Reconciliation of Mine Production Planning and Ventilation in an Underground Mine

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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 application of large airflow volumes and the utilization of low residence times constitute some of the factors considered by the design engineer. The mine ventilation must have such characteristics as flexibility, high air distribution efficiency, rapid air transit times, zero recirculation and no short-circuiting. Good mine planning and sequencing are critical for meeting all production requirements. As part of the planning program, the ventilation network must be carefully managed to meet production requirements for all areas of the mine while reducing energy costs and protecting the health of miners. A case study for an operating mine is presented to demonstrate how production plans can be met by optimizing the ventilation system to achieve a proper flow distribution throughout the network and to meet the flow requirements of each individual mining block. System optimization is the most important component of the reconciliation program of mine production planning and ventilation since it constitutes the primary means of reducing energy costs.

Keywords: mine ventilation; production planning; uranium mining; health and safety

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 behaviour 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.

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.

Air transit time, the period of time that radon gas resides in a producing mining area and contributes to the accumulation of radon progeny, is limited by the ventilation engineer. 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 is critical to control the cumulative radiation exposure of miners. 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.

Proper ventilation of headings in uranium mines is also critical to control exposure. 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. Cameco's 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 milling 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 17.5 million pounds of U_3O_8 at an average grade of 0.98%U_3O_8; total production for 2008 was 3.6 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. 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). An additional fresh air raise system (FAR #5) operates with an underground fan installation. The fresh air surface fans are 2.13m diameter fans and the surface 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. Figure 1 presents a schematic of the mine ventilation system.

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). FAR #5 is 2 m in size, it extendes to the 140 level and is designed to supply flow in order to balance the mine fresh air and exhaust.

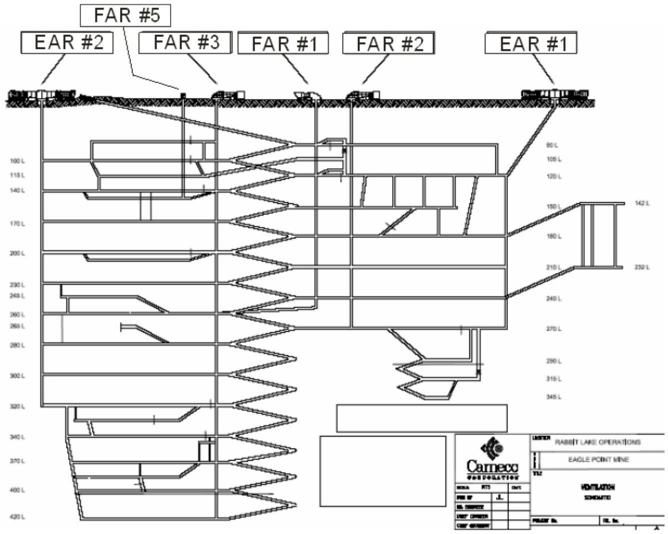

Figure 1. Rabbit Lake ventilation system schematic

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.

4. Reconciliation of Production Planning and Ventilation

With projected increases in production for future years, with a number of new development headings and production levels to be established in the North and South sections of the mine, Eagle Point Mine must frequently assess if the ventilation system would have the capacity to adequately meet flow requirements for each planned mining block. Three approaches are used to verify if the current mine ventilation system has the volume flow capacity to satisfy requirements for each planned production year: - requirements estimated based on planned annual activities versus overall supply; - requirements estimated based on planned monthly activities versus overall supply; - overall requirements versus planned supply based on simulated ventilation management programs.

A reconciliation study of mine production planning and ventilation, performed to verify the capacity of the mine ventilation system for three consecutive years, is presented in this section.

4.1. Minewide airflow supply versus airflow requirements

The estimation of airflow volume requirements for the production stopes and development headings is made based on the diesel fleet utilized for each operation. Eagle Point Mine considers airflow requirements of 37.8 m^3/s per production stope and 18.9 m^3/s for each development heading.

Figure 2 presents a general inventory of the mine ventilation system with required airflow volumes for each mining block for years 1 through 3. The estimation of total flow requirements includes requirements for sump and storage areas, and leakage. In general, the current mine ventilation system has the overall volume flow capacity to satisfy current and future requirements. Detailed assessment has however to be done to verify if the overall flow supply can be properly distributed throughout the network to meet the requirements of each individual mining block.

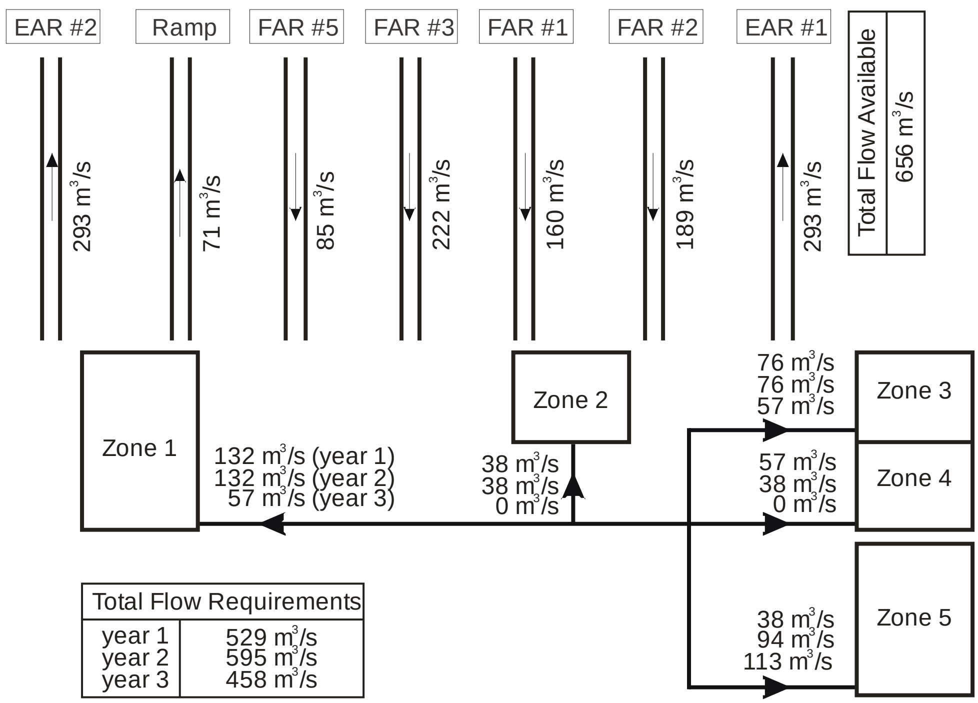

Figure 2. General ventilation schematic with required and available airflows

4.2. Mine production planning for years 1 – 3

In order to verify if the current mine ventilation system has the volume flow capacity to satisfy requirements for the years of 1 through 3 and can meet the requirements of each individual mining block, a detailed breakdown of planned development and production activities on an annual and monthly basis had to be first established. Table 1 presents planned activities for the three years being investigated. The allocation of activities was based on development and production plans and schedules developed by the planning department.

Mining Block	Year	Development	Production
1	1	8 levels	7 stopes
	2	1 level	24 stopes
	3	no development	2 stopes
2	1	2 levels	6 stopes
	2	no development	5 stopes
	3	no development	mined-out
3	1	2 levels	5 stopes
	2	2 levels	5 stopes
	3	1 level	4 stopes
4	1	3 levels	8 stopes
	2	no development	1 stope
	3	no development	mined-out
5	1	1 level	no production
	2	5 levels	no production
	3	7 levels	1 stope

Table 1. Mining activity timeline

4.3. Ventilation requirements based on annual activities

Planned development and production activities are evaluated for each mining block. Based on scheduled activities, the total flow requirements were estimated as shown in Table 2. For year 1, the required flow by 12%, for year 2, the required flow is lower than the available by 12%, and for year 3, the required flow is lower than the available by 44%. It is noted that, even though an excess flow exists for all years, the distribution of flow to individual mining blocks may not be attainable due to limitations in airway capacity and access.

Year		Development	Production	Leakage	Sump/Storage	Total
1	activity	10 - 12 levels	2 - 3 stopes at a time			
	flow requirements	227 m^3/s	113 m^3/s	68 m^3/s	99 m^3/s	507 m^3/s
2	activity	11 - 12 levels	3 - 4 stopes at a time			
	flow requirements	189 m^3/s	151 m^3/s	68 m^3/s	99 m^3/s	507 m^3/s
3	activity	9 levels	2 stopes at a time			
	flow requirements	170 m^3/s	76 m^3/s	68 m^3/s	99 m^3/s	394 m^3/s

Table 2. Yearly development and production flow requirements

4.4. Airflow supply distribution based on simulated ventilation conditions

Ventilation simulation studies are performed, using computer network models, to verify if the estimated flow requirements for each individual mining zone and levels can be met. An example of such analysis is presented in Table 4. Such simulations represent system management requirements to be applied on a shift-to-shift basis, such that air flows are properly controlled and distributed to all development and production areas of the mine.

	Planned Activities Within Zone	Flow Available	Flow Required
Zone 1 - 5 levels developed and 1 stope mined concurrently			
Development	level A level B level C level D level E	22 m^3/s 31 m^3/s 17 m^3/s 15 m^3/s 15 m^3/s	19 m^3/s 19 m^3/s 19 m^3/s 19 m^3/s 19 m^3/s
Total Development Flow		100 m^3/s	95 m^3/s
Production	1 stope between levels F and G to be mined	34 m^3/s	38 m^3/s
Total Flow Available / Required for Zone 1		134 m^3/s	133 m^3/s
Zone 2 - 2 levels developed concurrently; no stopes mined			
Development	level H level I	35 m^3/s 39 m^3/s	19 m^3/s 19 m^3/s
Total Flow Available / Required for Zone 2		74 m^3/s	38 m^3/s
Zone 3 - 2 levels developed and 1 stope mined concurrently			
Development	level J level K	24 m^3/s 26 m^3/s	19 m^3/s 19 m^3/s
Total Development Flow		50 m^3/s	38 m^3/s
Production	1 stope between levels K and L to be mined	46 m^3/s	38 m^3/s
Total Flow Available / Required for Zone 3		96 m^3/s	76 m^3/s
Zone 4 - 2 levels developed and 1 stope mined concurrently			
Development	level M level N	38 m^3/s	19 m^3/s 19 m^3/s
Total Development Flow		38 m^3/s	38 m^3/s
Production	1 stope between levels M and N to be mined	38 m^3/s	38 m^3/s
Total Flow Available / Required for Zone 4		76 m^3/s	76 m^3/s
Zone 5 - 1 level developed at a time; no stopes mined			
Development	level O	39 m^3/s	38 m^3/s
Total Development Flow Available / Required for all Zones		302 m^3/s	245 m^3/s
Total Production Flow Available / Required for all Zones		118 m^3/s	113 m^3/s
Total Flow Available / Required for all Zones		420 m^3/s	359 m^3/s
Overall Flow Available / Required for all Zones		**603 m^3/s**	**529 m^3/s**

Table 4. Available versus required flows for year 1

4.5. Managing the ventilation network to achieve future required flow distribution

The annual assessment of the mine ventilation system, presented in the previous sections, has indicated that the network offers the capacity to meet flow requirements based on the projected production schedule; but that a management program would need to be applied on a regular basis to attain and maintain the proper flow distribution to individual mining zones.

For years 1 and 2, minimum modifications to the current ventilation system would be required (regulation) in order to achieve the required flow distribution to ventilate each individual mining zone. For year 3, although overall flow volumes exceed requirements, it has been found to be impractical to transfer large quantities of air from the South section to the North section of the mine, where major mining activity is projected. Strategies for year 3 have been established. It consisted of establishing appropriate airway drift sizes (6 x 6 m) to transfer fresh air to Zone 5, and the development of an additional exhaust raise (EAR #5) extending from Zone 5 to the surface.

5. Conclusions

Eagle Point has established an effective management program and detailed operating practices which have ensured the health and safety of all mine employees. A ventilation management program is carefully maintained by the ventilation department to operate in conjunction with production activities, in order to achieve a proper flow distribution throughout the network and to meet the flow requirements of each individual mining block. System optimization studies are regularly performed as part of reconciliation programs of mine production planning and ventilation, with the primary goal of reducing energy costs.

6. References

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