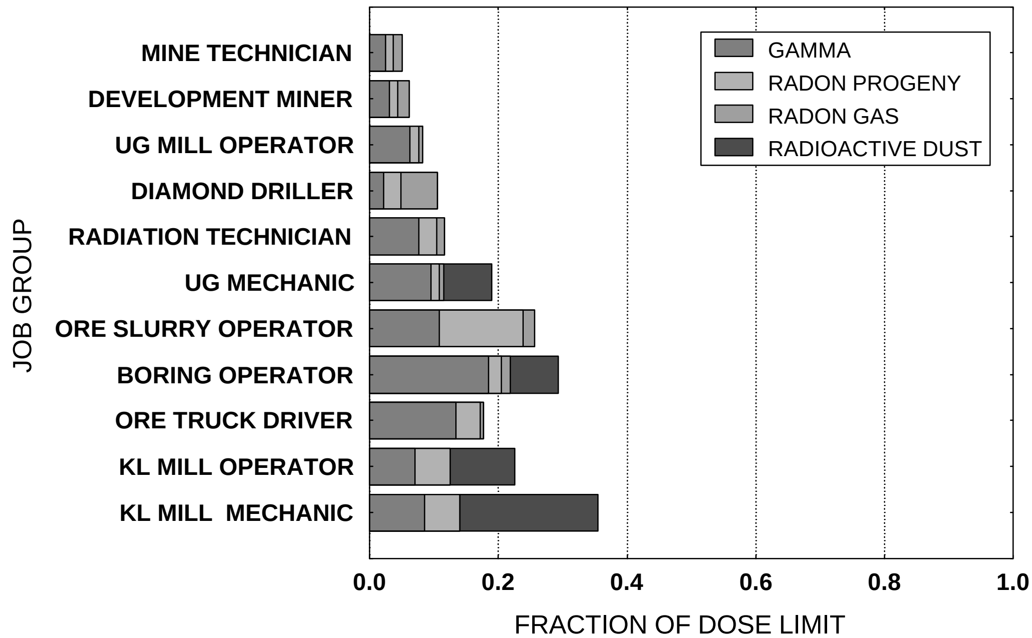
BOXHOLE MINING METHOD **FIGURE 8**



McArthur River Project

REMOTE BOXHOLE STOPING MINING METHOD FIGURE 9

FIGURE 10: PREDICTED ANNUAL RADIATION EXPOSURES



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