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Ventilation requirements for uranium mines

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ABSTRACT: The planning and operation of ventilation network systems for uranium mines require special considerations since ventilation is the primary technique of controlling ambient concentrations of radon progeny. The major environmental challenge facing the ventilation engineer is the requirement to dilute radon progeny to below the Working Level Month per year of worker exposure required by law. The application of large airflow volumes and the utilization of low residence times constitute some of the factors considered by the design engineer. Good mine planning and sequencing are also critical for protecting the health of miners. The mine ventilation must have such characteristics as flexibility, high air distribution efficiency, rapid air transit times, zero recirculation and no short-circuiting. A well established maintenance program for all ventilation appliances must be in place to guarantee control of the distribution system. Real-time monitoring systems permit assurance the adequate quality of air is delivered to working places. A case study for an operating mine is used to demonstrate how the ventilation system is successfully managed and operated using the above concepts.

1 Introduction

The ventilation of uranium mines is notably more complex due to the need to protect the workforce from radioactive occupational exposure. A number of strategies are employed by the ventilation engineer to effectively control exposure to radon progeny and other environmental hazards. Typically, the ventilation system is based on single pass ventilation and negative pressures are normally used. The primary goal is to exercise proper control and containment of radon sources. By employing proper management strategies, sound operating procedures and ventilation practices, and a detailed instrumentation program, occupational exposures can be kept to a minimum.

The radiation in underground uranium mines and methods of ventilation and exposure control have been well described by numerous authors (Bossard, 1983; McPherson, 1993; Smith, 2002), and are summarized below.

An understanding of the behavior of radon gas and progeny is imperative to eliminate the potential for occupational exposures to radon sources. The radiation in underground mines results primarily from the presence of radon, a gaseous decay product of the uranium series. On entering the mine atmosphere, radon continues to decay to form airborne radon progeny, positively charged atomic sized particles which tend to attach to respirable dust and to other free surfaces in the mine atmosphere. Fresh air volume flow rates through a mine, the distribution of airflow within the mine, and the radon emanation rate are the primary factors affecting the radon and progeny concentrations and working levels in ventilated areas. The total air volume flow rate through the mine determines the average time air takes to travel from the inlet to the production areas and to the outlet of the mine. During this residence time, radon progeny accumulate. The main method of controlling radon and progeny concentrations in underground mines is ventilation. It is essential to maintain a low radon concentration through dilution with fresh air and to allow the radon a short residence time (10-15 minutes) so that only 10-20% of the progeny are produced in the mine atmosphere.

<u>Protecting Worker Exposure</u> - The major challenge to the ventilation engineer is the requirement to dilute radon progeny to four working level months per year of worker exposure; this is the annual radon progeny limit for nuclear energy workers. Occupational exposure to radon progeny needs to be controlled so that no person will receive an exposure of more than two WLM in any consecutive three month period and no more than four WLM in any twelve month period. In high grade underground mines the above limits can be easily exceeded if effective management of ventilation and operating practices are not carefully exercised. Cameco has set its exposure limit for radon progeny to1 WL and normal targets are to maintain radon progeny levels below 0.10 WL in active working areas. The radon gas exposure limit is set to 60,000 Bq/s, and radiation work permits are required to work at any level above 3,000 Bq/s (Cameco Corporation Rabbit Lake Operations, 2007). By employing a work force management program, the cumulative radiation exposure of miners can be effectively controlled. A tracking system is normally used to determine the cumulative radiation exposure of each worker.

<u>Air Transit Time</u> - Air transit time is the period of time that radon gas resides in a producing mining area and contributes to the accumulation of radon progeny. If the radon which emanates into the mine atmosphere can be

removed through rapid air change, then radon gas entering the mine air will have insufficient time to build up appreciable quantities of its progeny products. Ventilation engineers normally try to limit radon residence times to 10-15 minutes, to limit to 10-20 percent of the theoretical yield of progeny products in the mine atmosphere. When the average residence time of radon in mine air is 20 minutes, 30 percent of the equilibrium decay product working levels will be developed underground.

Ventilation Planning - Engineering design of the ventilation system is based on the total mine operation; on ventilation-air-transit time; on the radon emissions from wallrock, broken ore, material handling, tailings backfill and groundwater. Effective mine production/ventilation planning can reduce the radon progeny control problem by providing an organized system of mine openings of adequate dimensions that maximizes the air distribution efficiency and minimizes the residence time. Proper planned relationship of the mining sequence to ventilation patterns are exercised so that most radon contamination resulting from mining is exhausted downwind from other active areas. Series ventilation systems, where air from upstream operations is used to ventilate downstream operations, is normally avoided. A parallel ventilation system is preferable because it reduces the hazards of cumulative air contamination. Contaminated air is never allowed to recirculate. Leakage of contaminated air into the fresh air stream is controlled through properly sealed doors and stoppings.

The Ventilation of Headings - Proper ventilation of headings in uranium mines is critical to control the cumulative radiation exposure of miners. Auxiliary ventilation must be used to ventilate development headings and dead-end stopes; an air change every three to four minutes should ideally be planned for working headings.

2 Ventilation Design Factors

Important factors to be considered when designing and managing a ventilation system include (Bossard, 1983; McPherson, 1993):

- the ventilation system should be designed for flexibility to permit adaptation to changing mining conditions.
- the design must consider mining and equipment systems, ventilation air-transit time, and total radon emissions from all sources.
- ideally, a retreat system should be used with a minimum possible number of working faces ventilated in series.
- mining areas should be separated into different ventilation blocks, affording better control capabilities. Ideally one should utilize a split system of ventilation in which relatively uncontaminated intake air is proportioned between working blocks according to individual requirements. Air from each section is collected in an isolated, return airway and exhausted to the surface without contaminating other active mining areas.
- broken ore should be removed as soon as possible after blasting to eliminate radon progeny formation. The ore handling system should be isolated from the fresh air intake system as much as possible.
- all sources of radon contamination must be adequately sealed or isolated.
- primary airways serving as fresh air inlets should not intersect uranium orebodies and should be driven through waste rock. Mined-out areas should be kept on the return side of the ventilation system.
- maintaining an appropriate pressure profile in the mine is important. Employing a push-pull system, a positive pressure can be maintained in the working area, preventing air recirculation from worked-out areas which are maintained at a lower pressure.
- pressure differentials across sealed old workings should be in a direction such that any leakage will pass into return airways and not into intakes.
- because of the appreciable solubility of radon in water, entering groundwater should be isolated, collected in pipelines and pumped to surface as quickly as possible.
- main airways should be kept as free from mining activity as is practicable, so that relatively high air velocities can be readily maintained.
- ore passes, conveyor ways and crushing stations should be ventilated so that exhaust air can be directed to the return air system quickly.
- shops and repair garages should be positively ventilated by controlled air volume flow rate.
- the number of personnel required to work or travel in return airways should be kept to a minimum.

3 Ventilation Planning at Rabbit Lake Operations

Rabbit Lake mine is the second largest uranium milling operation in the western world. Rabbit Lake is the longest producing uranium operation in Saskatchewan, with an annual capacity of 12 million lbs U_3O_8. Open pit mining activities at Rabbit Lake pit started in 1975 and underground mining started in 1994. The Rabbit Lake mill is the longest running uranium milling operation in Canada. Deposits include mined-out original Rabbit Lake open pit, Collins Bay A-, B- and D-zones as well as Eagle Point underground mine. Eagle Point has reserves of approximately 19 million pounds of U_3O_8 at an average grade of 1.18%U_3O_8; total production for 2006 was 5.1 million pounds.

The mining method used is vertical longhole blast-hole stoping with delayed backfill. Longitudinal retreat is typically applied where ore width is below 12 metres and transverse stoping is applied for wider orebodies. Broken ore is removed with remote-controlled scoop trams, operated from distances of 15 to 30 metres.

The ore grade is relatively low compared with other Cameco operations (McArthur River, 20.55% and Cigar Lake, 20.7%), yet there is risk for occupational exposure to radon and radon progeny concentrations. Ventilation constitutes the primary means of eliminating the potential for occupational exposures to radon and radon progeny. Real-time instrumentation monitoring and operating procedures that prevent the release of radon-bearing water into the mine environment are also important exercise practices of the mine ventilation management program.

3.1 The Rabbit Lake Ventilation System

The mine is ventilated by 5 surface fan installations: three intake fan systems (FAR #1, FAR #2 and FAR #3) and two exhaust fan systems (EAR #1 and EAR #2). The fresh air fans are 2.13m diameter fans and the exhaust fans are 2.74m in diameter. The total fresh air supplied to the underground is 566 m^3/s, with about 472 m^3/s exhausting through the exhaust fans, and the remaining 94 m^3/s exhausting up the portal. The overall system offers the capacity to satisfy current and future minewide flow requirements. Figure 1 presents a schematic of the mine ventilation system.

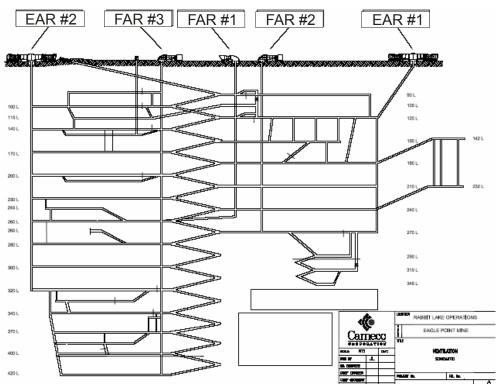

Figure 1. Ventilation system schematic.

FAR #1 is designed to supply air to the upper levels of the mine on the north side, at a volume flow rate approximating 160 m^3/s. From surface to 180 level the raise is a 3.05m x 3.66m Alimak raise with a steel ladder escape way system and below 180 level it is a 4.3m diameter raisebore. FAR #2 is designed to supply air to the lower levels of the mine on the north side, at a volume flow rate approximating 184 m^3/s. From surface to 180 level the raise is a 3.05m x 3.66m Alimak raise and below 180 level is a 4.3m diameter raisebore with a steel ladder escape way system. FAR #3 is used to provide all the ventilation for the south side of the mine. It supplies about 193 m^3/s to the mine. The raise is part Alimak (4m square) and part raisebore (2.4 - 4.3m diameter).

EAR #1 is an Alimak raise used to exhaust air on the north side of the mine, designed to handle about 140 to 158 m^3/s. EAR #2 is used to exhaust air on the south side of the mine, designed to handle about 281 to 307 m^3/s. It runs from surface to 420 level on the south side of the mine. The raise is part Alimak (4.3m square) and part raisebore (4.3m diameter). The main ramp runs from surface to 420 level and is designed to exhaust between 44 to 88 m^3/s on surface.

The airflow requirements are based on diesel engine requirements, which is sufficient for radon removal since single pass ventilation is practised in all ore headings and an effective ventilation management program is practised to keep occupational exposures to a minimum. In cases when some radon progeny is released into the mine atmosphere the primary action is to quickly remove it or dilute to acceptable levels.

3.2 Ventilation Management and Operating Practices

Planned management and operation of the ventilation system is vital to ensure the system meets all regulatory and safety requirements. Management plans are carried out on a regular basis to meet the objectives of its management program. Operating practices at the mine generally consist of three levels of safety: ventilation, containment, and instrumentation. Single-pass ventilation is practised to allow the radon a short residence time so that only minimum concentrations of progeny are produced in the mine atmosphere.

Ventilation surveys and safety inspections are used to verify if the ventilation system is in compliance and if it meets all defined objectives of the program. Any deficiencies found during an inspection are acted upon promptly. Ventilation directives are issued for all changes in the ventilation of underground workings and verification programs are used to ensure that conditions are adequate and as expected.

The release of radon and its progeny in the mine atmosphere can be quite unpredictable depending on the hydrogeological complexity of the ore body. The most effective way of minimizing atmospheric radiation contamination and human exposure is to control radon emanation at the source.

3.3 Daily Operating Inspections

Daily inspections are performed to check the following:
- proper direction of airflow travel.
- proper functioning of booster and auxiliary fans.
- proper setting and condition of regulation devices.
- good condition of ventilation ducting.
- radiation monitoring equipment in active work areas are in good operational condition.
- radon and gamma levels are checked, ensuring that the Radiation Code of Practice is being followed.
- primary refuge stations and communication centres are in good order.
- safe working practices, including the Five Point Safety System, are being followed.
- travel ways are in good condition.
- ground conditions are safe in active work headings.
- mining equipment is in good operational condition.
- the required flow volume is provided for each operating diesel equipment.
- pumps and pipelines are in proper operating conditions.
- raisebores have appropriate secondary ventilation installed.

3.4 Ventilation Surveys and Gas Monitoring

Minewide ventilation surveys are conducted on a weekly basis to record changes to the ventilation system, including the movement of fans and airflow distribution, and to verify if the system meets design and regulatory requirements. When minimum airflow volumes at any specific area of the mine are not achieved, procedures are followed to restore the ventilation to design conditions before access to the area and planned work can start.

Atmospheric gas surveys are used to determine and record the quality of the underground air and to ensure the air quality meets regulatory requirements. Monitoring is performed with hand held monitors. Air quality is measured throughout the ventilation circuit including all production faces, active diamond drill bays, active development headings, and all other active areas. Oxygen and airborne contaminants, including carbon monoxide, carbon dioxide and nitrogen dioxide, are measured as part of the monitoring program.

3.5 Continuous Working Level Monitors

Alpha nuclear prisms are located at all strategic points underground to provide continuous monitoring of radon progeny. A distributive control system is utilized to allow personnel to view the information remotely and in real-time. The monitors are represented by a set of prisms resembling a traffic light. Five combinations are used, as described in Table 1. In most areas the prism updates its output every ten minutes but in areas of high radiation potential the prism is updated every minute. Grab samples are taken daily or weekly, depending on risk, in all areas of the mine to confirm the proper functioning of the prisms and whenever investigative and corrective action is necessary.

Table 1. Working level ranges for alpha nuclear prism lights (Smith, 2002).

Prism Light	WL Range
Green	≤0.10
Green & Amber	0.11 to 0.25
Amber	0.25 to 0.50
Amber & Red	0.51 to 1.00
Red or Red with white strobe	>1.0

3.6 Fan Run Indication

The continuous operation of the main fans is critical in order to satisfy diesel requirements and keep radon progeny at safe levels. The main fans are equipped with an alarm system that gives a continuous alarm indicating a fan failure. If a fan failure is detected evacuation of underground personnel in the affected work headings is followed and a mine electrician is dispatched to restart the fan. All mine air heating systems are equipped with a CO detecting device that is wired into the main control room. The alarm levels are set so that if there is a malfunction with the system, immediate warning is given to affected personnel. Any deficiencies to the system are repaired immediately. All booster fans are regularly inspected for any conditions adversely affecting fan performance.

3.7 The Ventilation of Headings

Development headings are higher risk areas and require more detailed control. Auxiliary ventilation constitutes the primary means of ventilating all headings at the mine. Auxiliary ventilation is required for any workplace located more than 12 meters from a ventilation circuit. Auxiliary fans are situated so as to minimize re-circulation. Ducting is maintained at a distance no more than 30 duct diameters from the face.

3.8 Operating Practices for Ore Development and Production

A number of engineering measures are used to help control radiation exposures in all active mining areas:

- Air from all ore development and production work areas is not reused to ventilate other active work areas.
- Shotcrete is used to reduce gamma radiation from exposed ore on the back or walls. The goal is to keep gamma levels to about 10μSv/h on completion of the drift development and preparation.
- A shotcrete jumbo is used to remotely apply shotcrete to help reduce gamma radiation exposures to the miners applying the shotcrete.
- Stope mucking of ore is done remotely and cut out bays are established and shielded to reduce exposure.
- All drift sills in ore are covered with clean rock with a nominal thickness of 30cm when required for gamma shielding.
- During the stope production operation a flow-through ventilation system is used to keep workers in fresh air.
- During the development cycle a push ventilation system is used to deliver fresh air to the face.
- Ore passes are maintained under negative ventilation to prevent radon and dust from escaping these locations and contaminating fresh air in the work areas.
- Auxiliary shielding is installed on some mining equipment to help shield miners from gamma radiation from the back, walls or sill.
- Groundwater is prevented from entering the mine workings by applying grout covers ahead of development.
- Proper mine drainage is maintained to avoid creating stagnant pools of water that may contain harmful levels of radon gas and progeny that are released when disturbed.
- Sumps are ventilated by secondary exhaust ventilation systems.
- All unventilated areas in the mine are barricaded and signs posted, stating the nature of the hazard, to prohibit inadvertent entry by unauthorized personnel.

4 Conclusions

Eagle Point has established an effective management program and detailed operating practices which have ensured the health and safety of all mine employees. Some of the key practices used to keep occupational exposures to a minimum are the proper monitoring of the ventilation system, the effective containment of all radon sources, and the prompt response to upset conditions. The mine has been proactive in adopting very restrict exposure limits; the exposures experienced at the mine are well below the annual limit and indicate that the management programs and radiation protection practices in place are exceptionally efficient.

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