Radiation Protection as Part of a Uranium Mine Pre-Feasibility Study

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Abstract

Golder Associates Ltd. (Golder) has conducted a number of pre-feasibility studies for prospective uranium mining projects. This work has ranged from a preliminary scoping analysis of the viability of a particular project to a formal pre-feasibility study. This paper will address the radiation protection requirements for uranium mining and the impact of these radiation protection requirements on the feasibility of a uranium production project. As is discussed, the ore grades of an ore body will strongly influence the choice of mining methods that are available for any specific project. This in turn will affect the projected capital and operating costs for a prospective uranium production facility.

1. Introduction

In spite of the controversy surrounding nuclear energy and uranium mining, there continues to be considerable exploration for uranium, both in Canada, and elsewhere. After an exploration company has identified a potential uranium ore body, questions will inevitably arise as to the potential for the development of a producing uranium mine. The answer to such a question is complex and requires a consideration of many factors, including the costs of providing adequate radiation protection for uranium workers.

This paper will focus largely on underground uranium mines, but the radiological requirements will also impact the costs for open pit mining and for milling the ore. Radiation protection is generally more easily provided at open pit mines, and the capital and operational costs for open pit uranium mining will not be as strongly impacted by the radiation protection requirements. The regulatory and environmental costs for any uranium mining project will be similar and are addressed in this paper.

2. Radiation Protection for Uranium Miners

Generally, uranium mine workers will be subject to chronic low-level radiation exposures on a routine basis. While the radiation levels at a uranium mine are usually lower than the levels present at a power reactor, the constant low levels of radiation exposure at uranium mines will add up to annual radiation exposures that are higher than the exposures of reactor workers. Underground uranium miners, generally, receive the largest average radiation exposures of any work group in Canada.

Uranium miners will receive radiation exposures through a number of pathways. The major dose components for uranium workers are:

- External gamma radiation from mineralized rock and from the process stream carrying the Ra-226 in the ore through to the tailings management facility;
- the inhalation of radon gas and radon progeny; and
- the inhalation of long-lived radioactive dust (LLRD).
    - The LLRD will consist of ore dust at the mine and in the early stages of the milling process and of yellowcake at the back of the mill process.

All three radiation exposure pathways must be taken into account in the design of a uranium production facility.

The control of these radiation exposure pathways will have a profound effect on the design and potential viability of any proposed uranium mining project.

3. Worker Radiation Dose Limits

With a few exceptions, the international standards as promulgated by the International Commission on Radiological Protection (ICRP) have been adopted as regulatory requirements in almost every country.
The international worker dose limits are:

- An annual limit of 50 mSv.
- A limit of 100 mSv in any 5 year period.

These radiation dose limits apply to the total worker radiation exposure from all three of the radiation pathways listed previously. That implies the summation of a worker's exposure from external gamma radiation, the inhalation of radon progeny and the inhalation of long-lived radioactive dust.

In addition to the absolute radiation dose limits, the ICRP has stated that the continued exposure of workers at these dose limits would be unacceptable. This leads to the "As Low as Reasonably Achievable" (ALARA) principle, which has been adopted into the regulatory framework of most uranium mining jurisdictions. As per the ALARA principle, a uranium mining project must not only adhere to the radiation limits, it must also be able to demonstrate that all worker radiation exposures are being minimized.

The net result of these radiation protection requirements is that most national regulators will require that any uranium mine must be designed and operated to not only meet the radiation dose limits, but also to minimize worker radiation exposures. For example, the systematic rotation of workers into and out of high-dose jobs will not be permitted. Nor will the regulators permit the use of contract miners who are rotated into the mine for a short period of time and then replaced by other miners after the first group of contract miners has reached their annual dose limit.

The worker radiation doses at any mining operation are likely to fall along some type of normal distribution. It would be very difficult to operate a mine in a manner that would result in a distribution of workplace radiation exposures where every worker was exposed at, or near the annual radiation dose limits. This has the effect of lowering the practical worker dose limits to a level well below the average 20 mSv/year dose limit.

4. The Effect of Ore Grade on Gamma Radiation Levels Underground

The gamma radiation levels for a worker within a production stope will depend on:

- Whether the stope is completely within the ore body. Where the stope is adjacent to non-radioactive backfill or barren waste rock, the radiation levels will be lower than when the worker is completely surrounded by ore. The highest level of gamma radiation can be expected when the worker is close to the mining face and when the stope is entirely enclosed by ore.
- Whether the worker is within the cab of a piece of mobile equipment and on whether additional shielding around the cab has been provided to reduce the level of gamma radiation.
- On the thickness of shotcrete that has been applied to the back, sill and walls of the stope, both for ground support and for shielding the gamma radiation

As an indication of the gamma radiation dose rates to be expected, consider a worker standing in a circular stope, 5 m diameter and entirely enclosed in ore, but back, away the mining face. Figure 1 presents the unshielded gamma dose rates to be expected as a function of ore grade.

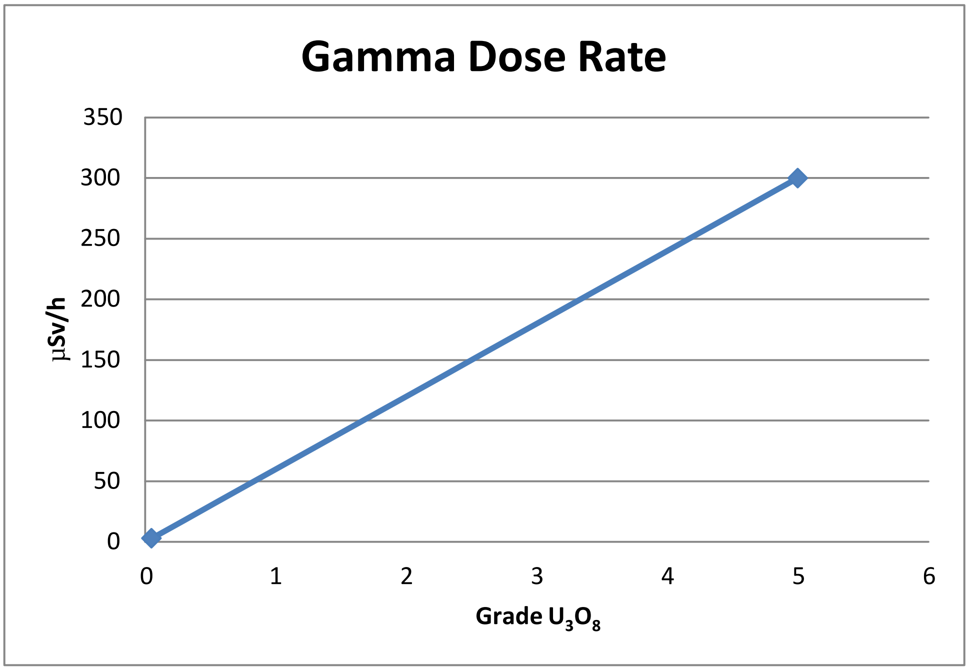

Figure 1 Unshielded gamma dose rates to be expected as a function of ore grade

Next consider a few examples.

For an ore body with a grade of 0.05% U_3O_8 the unshielded dose rate within such a stope would be 3 µSv/h. A worker who spends 2000 h a year at this radiation level would expect to receive an annual gamma radiation exposure of 6 mSv.

This is in good agreement with the experience in the old Elliot Lake mines. The grade of the Elliot Lake ore body was about 0.05% and the ore was distributed diffusely throughout the mine workings. Operationally, there was little effort spent at reducing the gamma radiation exposures since the ore was everywhere and there were no low-dose rate areas underground to which workers could retreat. Hence the worker gamma doses recorded by their TLD badges were generally about 5 – 6 mSv/year.

If we consider higher ore grades, the need for gamma dose control becomes immediately apparent. For an ore body grading 5% U_3O_8 the calculated gamma dose rate is 300 µSv/h. Any worker spending 2000 h annually in such a gamma field would receive an annual gamma radiation dose of 600 mSv. Such radiation doses are far above the regulatory dose limits and a mine would not be allowed to operate at such worker radiation exposures.

In practice, it has been found in Saskatchewan that variations of long-hole mining or blasthole stoping can be used for ore grades up to about 2% - 4%, but both the design of the mine and the operational controls must take careful account of the gamma radiation dose rates. A further caveat is that the ore body must lend itself to the specific requirements for such mining. That would include a reasonably defined boundary between the ore and the barren waste rock. Underground mining at these ore grades depends on the ability of the mining operation to limit direct exposure of the worker to the ore and on the intensive use of shotcrete for shielding the gamma radiation at critical locations.

Saskatchewan has ore bodies where the ore grades extend to 20% and beyond. These ore bodies are being mined successfully using remote mining methods such as raise boring by which the workers are maintained in low-dose rate areas away from the ore and where entries into areas within and adjacent to the ore body are strictly limited. Mining an ore body by raise boring is going to be expensive. The grade of the ore will have to justify the additional mining costs.

5. Radon Progeny

While the gamma dose rates within an ore body are a simple function of ore grade, the projection of the radon progeny levels within the mine workings is more complex. There are two sources of radon progeny within an underground mine;

- Radon gas carried into the mine with the mine water. The radon gas will be released from the mine water as it daylights within the mine workings.
- Radon gas moving through fissures in the rock adjacent to the mine workings and directly out of muck piles.

For wet mines, the ingress of radon gas with the mine water is generally the most important source of radon progeny. The amount of radon gas in the mine water will depend on the grade of the ore through which the water is passing and on the distance which the mine water has travelled through the rock. There are examples of underground (non-uranium) mines with high radon levels where significant grades of uranium have never been identified. Presumably the radon gas in the mine water simply accumulated in the water as it passed through relatively long distances within the rock surrounding these mines.

At the scoping or pre-feasibility level, it is important that the mine evaluation take into account the additional costs of delivering clean ventilation air to mine workplaces and the shunting of contaminated air directly to the mine exhaust. Any water inflows will have to be directed to enclosed sumps with the air in the sumps vented directly to the mine exhaust.

The series ventilation systems commonly employed at non-uranium mines will not provide adequate radon progeny protection for uranium mines.

While careful control of the ventilation air within an underground uranium mine is essential, experience has shown that the total volume of ventilation air required is comparable to the requirements for any trackless underground mine. The rule of thumb of “100 cfm per diesel HP” has been found to provide a good preliminary estimate of the total underground ventilation requirements.

The restrictions on the overall mine design imposed by the need to control the radon progeny levels should not be underestimated. This is true for any uranium mine but even more important for larger low-grade workings. Clearing the radon gas effectively and quickly from a large underground mine is going to impact significantly on the mining costs.

6. Airborne Long-Lived Dust

As should be evident, the control of gamma radiation and radon progeny will impact significantly on mine design and ultimately on the costs of a prospective uranium mining project.

While the design of the mine should incorporate steps to control the generation of airborne dust, the costs of such controls are likely to be less significant than the costs of gamma and radon progeny control.

The most important effect on mine costs from airborne long-lived dust is that some worker radiation exposure from the inhalation of long-lived dust is unavoidable. Any worker radiation exposures incurred from the inhalation of long-lived dust will constitute dose that is no longer available to be incurred from exposures to external gamma radiation or to radon progeny. Effectively the LLRD dose lowers the operational dose limits for gamma radiation and radon progeny.

The general rule is that even with the careful control of LLRD, the workers' radiation exposures from the inhalation of long-lived dust will be comparable to their exposures from radon progeny. Such a correlation should not be surprising since the control of worker radiation exposures from long-lived dust and from radon progeny are strongly dependent on the mine ventilation.

7. Operational Worker Dose Limits

The general experience in Saskatchewan has been that the worker radiation exposures from all three of the radiation exposure pathways tend to be approximately equal. In other words, for many workers, the radiation exposures from external gamma radiation are approximately equal to the worker's exposure to radon progeny which are approximately equal to the worker's exposure from the inhalation of long-lived dust. This is a general rule. The distribution of sources of radiation exposure will vary from one mine to another and from one workgroup to another. However, this provides a reasonable rule of thumb for an initial scoping or pre-feasibility study. The implication is that the practical operational annual dose limit for any of the three radiation exposure pathways is $20/3 \sim 7$ mSv.

Since the initial conceptual mine design for any specific ore body usually begins with a analysis of the external gamma radiation exposures, the operational annual 7 mSv gamma radiation dose limit will provide the first constraint on the selection of potential mining methods

8. Regulatory Considerations

Any large mining project is likely to be publically controversial. A prospective uranium mining project can be expected to generate even more public and regulatory interest. This paper is focussed on the Canadian regulatory requirements, but Golder's experience in other countries is that uranium mines are controversial everywhere and that the regulatory hurdles may be even more onerous in countries that have limited experience with modern uranium mining.

8.1 Environmental Assessment (EA)

In Canada, a new uranium project will require a full Environmental Assessment. This starts with a Project Description submitted to the Province and the Canadian Nuclear Safety Commission (CNSC) under the federal CEAA Process. The Regulators will respond with a detailed list of Project Specific Guidelines for the preparation of the EA. For a company with no previous uranium mining experience this is likely to be at the Comprehensive Study Level or, possibly, it might include Panel Hearings.

8.2 Licensing

The company will need various licensing permissions from the CNSC in order to mine and mill uranium. In order to ensure consistency, the licensing strategy and documentation should be developed concurrently with the EA. The license application can be submitted immediately after the submission of the Environmental Impact Statement (EIS). The construction and operating licensing documents are much more detailed than the EIS. The major elements within the licensing submission will include the:

- Description of the Project (Facility Licensing Manual and Facility Description Manual);
- Quality Assurance Program for the construction and operation of the mine;
- Radiation Protection Program;
- Environmental Monitoring Program;
- Conventional Safety Program for Workers;
- Site Security Program;
- Public Information Program;
- Corporate Emergency Response Program; and
- Decommissioning plans for the site.

In considering the licensing requirements, one should note the basis on which the CNSC will issue a license to mine. The quotation below is standard and always cited by the CNSC in issuing a license:

> *The Commission concludes that COMPANY XX is qualified to carry on the activity that the licence will authorize. The Commission is also satisfied that COMPANY XX, in carrying on that activity, will make adequate provision for the protection of the environment, the health*

and safety of persons and the maintenance of national security and measures required to implement international obligations to which Canada has agreed.

Therefore, a company wishing to mine uranium cannot simply hire a consultant to provide the licensing documentation. The company must demonstrate to the CNSC that it is capable of carrying out the commitments made during the licensing process. That implies the establishment of a corporate Environmental Health and Safety Department.

8.3 Regulatory Costs

The costs for meeting the regulatory requirements listed above are significant. A scoping or pre-feasibility study should include the costs of:

1) The establishment of a corporate Environmental Health and Safety Department capable of coordinating the production of the Environmental Assessment and the licensing documentation.
2) The CNSC licensing fees. The CNSC operates on a “cost recovery basis”. The mining proponent will have to pay the CNSC for their regulatory activities.
3) Consultants to provide the planning and the requisite studies.
4) Operational radiological requirements including lab analysis of environmental samples and the radiation instrumentation used at the mine.

Last, but not least, it should be noted that meeting these regulatory requirements will take time. The length of time needed to meet the regulatory requirements will add significantly to the projected costs of any new uranium mining project.

9. Radiological Scoping/Pre-Feasibility Analysis

9.1 Site Information

In order to begin the Analysis, it will be necessary to obtain sufficient information about the site and the ore body. This information will include:

- Ore grades and total tonnage
- A 3-D map of the ore body including information about outlying stringers if possible
- Strength of the rock within and around the ore body
- Hydrological information including projections of the mine water inflows
- Measurements of the radon gas levels in the water
- Other ground water contaminants
- General information about the site including potential sites for the location of the tailings, waste rock facilities and effluent water release points

The amount of information available will depend on the stage of the project. The more information that is available, the more accurate any Scoping or Pre-Feasibility Study can be.

9.2 Initial Mine Design – Dose from Gamma Radiation

For an underground uranium mine, the first parameter usually considered in the design of the mine will be the gamma radiation levels (or the ore grade). There are limits on the length of time a miner can be exposed directly to the ore. Hence a time/gamma dose study for the mining cycle is a good place to begin. Each stage of the mining cycle should be addressed:

9.21 Drilling

A jackleg drill will leave the miner fully exposed to the ore at the face. A shielded Jumbo drill will reduce the gamma radiation levels at the worker. Long-hole drilling from outside the ore body will result in much lower gamma radiation exposures for workers.

9.22 Blasting

In conventional mining, the time required for a miner to load the holes at the mining face is often problematic because this is where the gamma dose rates will be at a maximum. While it is possible to apply shotcrete to a mining face, it is usually not desirable. Options should be considered to expedite the loading of holes. Equipment that allows the miner to load the holes while located back from the face has been used, but with limited success. Long hole mining or a variation of this will reduce the gamma radiation exposures of blasters.

9.23 Ground Support

The application of screening can be a problem since it is difficult to automate the screening process. Bolters with automatic carousels will allow for lower worker radiation exposures, but the remote application of screen does not appear to be practicable at present. Many uranium mines use shotcrete applicators where the shotcrete nozzle is located well ahead of the operator. The shotcrete will reduce the gamma radiation levels as well as providing ground support. Some mines use much higher applications of shotcrete than would be required simply for ground support in order to provide attenuation of the gamma radiation. There are increased costs associated with the application of thick layers of shotcrete including operational delays in the mining cycle occasioned by the necessity to apply multiple layers of shotcrete.

9.24 Mucking

The use of remotely controlled scooptrams is very common at underground uranium mines. The caveat is that the operator is usually located in a low-dose rate area within line-of–sight of the scooptram. This may be problematic for some mine designs.

9.25 Summary

A consideration of the worker gamma radiation exposures for various mining methods for a given ore body will allow for the identification of a practicable mining method for the purposes of a Study. It is important that this selection of the mining method is performed carefully and methodically. The goal should be to develop a practicable mining method that will result in worker radiation doses that are well below the regulatory dose limits. Experience has shown that a uranium mine operating at a point near the worker dose limits will encounter operational difficulties. These operational difficulties will lower the efficiency of the work force and raise the operating costs.

9.3 Radon Progeny

After the appropriate mining method has been identified, it will be necessary to consider the layout of the mine. Since radon gas will quickly grow into radon progeny, it is important that fresh ventilation air is delivered to active workplaces through airways that are free of radon gas. Maintaining the access to the workplaces in clean waste rock is one option, but this option may not be cost-effective. Other options include the strategic placement of fresh air raises close to active workings as well as the construction of exhaust air raises in locations that allow for the shunting of contaminated air out of the mine.

A detailed modelling of the radon progeny levels should be included in the mine design to verify that the ventilation design for the conceptual mine has been optimized.

9.4 Long-Lived Radioactive Dust (LLRD)

LLRD is generally produced by active mining operations. Some of the most significant sources of LLRD will be:

- Mucking operations
- Loading of haul trucks at remuck stations
- Use of ore passes

All the main sources of LLRD should be identified at this stage. The design of the mine should include steps to prevent the LLRD from moving into the general mine workings.

It will be necessary to consider the protection of workers engaged in operations that produce airborne dust. For example, a worker operating a remotely controlled scooptram must be stationed so that the LLRD generated by the action of the scooptram picking up the muck is not carried back to the worker by the ventilation airflow.

9.5 Estimate of Worker Exposures

The final step in the radiological part of the analysis is the estimation of the radiation exposures for each work group. As stated previously, it is important that the projected radiation exposures are well below the dose limits.

An additional factor is the impact of operational radiation protection controls. A good radiation protection program will reduce worker radiation exposures. In that sense the doses estimated in this paper are conservative and probably constitute an upper bound on the actual worker radiation exposures that will be incurred. However, operational controls are likely to impact on the efficiency of the mining operation and therefore, will increase the mining costs.

The provision of a mine design that minimizes worker radiation exposures is likely to allow for more effective and less onerous operational radiation protection control measures.

10. Conclusion

A scoping or feasibility study for a prospective uranium production facility is very similar to such a study for any other non-uranium mine. However, the radiation from the uranium ore will impose constraints on the mining methods and mine design. A failure to recognize these constraints may result in an inadequate assessment of the viability or non-viability of a project.