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Radon bearing water protection in underground uranium mining – A case study

Yun Xiaoyou *, Tang Baoyao, Greg Murdock, Brian McGill, Brian Mattie

McArthur River Operation, Cameco Corporation, Saskatoon S7M 1J3, Canada

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ABSTRACT

High pressure, radon bearing water has been identified as one of the most critical challenges in mining the high-grade uranium deposit at the McArthur River Operation, Cameco Corporation. The ore deposits are located between 490 and 640 m below the surface and surrounded by water bearing Athabasca sandstone, a graphitic P2 fault zone, and highly altered ground. This paper introduces the inflow risk management program at McArthur River Operation, which includes various hydrogeological challenges and the corresponding strategies applied, such as risk-based probe and grout programs (geological, hydrogeological, and geotechnical), ground freezing programs, and comprehensive ground control programs. These programs have been developed, tested, and proven successful over years of mining practices. Working with this world class deposit of high risk and low tolerance, it is believed that these experiences might be beneficial to other mining operations with similar hydrogeological characteristics.

1. Introduction

The McArthur River Operation is an underground mine located in the eastern part of the Athabasca Basin of northern Saskatchewan, approximately 620 km north of Saskatoon, Canada.

As the world's largest high grade uranium mine, it has proven and probable reserves of 336.5 million pounds of U_3O_8 (Cameco's share–234.9 million pounds) with an average ore grade of 10.94% U_3O_8 as on December 31, 2015. Cameco is the operator of the mine with 69.805% ownership in partnership with AREVA Resources Canada Inc. who owns the remaining 30.195%. Multiple mining methods have been developed and approved, and are being employed at McArthur River. The first one is a unique non-entry raisebore mining method; the second one is boxhole mining; and the third is drill and blast stope mining, which has the potential to be one of the major mining methods in future at McArthur River. Ore grinding into slurry takes place underground, and then pumped to surface where it is loaded into special containers and shipped to Key Lake Operation which is located approximately 80 km south of McArthur River Mine by slurry truck for milling. In 2015, the total ore production at McArthur River was 8,973,235 kg of U_3O_8.

As an underground, high grade uranium mining operation, the protection of workers and the environment during the mining activities has been a top priority in all phases of design, development, and operation of the mine. The mining activity at this operation is always facing three major challenges at this operation [1]:

(1) Hydrogeological: ore is found in proximity to water-enriched sandstone with high hydrostatic water pressures;
(2) Geotechnical: mine openings must be developed in highly variable ground conditions ranging from excellent rock to wholly unconsolidated clays and gravels; and
(3) Radiation protection: workers must be protected from radon-bearing water and mineralization with high grade uranium.

This paper intends to introduce the hydrogeological challenges at this operation, and presents the corresponding strategies that have been successfully employed by the site to maintain safe mine operations.

2. Mine geology and inflow mechanisms

The McArthur River uranium deposit is located in the south-eastern portion of the Athabasca Basin, within the southwest part of the Churchill structural province of the Canadian Shield. The crystalline basement rocks underlying the deposit are members of the Aphebian Wollaston Domain meta-sedimentary sequence. These rocks are overlain by flat lying sandstones and conglomerates of the Helikian Athabasca Group. These sediments are over 500 m thick in the deposit area.

* Corresponding author.
E-mail address: Xiaoyou_Yun@Cameco.com (X. Yun).

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High grade uranium mineralization has been delineated from surface drilling over a strike length of 1700 m, occurring at or close to the unconformity, which separates the overlying, horizontally bedded sandstones of the Athabasca Group from the metamorphosed basement rocks, located between 500 and 640 m below the surface. Underground exploration drilling programs have covered approximately 750 of the 1900 m strike length delineated from surface. Ore body widths are variable along strike but the most consistent, high grade mineralization occurs proximal to the main graphitic thrust fault around the "nose" of the up thrust basement rock. Less consistent and generally lower grade mineralization occurs down dip along this fault contact between basement rock and sandstone. 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 with other Athabasca deposits. The mineralization at McArthur River is associated with a northeast trending, southeast dipping zone of reverse faulting, along which the unconformity is displaced vertically 60–80 m, as shown in Fig. 1.

From the point of view of hydrogeology, the brittle, flat lying sandstone is highly fractured by the tectonic forces of the thrust fault and these fractures are water bearing [3]. Drawdown testing has demonstrated that the fracture patterns, along with water bearing joints and bedding planes are directly connected to surface groundwater table. This indicates that an unlimited volume of high pressure water is sourced within the sandstone, and significant flows could be produced if water channels intersect the mine development.

There are two major channels by which water could enter the underground openings. They are boreholes-grouted but there is no way to verify the grouting quality, or un-grouted; and geological formation-directly or indirectly.

Underground probe/exploration holes are drilled into all planned mining areas to collect hydrogeological and structural information prior to mining through it. These drill holes could intersect intervals, generally structurally related, which contains a substantial amount of high pressure water. Any loss of control might result in these holes being conduits for a significant inflow of water into the mine. To minimize this risk, rigorous collar security standards have been developed for all underground drilling.

There is a potential risk for encountering un-grouted or poorly grouted surface holes during underground excavation. Therefore, additional precautions need to be taken near a surface hole during design and development phases. Any underground development within 8 m of a surface borehole is treated as high risk as per ENG-01-09 Underground Development Risk Classification.

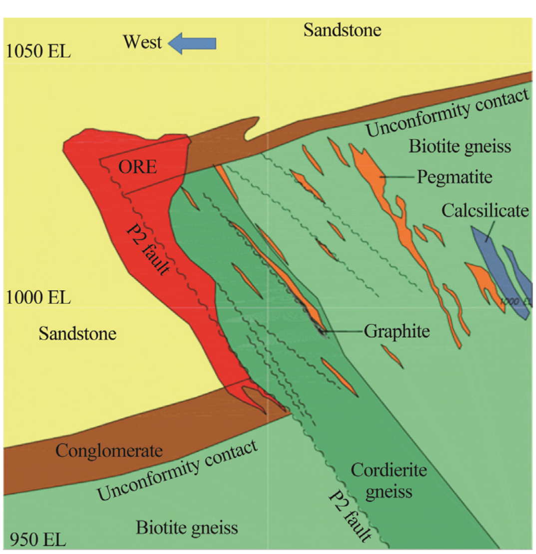

Fig. 1. Typical Zone 4 geological section–facing north.

Water inflows into the mine could also occur if a water bearing geological structure is encountered during development or if the mine development inadvertently breached the unconformity. In 2003, a breach of the unconformity in Bay 12 of 530 level during development resulted in a peak inflow of 1,069 m^3/h, and then stabilized at approximately 700 m^3/h within a few days.

To prevent high pressure and radon bearing water from entering the mine, several different tactics have been developed and applied at the McArthur River Operation over the past ten years. They are artificial ground freezing to form a frozen curtain between the water bearing sandstone and the ore body; probed and grouted drilling to evaluate hydrogeological and structural conditions prior to drift development and to reduce the water conductivity of the surrounding rocks with pressure grouting, if no freeze wall protection exists; and strategically located the underground excavations away from known water sources whenever possible.

3. Ground freezing

Artificial ground freezing is an excavation support method that involves the use of refrigeration to convert in-situ pore water into ice [1]. Over the last several decades, many mining operations have successfully utilized artificial ground freezing for deep excavation support while shaft sinking [2–5]. McArthur River successfully maintains a very large scale ground freezing infrastructure for both development and production: (1) use of freeze shields in higher-risk development in order to create a barrier to likely potential water flow paths into the tunnel under development areas, and (2) use ground freezing to create barriers to water inflow around production areas where the resulting freeze walls are tied into dry basement rock. Low temperature brine is distributed to each individual freeze hole through brine supply line from the collar of inner poly tube to toe of hole, and then circulated between the gap of HWT and Poly tube to implement heat exchange with ground. A cross section of the freeze hole is indicated in Fig. 2. A freeze plant is located at surface to supply low temperature brine to underground through shaft #1, and two stage heat exchangers were established at shaft 1 station and Bay 13 in 530 level respectively for different mining zone. The resulting freeze walls act as barriers between the underground mine workings and the water bearing formations.

Freeze methods used consist of the following three categories.

3.1. Freeze wall isolation

Freeze wall isolation consists of creating one or more freeze walls to isolate an area from water bearing ground. In order to be effective, the freeze walls must be tied together and completely enclosed or anchored into non-water bearing and non-permeable

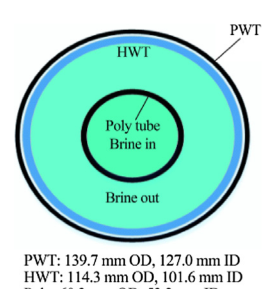

Fig. 2. Cross-section view of freeze hole–facing toe of freeze hole.