URANIUM MINING: INFRASTRUCTURE, OPERATIONS AND IMPACTS

Presented by: the Canadian Nuclear Safety Commission, the Quebec Ministère de l'Énergie et des Ressources Naturelles, and the Quebec Ministère du Développement Durable, de l'Environnement et de la Lutte contre les changements climatiques

Québec

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Presentation Overview

- Federal and provincial regulatory framework
- MERN, MDDELCC and CNSC requirements for open-pit and underground mines
- Risk Management
- Environmental footprint
- Worker protection
- Control of air emissions
- Control of liquid releases
- Solid material management

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Federal and Provincial Regulatory Framework

- The mining framework is under provincial jurisdiction and is primarily the responsibility of MERN and MDDELCC
- The nuclear framework is under federal jurisdiction, with the CNSC as the nuclear regulator

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CNSC Areas of Jurisdiction and Requirements

- CNSC areas of jurisdiction: regulatory oversight of site preparation, construction, operation, decommissioning (site restoration and monitoring) and release from licensing
- CNSC requirements: protection of the environment, the health and safety of persons, maintenance of national security, and compliance with international obligations

Open-pit and Underground Operations

MERN requirements:

- To obtain a mining lease:
  - survey plan
  - a report certified by an engineer or a geologist about the nature, scope and probable value of the mine, as well as a feasibility study
  - rehabilitation and restoration plan including financial guarantees approved in advance by MERN
  - authorization certificate issued in advance by MDDELCC
- Annual disclosure of information about the quantity and value of the ore extracted and the royalties paid

Open-pit and Underground Operations

MDDELCC: Compliance with the *Environment Quality Act* and its regulations

- Environmental and social impact assessment including:
  - project description based on the completed feasibility study
  - characterization of the physical and human environment, establishment of reference levels
  - impact analysis and mitigation, demonstrating compliance with environmental standards
  - analysis of technological risks and preliminary emergency measures plan
  - work surveillance and environmental monitoring program
  - etc.

Open-pit and Underground Operations

CNSC requirements: *Uranium Mines and Mills Regulations* (SOR/2000-206)

- A surface plan indicating the boundaries of the mine and the area where the activity to be licensed is proposed to be carried on
- The proposed plan for the rehabilitation and restoration of the mine or mill site
- The effects on the environment that may result from the activity to be licensed, and the measures that will be taken to prevent or mitigate those effects
- Etc.

Main Types of Mining Operations

Open-pit mine

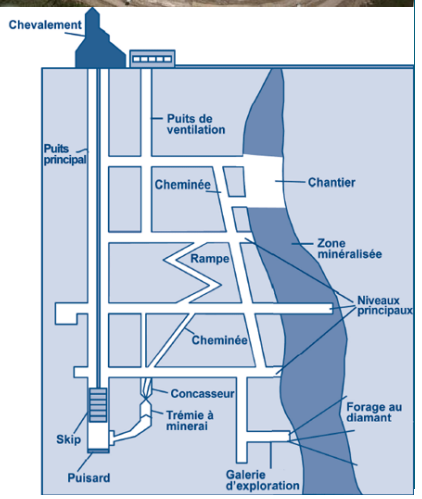
- Ore close to the surface
- Large deposit
- Works for low grades
- High production volume
- Low operating costs
- Larger surface footprint

Underground mine

- Ore at a greater depth
- Characteristics of the deposit must allow it to be extracted (type of deposit, depth of mineralization, width, etc.)
- Grades must be higher
- Several types of operations (block caving, long hole, room and pillar)
- Moderate surface footprint

Leaching

- In situ: injection well, in situ dissolution, pumping well
  - minimal surface footprint
- Heap: piled ore, surface leaching
- This method is not used in Quebec or anywhere in Canada



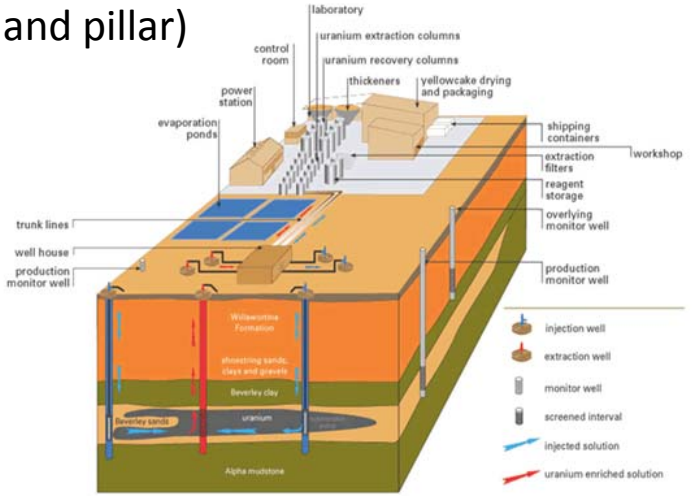


Fig 1. Pictorial representation of the ISL process

Image courtesy Heathgate Resources

Typical Underground Mining Method Example: Eagle Point Mine in Saskatchewan

- Requires stable ground condition and relatively dry
- <~5% U3O8 for radiation
- typical drill, blast and mucking cycle
- Enables reserves to be stored on the surface to supply the mill

Non-conventional Underground Mining Operations: Geological Considerations

Two of the most important features to consider in underground extraction of high-grade (> ~5%) uranium ore are:

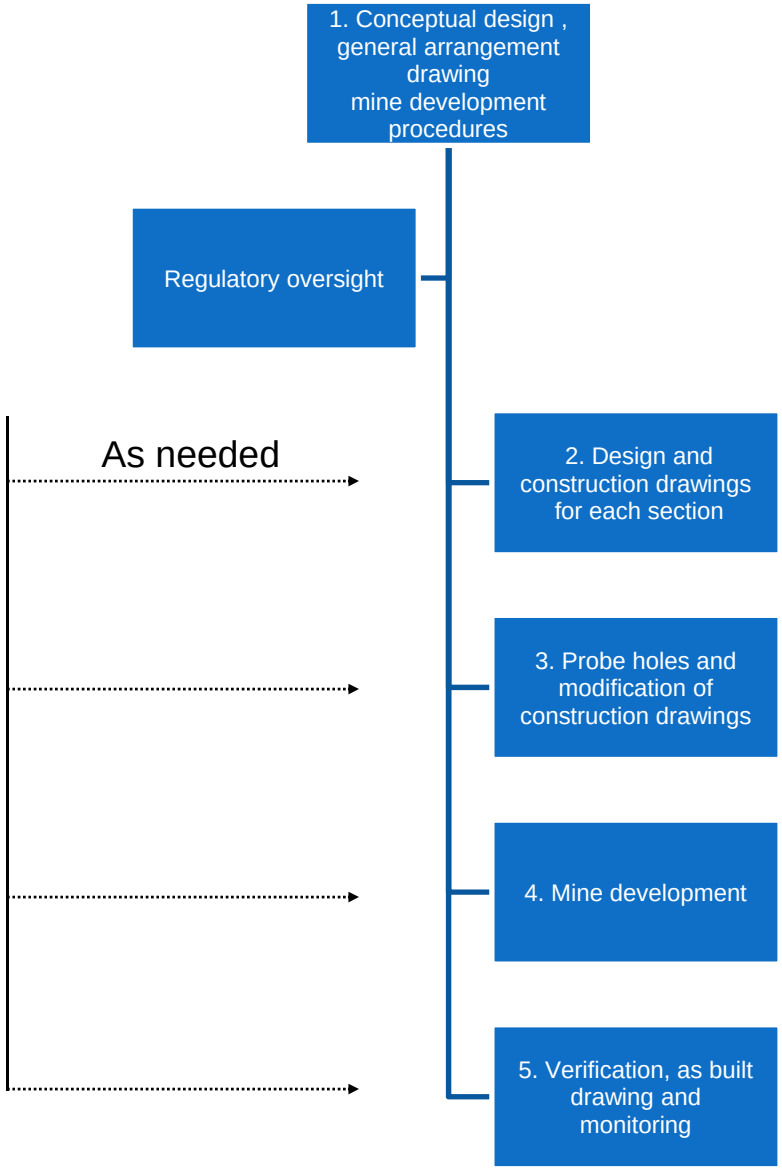
1. The stability of the underground rock type for excavation
2. The volume and potential flow rate of groundwater held within the rock

- There are only two mines in the world with these high grades. Both are in Saskatchewan.

Non-conventional Underground Mining Operations: Geotechnical and Hydrogeological Conditions

- Fractures, faulting, alteration and weathering of the host rock pose some challenging conditions to mining in such an environment
- The mine operator must:
  - ensure stable ground conditions to protect workers safety
  - minimize groundwater inflow to reduce radon exposure and reduce loading to the environment
- The design of the mine in order to achieve the above requirements has to be based on geotechnical and hydrogeological data obtained during exploration and possibly test mining

Adaptive Management Method



Risk Mitigation

- Risk Assessment
- Credible Scenarios
- Mitigation Measures, for example:
  - safe removal of workers
  - freeze walls
  - grout curtains
  - increased water storage and pumping capacities
  - area isolation measures

Conventional Safety Hazards and Control for a mine

- Airborne hazards include: diesel fumes, dust, blasting gases and other mine gases
- Controlled by adequate supply of ventilation and dust control measures as prescribed in provincial mining regulations
- Mine design of ramps, drifts and shafts

Footprint
Examples of area

Footprint

Land affected by mining activities: all areas occupied by mine infrastructure (mining camp, buildings, plant, waste rock and tailings piles, settling (polishing) ponds and open pit).

In 2014, active mining claims represent:

4.5% of the area of Quebec

Active mines occupy:

0.005% of the area of Quebec

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Footprint
Examples of area

Underground mines: the footprint could range from 45 to 300 ha
Open-pit mines: the footprint could range from 500 to 5,000 ha
Examples of other footprints: • Average shopping mall: 72 ha • Airport (e.g., Dorval): 800 ha

Environmental Footprint
Factors that Affect the Footprint

Factors that can affect the environmental footprint: Varies from one site to another depending on:

- Type of operation (open-pit, ramp, well)
- Waste rock : ore ratio
- Production volume (500, 2000 or 55,000 tons per day)
- Use of waste material (paste backfilling, underground storage, restoration of other sites)
- Site configuration (topography, hydrographic profile)
- Related infrastructure (concentrator, hydrometallurgical plant, garages, administrative office, camp, aerodrome, waste rock dump and tailings site, etc.)
- Current land use prior to construction (e.g. private, public, agricultural, recreational, others.)
- Proximity of existing infrastructure (roads, power lines, residents, etc.)

The objective: establish the best operating scenario in a context of sustainable development

Worker Radiation Protection Framework – CNSC Requirements

Management Controls

- Risk assessments
- Work and process controls
- As low as reasonably achievable (ALARA) program
- Training

Engineering Controls

- Mining method, ventilation and dust control
- Monitoring (internal and external)
  - individual dosimeters
  - continuous monitors with warning lights
  - area/time monitoring
- Time-distance-shielding

Administrative Controls

- Dose limits, action levels, codes of practice
- National Dose Registry (NDR)
- Periodic and event reporting

Shielding – Shotcrete Application

The walls of the mine are covered in concrete to block radiation and radon ingress

Distance Control – Remote Mucking

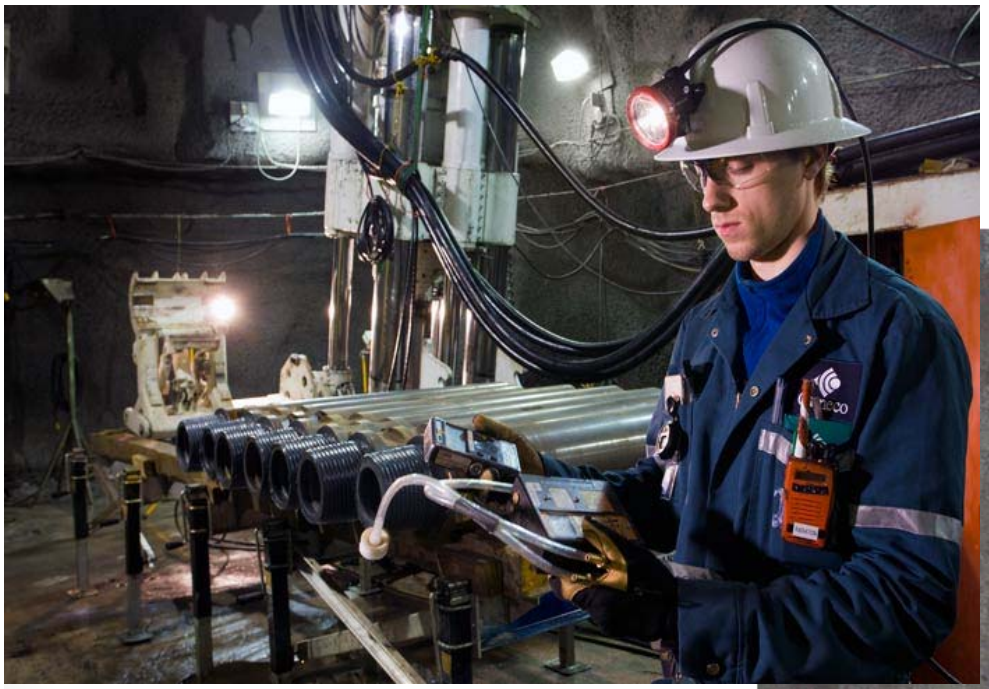
Operators use remote-controlled equipment to work at a distance from the radioactive ore

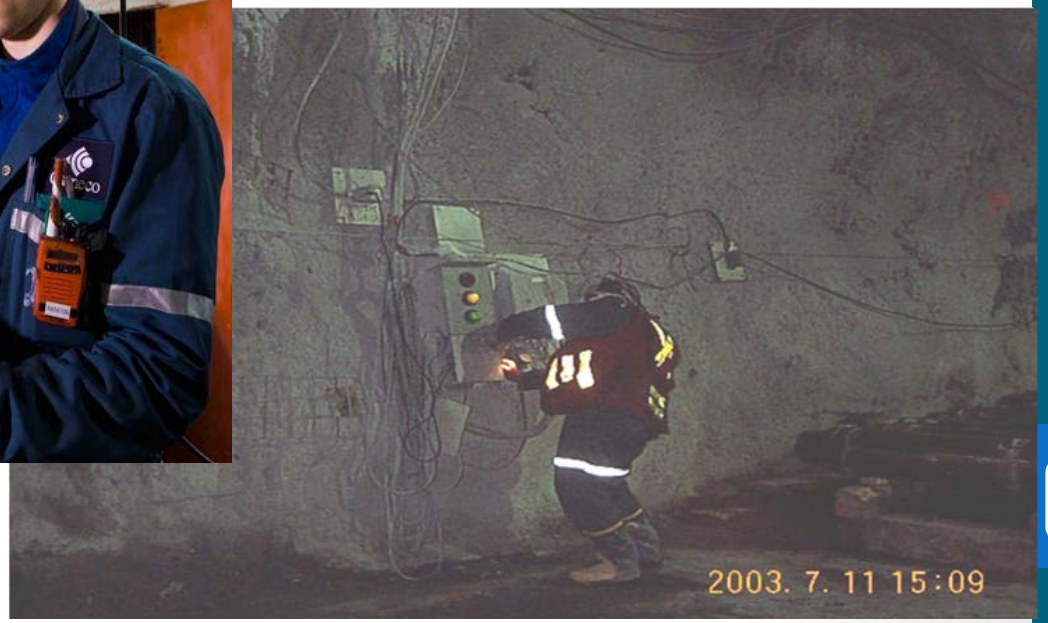
Radon Gas - Ventilation Source Control

- Dilution requirements as based on 3 air changes per hour and the air requirement for diesel engines
- Main ventilation fans are equipped with visual and audible warning devices
- Regular inspection and maintenance schedules are developed for preventative maintenance
- Normal work is stopped during ventilation interruptions and the mine is monitored prior to work restart

Radiation Monitoring, Sampling and Continuous Surveillance

Continuous radiation monitoring measures are carried out by employees in the workplace





Radiation Protection Measures Open-pit Mines

- Radon gas and radon decay products diluted by atmospheric conditions to low levels
- Dust controls incorporated into mining equipment air filtration systems in the enclosed operator compartment
- The ore is covered with waste rock to act as shielding against radiation.

Waste Segregation

- Mine development based geotechnical drilling
- Probe holes drilled (30 m) to identify ground water potential, ground conditions and chemical characteristics (mineralized, acid generating, benign)
- Mined material stored based on segregation criteria: waste, mineralized, acid generating and ore and stored on surface pads

Water Management and Treatment

- Mine water is stored in lined containment ponds and treated at the water treatment facility before being released.
- The sump design includes settling to minimize solids
- Clean water can be diverted to separate storage for use in mining operations to minimize fresh water usage
- Radon gas concentrations can be elevated in ground water and contact water so mechanical ventilation systems are required around the sump to manage the air quality
- Mine water is stored in lined storage ponds and treated in the water treatment plant prior to being discharged

Water Management and Treatment Open-pit Mines

- CNSC regulatory requirements:
  - water management
  - treatment and quality (effluent limits, action level, etc.)
- Mine water can be intercepted by dewatering wells and discharged separately
- Mine water can be collected in in-pit sumps for storage and pumping
- Mine water is stored in lined containment ponds and treated at the water treatment facility before being released.
- The sump design includes settling to minimize solids
- In-pit water contains suspended solids and radium
- Mine water is stored in lined storage ponds and treated in the water treatment plant prior to being discharged
- Diversion ditches may be used to re-direct surface runoff to avoid contact with mineralized rock

Water Management and Treatment

Annual average concentrations of elements and total suspended solids and pH of effluents released into the environment in 2013

Parameters	Authorized Release Limits	Cigar Lake	McArthur River	Rabbit Lake	Key Lake	McClean Lake
Arsenic (mg/L)[1]	0.5	0.0006	0.0017	0.0055	0.0080	**0.0006**
Copper (mg/L)	0.3	0.0032	0.0011	0.0045	0.0130	**0.0030**
Lead (mg/L)	0.2	0.0001	0.0001	0.0001	0.0100	**0.0001**
Nickel (mg/L)	0.5	0.0038	0.0012	0.0144	0.0067	**0.0180**
Zinc (mg/L)	0.5	0.0029	0.0014	0.0100	0.009	**0.0009**
Selenium (mg/L)	0.6	0.0005	0.00014	0.0052	0.0170	**0.0004**
Molybdenum (mg/L)	1.0	0.017	0.188	0.324	0.15.	**0.005**
Uranium (mg/L)	2.5*	0.0011	0.0107	0.0630	0.0080	**0.0015**
TSS[2]	15	1.4	1.0	2.0	1.8	**1.0**
pH	**6.0–9.5**	**7.2**	**7.2**	**7.2**	**6.3**	**7.2**

[1] mg/L – milligrams per litre
[2] Total suspended solids
* CNSC objective of 0.1 mg/L

Enhanced Environmental Controls for Uranium

- Uranium was determined to be CEPA toxic which required a plan to reduce releases from uranium mines
- This determination was based on chemical toxicity not radiological concern
- The uranium reduction program was initiated at Rabbit Lake operations to reduce releases of uranium
- The program has been successful

Enhanced Environmental Controls for Molybdenum and Selenium

- Molybdenum and selenium are liberated during the milling process. Weight-of-evidence suggested potential for biological effects
  - Mo represented a potential risk to ruminants (e.g. moose)
  - Se confirmed as affecting fish reproduction
- The Commission required treatment for both these substances. Special circuits and treatment controls were installed. These modifications are effective.

Solid Material Management

- CNSC regulatory requirements
  - RD/GD 370
- Segregation of waste rock
- Reduction and re-use
- Temporary storage of waste rock
- Leachate containment and control

Cigar Lake mine

Uranium Mines
Differences and Similarities

The uranium mine framework is the same as that for other mining operations in Quebec

- Except for:
  - nuclear legislation for which CNSC is responsible as the Canadian regulatory agency
    - additional regulatory oversight and control
  - radioactive emissions control measures
  - radiation protection measures for workers

Conclusion

- A nuclear safety culture is applied to uranium mines which emphasizes reliability, defense in depth and continuous learning
- Radiation protection measures have evolved to accommodate the low, medium and high grade ore deposits currently being mined in Saskatchewan
- Environmental performance of uranium mines and mill are reviewed annually and modification or revised control measures are developed to address any new or developing conditions indicated by the environmental monitoring results of the local and receiving environment
- The CNSC ensures alignment with provincial and federal regulatory frameworks with regard to releases into the environment
- Uranium mines and mills are regulated from “cradle to grave” and financial guarantees are in place to decommission these facilities.