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DEVELOPMENT OF THE CIGAR LAKE JET BORING MINING METHOD

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Abstract

The Cigar Lake high-grade uranium mine in northern Saskatchewan is finally in operation after 25 years of test mining, construction, and mine flood remediation. Cameco Corporation, on behalf of a joint venture, is the operator.

The Cigar Lake orebody is situated 430 metres below surface at the unconformity between metamorphic basement rocks and flat lying sandstone. Major technical factors influencing the mining method selection include ground stability, control of ground water, radiation exposure and ore handling. A 10-year test mine program resulted in the selection and validation of "jet boring", a non-entry mining method accessing the orebody from below.

Cigar Lake's jet boring mining method involves several major steps; artificial ground freezing of the orebody and surrounding rock, new Austrian tunneling method (NATM) development of access crosscuts below the orebody, installation of cased pilot holes upwards through the ore, and ore extraction using a rotating high-pressure water jet within the pilot holes. The resulting cavities are surveyed and backfilled with concrete. The ore slurry is ground and thickened underground, pumped to surface and trucked to the McClean Lake mill operated by AREVA Resources Canada Inc. for processing to uranium concentrate.

This paper includes highlights of the development of the jet boring mining and ground freezing methodologies, and the first two years of production.

1. Introduction

The Cigar Lake deposit is in northern Saskatchewan, 660 kilometres north of Saskatoon, Saskatchewan, Canada at the east edge of the Athabasca basin (Figure 1) [1].

The operation is jointly owned by Cameco Corporation, AREVA Resources Canada Inc., Idemitsu Canada Resources Ltd., and TEPCO Resources Inc. Cameco has been the operator of Cigar Lake since January 2002. The discovery hole was drilled in 1981. Commercial production was declared in May 2015 and Phase 1 operation will have a mine life of 15 years.

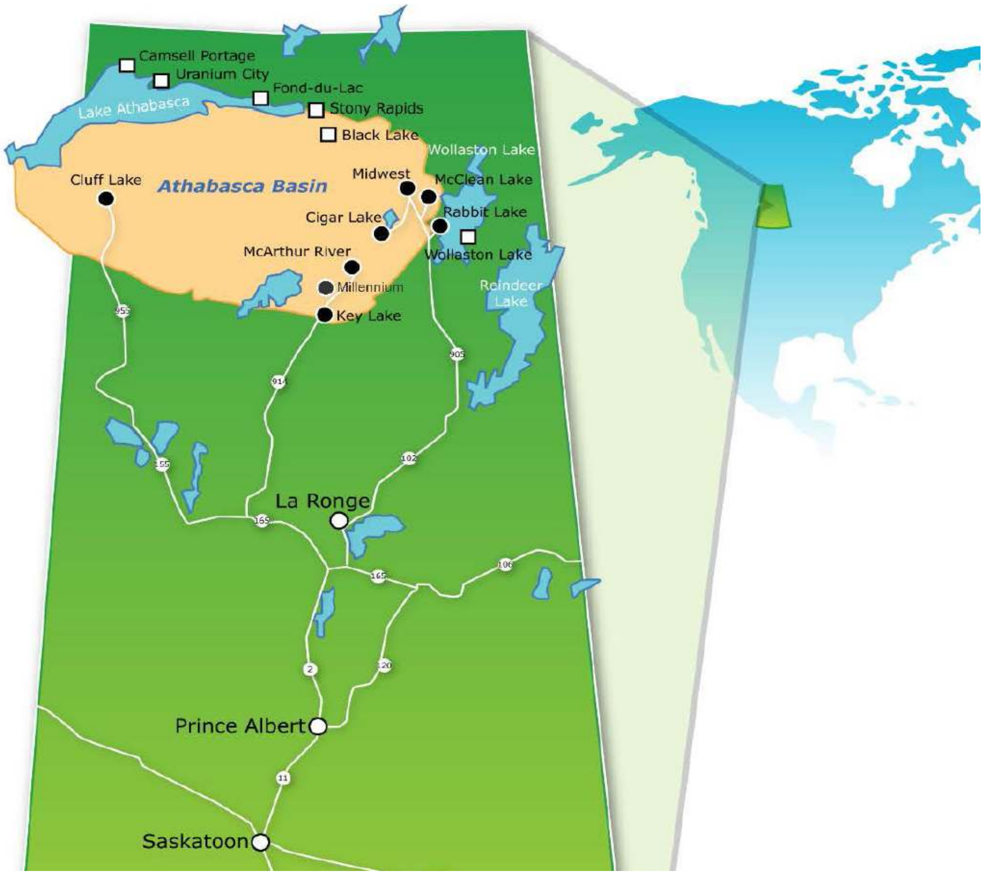

Figure 1. Map of central and northern Saskatchewan

Cigar Lake is the highest grade uranium mine in the world and is the second largest uranium producing mine (behind McArthur River). At an average grade above 16%, the deposit is 100 times the world average. Some zones have grades of 40% grade or higher.

2. Geology and Challenges

The deposit is crescent shaped and flat lying, averages 5.4 metres thick, and is 20 to 100 metres wide. The overall deposit is approximately 1,950 metres long and is about 430 metres below surface.

The ore and surrounding rock contain clay and altered sandstone, are weak, highly fractured and have high water content at significant pressure. The basement rock below the ore zone has lower porosity with less fracturing and a lower water content. Figure 2 shows a geological cross section of the deposit and surrounding features [2].

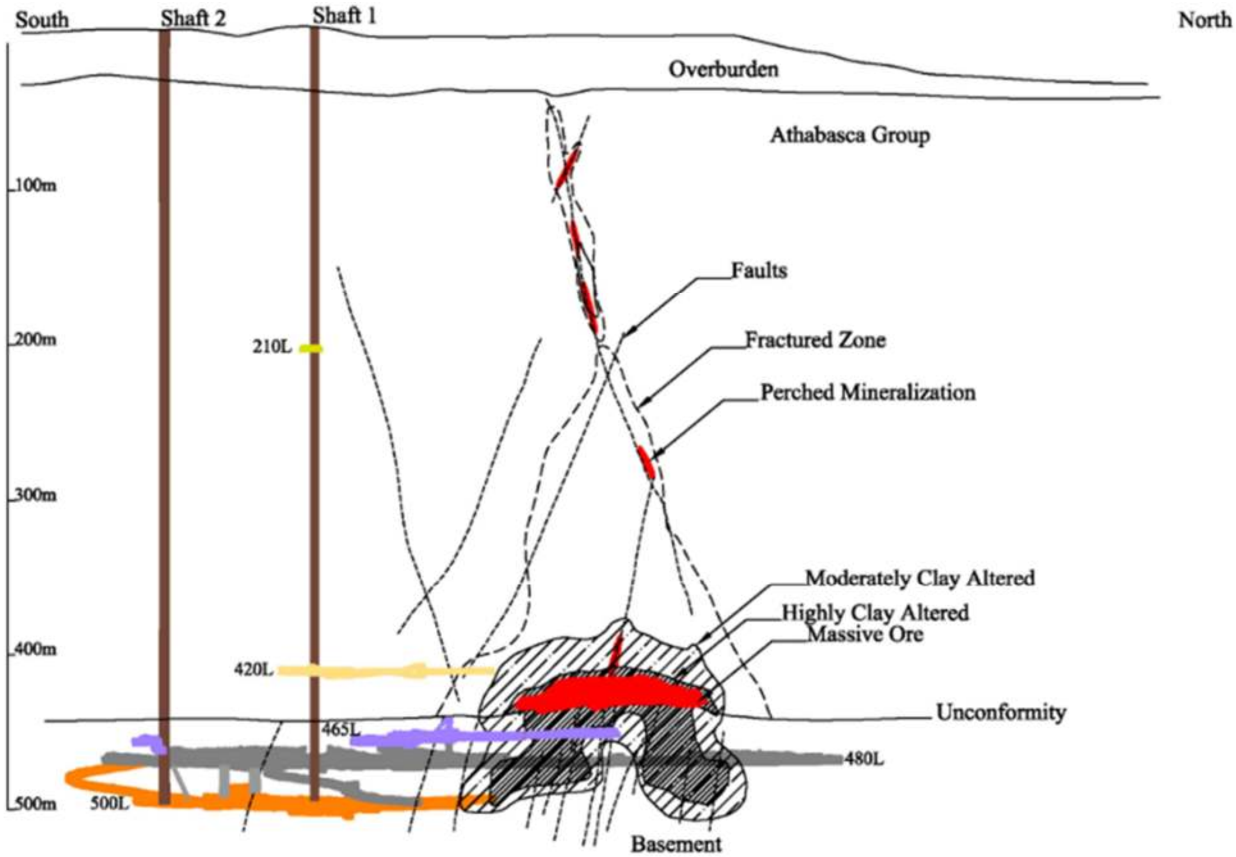

Figure 2. Geological cross-section of deposit

Right from the outset following core logging and initial scoping studies, major challenges were identified, including ground stability, high-pressure ground water, radiation exposure, and ore handling and storage.

3. Mining methods

Around the world, uranium is mined using one of three general mining methods; open pit mining, in-situ leach mining via wells drilled from surface, and underground mining. At Cigar Lake, open pit mining is not feasible due to the depth of the orebody and in-situ leaching is not possible due to the orebody's low permeability and very high grade.

Most underground uranium mines in the world are low grade (less than 1% U_3O_8) thus conventional mining methods such as drill and blast can be utilized. McArthur River, a high-grade operation, uses two non-entry methods; raisebore mining with drill on upper level, reaming upwards from a lower level (Figure 3) and blasthole stoping which includes drilling and blasting around a raise bored hole (Figure 4) [3].

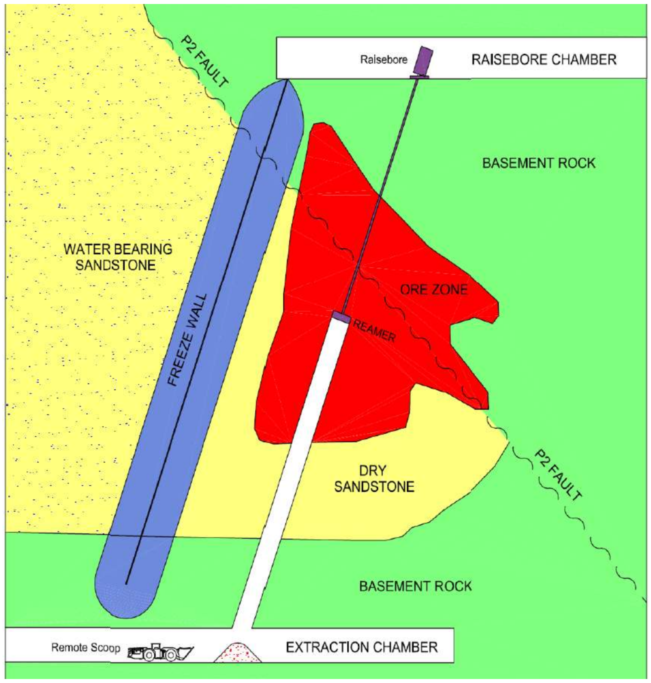

Figure 3. Cross section schematic of raisebore mining at McArthur River

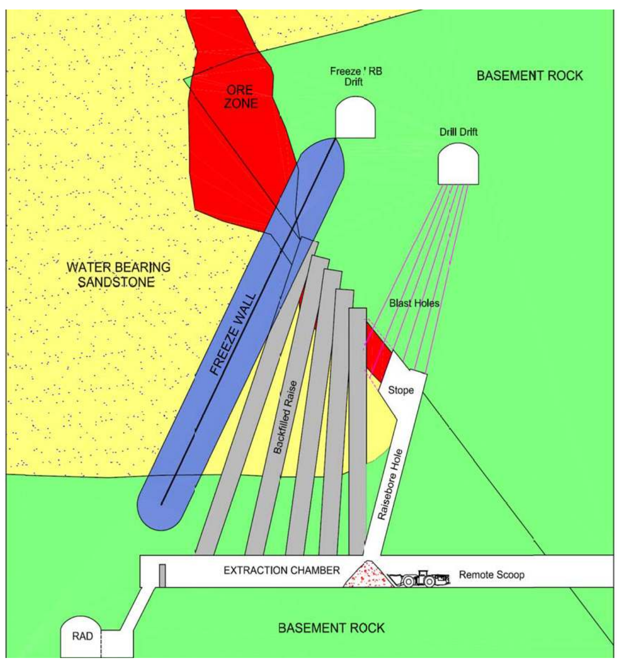

Figure 4. Cross section schematic of blasthole stoping via raisebore holes at McArthur River

At Cigar Lake, underground mining methods initially considered included raisebore mining, blind hole boring (drilling a large hole downwards from an upper level) and box-hole boring (drilling a large hole upwards from a lower level). A test mine was launched in 1987 to assess underground conditions and test one or more of these mining methods.

4. Test mining, 1987-2000

Two levels of development underground were started, the 420 level above the deposit and the 480 level below the deposit (Figure 2).

From the 480 level, bulk freezing of the ore and surrounding rock was undertaken to mitigate three risks, being groundwater control, ground stability and radon control, as discussed immediately below. Ground freezing prevents orebody water at high pressure from entering the access tunnels, improves ground stability during mining, and minimizes radon bearing water from entering the mine (Figure 5).

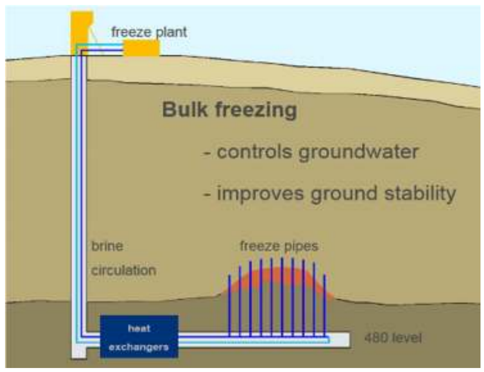

Figure 5. Bulk freezing

A European drill supplier recommended adapting their tools for jet grouting (construction method) to tools for a water jet boring test. As shown in Figure 6, the jet boring steps include:

- drill pilot hole
- rotate high pressure water jet within pilot hole creating a cavity
- backfill the cavity with concrete

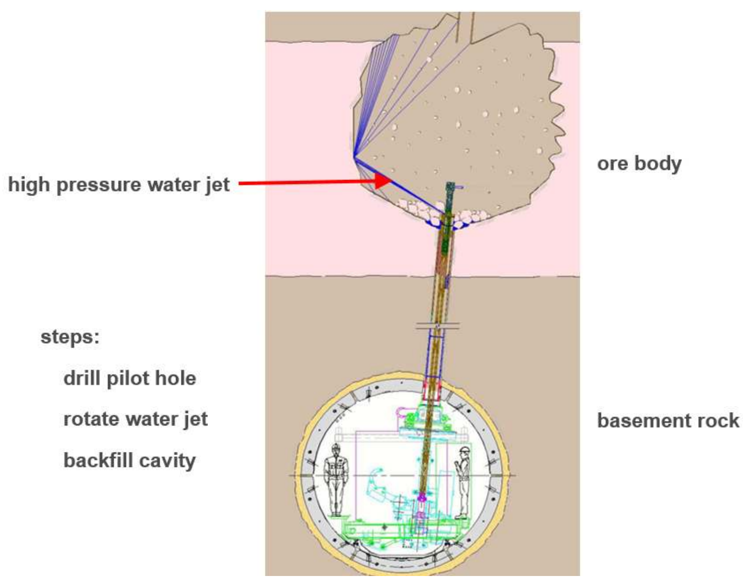

Figure 6. Jet boring layout and steps

Initial testing of jet boring involved adapting a drill with an 80 MPa waterjet through a 2.5 mm nozzle. Using this setup, six cavities of 1 to 1.5 metre in diameter were excavated in frozen ore at a rate of three tonnes per hour while jetting. During the test, a cavity flush water circuit was added to help transport the clay and minimize plugging.

During these initial tests, several significant advantages of jet boring were identified.

1) Containment
2) Radiation control
3) Dust elimination
4) Cost effective ore transport
5) Collar security preventing water inflows if the top of the frozen zone be breached
6) Ability to mine in a fan pattern
7) Small diameter pilot holes below the orebody minimizes the waste rock created

The jet boring mine plan from 1993 to 2010 included two levels below the ore body; the lower 480 level for freezing and the upper 465 level for production (Figure 7).

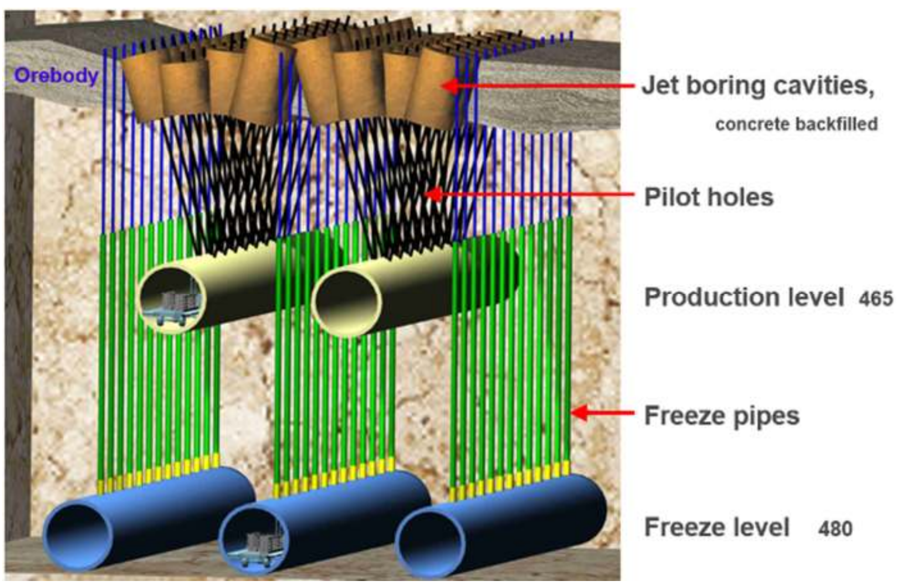

Figure 7. Jet boring mine layout 1993- 2010

Most of the ground immediately below the orebody is weak and deformation was a concern given the natural ground pressure and ground freezing pressure observed. Thus, special ground support was required below the orebody. A custom tunnel boring machine erected high strength concrete segment rings as it advanced (Figure 8).

Figure 8. Concrete segment lined tunnel with freeze piping

Lab tests and modeling were conducted to determine production jetting and associated power requirements. Within this testing and modeling phase, the following was found:

1) To achieve the target production rate of 10 tonnes per hour and cavities 2 metres in diameter, the jet required increased pressure and flow rate which was accommodated with additional underground pumps. Compared to a car wash wand, the Cigar Lake water jet is approximately 10 times the pressure, 100 times the flow and 1000 times the power.
2) Incorporation of a custom nozzle and an turning vane elbow into the nozzle "sub" ensured an effective waterjet capable of mining harder rock at distances of 1 to 2 metres.
3) Control of the size of the ore exiting the cavity using a "blade" screen attached to the nozzle prevented slurry plugging (Figure 9).

Figure 9. Nozzle sub and blade screen. The blade screen consists of vertical, radial blades mounted within two concentric pipes. This screen is attached to the nozzle sub just below the nozzle and is essentially the drain or exit from the cavity. The nozzle sub is free to rotate within the blade screen. Pieces of rock about the size of a small potato can pass through the openings.

Tests of the all prototype jetting tools and the new high-pressure pump system were conducted in 1999. Between two levels underground, a 3 metre diameter culvert was installed and filled with simulated ore including concrete, clay, steel and 250 MPa granite boulders. The jet easily mined out the entire culvert setting the target for future cavities at 3 metre diameter.

A production jet boring system (JBS) was designed to execute all mining steps including:
1) drill pilot hole and install casing
2) operate jetting tools
3) pump slurry to storage, and
4) backfill cavity with concrete

The JBS is comprised of six cars which move together on rails in the tunnel (Figure 10).

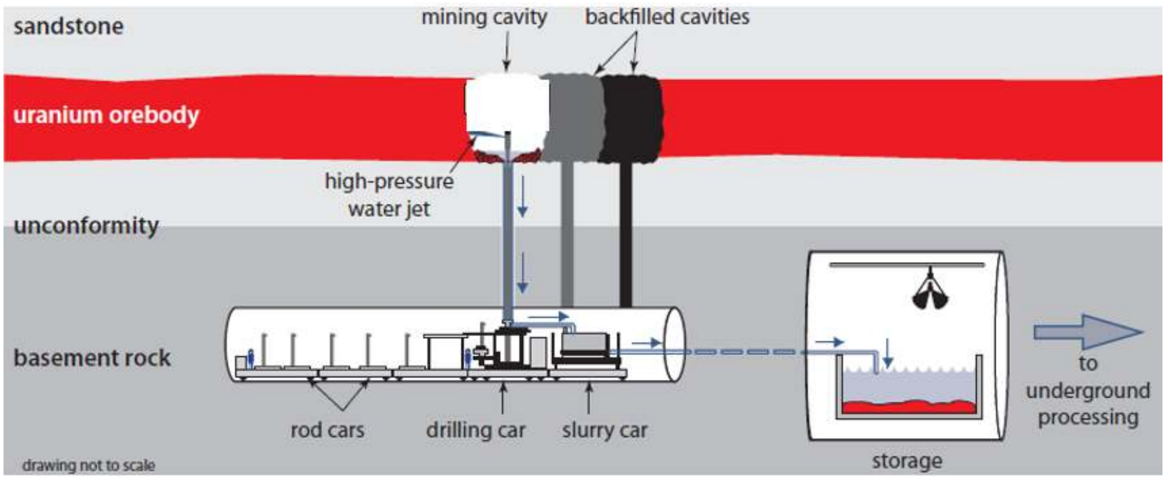

Figure 10. Jet boring system or JBS

In 2000, a complete mining test of all equipment and procedures was executed in frozen ore. Four cavities in frozen waste rock and four cavities in frozen ore were excavated. Overall, the 2000 test was deemed successful as a result of the following:
1) ore cavities averaged 4.5 metres in diameter
2) the target rate of 10 tonnes per hour while jetting was achieved
3) ore slurry was pumped without problems, and
4) backfill concrete saw minimal deterioration from the jet.

5. Mine construction and production ground freezing

Mine construction started in 2005 on both surface and underground. Construction included a second shaft, underground process circuits, underground freeze pipes, surface freeze plants, and additional tunnels under the orebody. Based on the test recommendations in 1999 and 2000, the JBS, jetting tools and surveying tools were redesigned, manufactured and tested.

Surface freezing significantly reduces the risk of water inflow as the frozen cap above the orebody is much larger than underground freezing. Surface freezing was implemented to decouple underground production from ground freezing to improve the schedule for production ramp up.

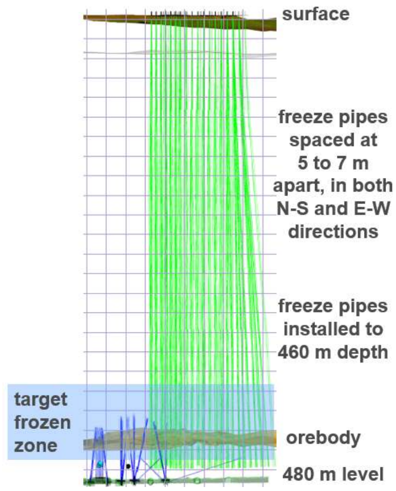

Figure 11. Cross section of surface freeze pipes

Figure 11 shows a cross section of surface freezing. Over 600 surface freeze pipes of 125 mm outside diameter have been installed to date. As of early 2016, over 300 are freezing the ore and surrounding rock with more being activated every day.

Freezing a zone requires two to four years depending on pipe spacing, rock properties and water content. Temperature sensors in the ground monitor freezing progress and boundaries. Finite element modeling, supported by field data including rock properties and temperature, is used for production planning and troubleshooting performance of the freeze program.

Figure 12 includes plan views at the orebody elevation showing the 2016 freeze status and the predicted freeze growth by 2018.

Q1, 2016 Q2, 2018

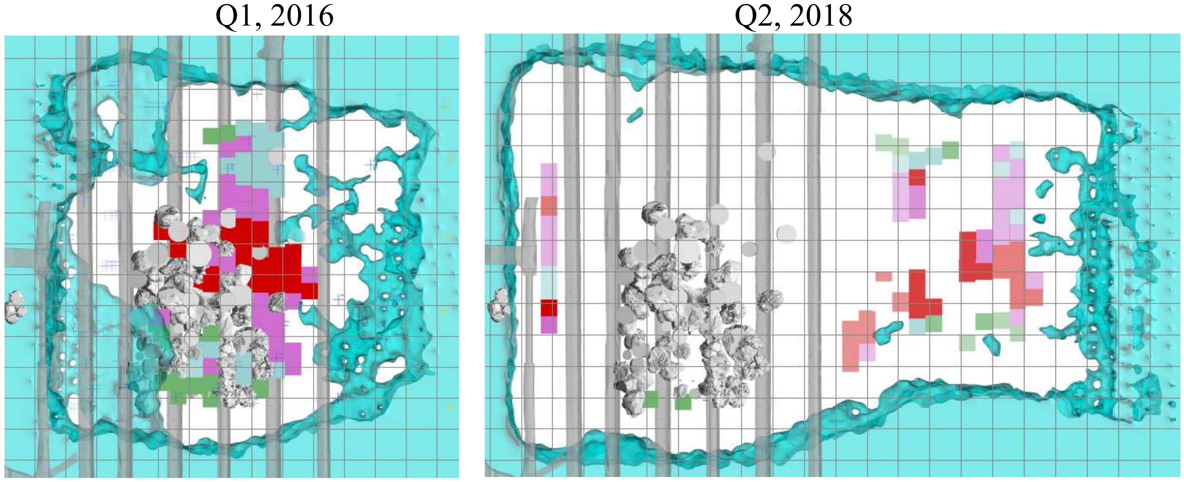

Figure 12. Plan views of freeze status 2016 and predicted freeze growth by 2018

- white areas: ground is -5°C or colder, available for mining if all criteria met
- blue areas: ground is between -5°C and ambient temperature of +8°C
- grey shapes: cavities mined as of Q1, 2016
- color squares: new cavities available for mining in preceding 3 months

The segment lined tunnels below the ore experienced excessive deformation from freeze pressure, causing interference with the JBS. Segment liner repairs were not possible. The new Austrian tunneling method (NATM) was implemented to retrofit and enlarge existing tunnels (Figure 13) and for the construction of slightly larger, future tunnels. The NATM method includes a compressible shotcrete liner with embedded engineered yielding elements and lattice girders [4]. Spot repairs on NATM liners have been undertaken after excessive deformation occurs.

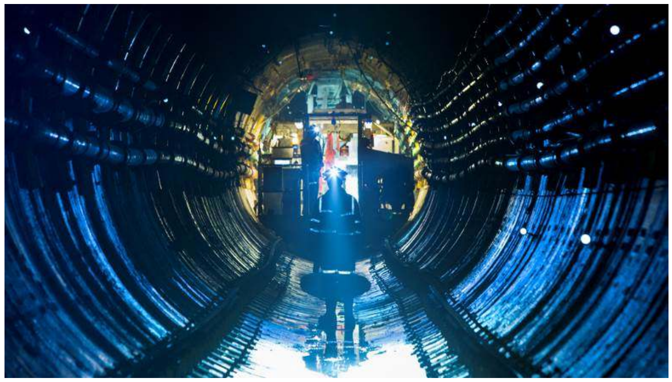

Figure 13. Retrofitted tunnel with JBS and services

6. Production mining

Figure 14 shows the Phase 1 orebody, the mining tunnels below the orebody and the ore processing areas and maintenance shops around the two shafts to surface.

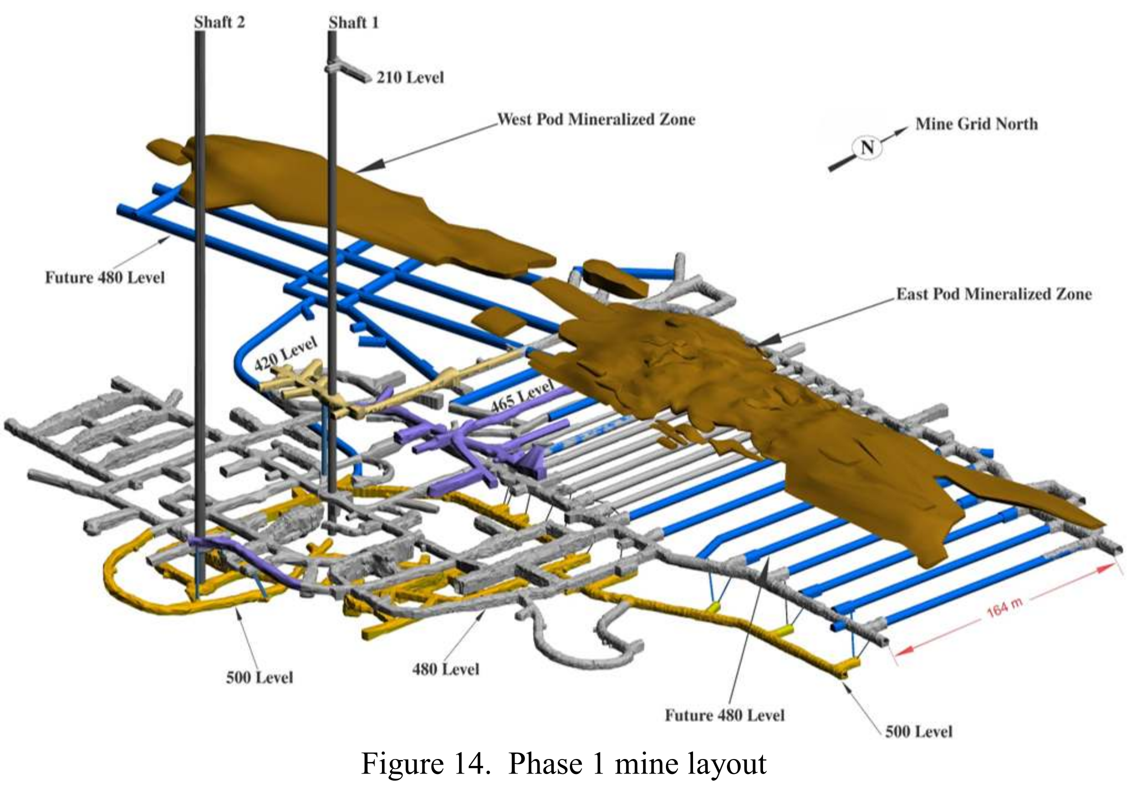

Figure 14. Phase 1 mine layout

The first production ore cavity was mined in December, 2013. As of June 2015, three JBS units were operating in three tunnels, mining cavities in frozen ore. Figure 15 shows a JBS in operation.

Figure 15. JBS in operation

In 2015, 11.3 million pounds of uranium concentrate was produced from approximately 50 cavities and full production of 18 million pounds per year is expected in 2017.

Figure 16 shows 90 cavities mined as of May 2016. On average, the cavities to date range from 4.5 to 6 metres in diameter and yield about 200,000 pounds of uranium concentrate. Several very large cavities in 40% grade ore have each yielded approximately 1,000,000 pounds of uranium concentrate.

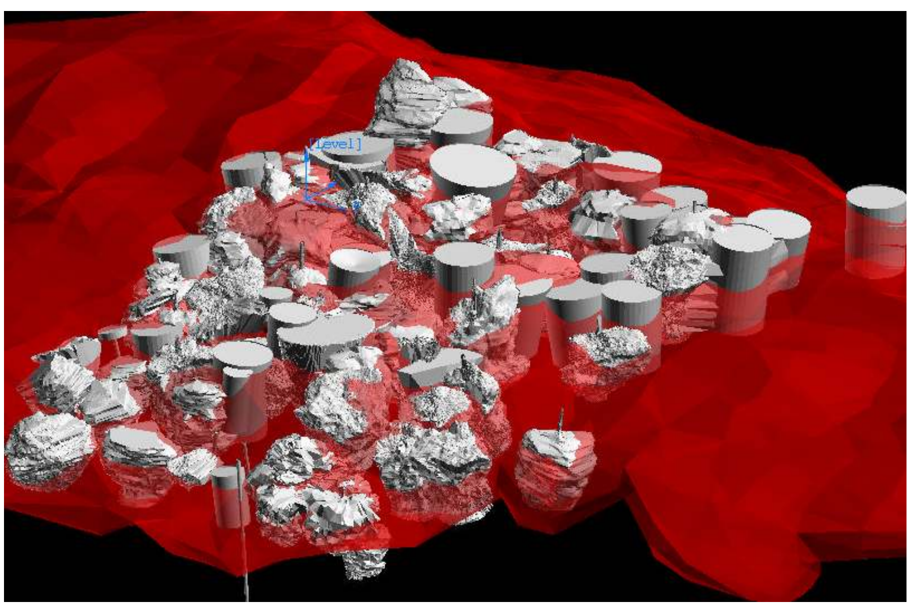

Figure 16. Cavities mined as of May 2016
Ore body thickness and cavity height: 5 to 8 metres
Cylindrical cavities shown are estimates based on backfill volume when surveys are unavailable

Jet boring to date has met or exceeded targets on production, tonnes per hour, cycle times, cavity size and diameter, and recovery. In 2015, the full cavity cycle time including backfilling was approximately 10 days.

The ore handling system has been designed to ensure high-grade ore is not handled manually to reduce the potential for radiation exposure to employees. The ore slurry is pumped to one of two underground storage sumps. Remote controlled clam shells on monorails pick up slurry from storage sumps and delivers it to underground process circuits for grinding, thickening, and pumping to surface as a slurry.

On surface, the thickened slurry is loaded in containers on a trailers and shipped 80 kilometres to AREVA's McClean Lake mill where yellowcake is produced. Facilities in Ontario and elsewhere provide further processing to create nuclear fuel for worldwide reactors.

7. Conclusion

Through innovation, Cameco has brought Cigar Lake into production by implementing ground freezing and jet boring mining.

Bulk freezing of the orebody and surrounding rock has been successful in preventing water inflows and providing cavity stability. Hundreds more freeze pipes will be installed and activated during the remainder of Phase 1 operation.

Jet boring has met or exceeded production targets to date and was declared a commercial mining method in May 2015. Full production of 18 million pounds of uranium concentrate per year is expected in 2017. Phase 1 operation will involve mining approximately 1500 cavities over a total of 15 years.

8. References

[1] C.S. Bishop, A.G. Mainville, L.D. Yesnik, "Cigar Lake Operation, National Instrument 43-101 Technical Report", www.cameco.com, March 2016, page 22.

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[3] D. Bronkhorst, A.G. Mainville, G.M. Murdock, L.D. Yesnik, "McArthur River Operation, National Instrument 43-101 Technical Report", www.cameco.com, November 2012, page 119 and 125.

[4] C.S. Bishop, A.G. Mainville, L.D. Yesnik, "Cigar Lake Operation, National Instrument 43-101 Technical Report", www.cameco.com, March 2016, page 103.