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ABSTRACT

The U.S. Department of the Interior, Bureau of Mines, has developed a data acquisition system to continuously monitor radon, working level, absolute pressure, temperature, relative humidity, and air velocity. Data have been taken in intake and exhaust drifts, working stopes, and sealed-off areas of positive and negative ventilated uranium mines.

Radon emanation rates, ranging from 1.7- to 12.2 x 10⁻¹⁴ Ci/cm²/sec were determined in four mines. The ratios of short duration, primary fan shutdown time to radon normalization time were 1 to 2 and 1 to 4, respectively, for negatively and positively ventilated mines. Blasting and slushing caused radon increases of 160 and 67 percent, respectively.

INTRODUCTION

The U.S. Bureau of Mines radiation research includes dosimetry, control measures, and monitoring. Most is directed toward uranium mining.

The most common radon control method is diluting and flushing with fresh air. Most mines use exhausting ventilation. Whether exhausting or blowing is better depends upon the mine. Indications are that blowing ventilation in shallow mines (<200-foot overburden) with highly-fractured rock can reduce the radon concentration by 20 percent or more (1,2) compared to exhausting ventilation.

Sealing off worked-out areas with radon-tight bulkheads is extremely difficult to accomplish, particularly with highly-fractured porous sandstone. The leakage out of the sealed-off area can be stopped by installing a 3- to 6-inch bleeder pipe (1,12) to create a small negative pressure behind the bulkhead and drain radon to an exhaust drift. Another control method is backfilling worked-out areas with mill tailings (13).

Workshops, lunchrooms, and high emanation areas in intake airways can be controlled with sealants (4,6,7, 10). Approximately 100 different sealant materials were laboratory tested with only six being field tested. Up to 75 percent reduction in radon flux was observed in the small-scale field tests.

Bates (3) reports on theoretical models examining radon flux relative to positive and negative pressurization, pinholes in sealants, and cycling pressurization. These models have been used as guidelines to some of the experimental projects conducted by the Bureau.

This paper primarily discusses work in radon control techniques; including sealing the rock, bulkheading and backfilling worked-out areas; and exhausting versus blowing ventilation systems.

INSTRUMENTATION

Initially, all field radon measurements were taken in batch samples using scintillation flasks. Because of extreme changes in the radon concentration from one day to the next, it was difficult to evaluate the results. Therefore, a continuous monitoring and recording system was developed so that the radon changes could be observed and recorded (8) along with absolute pressure, temperature, relative humidity, and air velocity (21).

The radon monitor is constructed for mine use. The scintillation flask, filters, photomultiplier tube, discriminator circuit, and pulse shaping and driving circuits are housed in an aluminum box. The monitor calibrations are traceable to standard radium chloride solutions.

A beta continuous working-level monitor developed by Drouillard (5) has also been incorporated into the continuous monitoring system. The control for sampling duration, frequency of sampling, Julian date, and time comes from the data acquisition system (DAS). The data from monitors and sensors are recorded on paper tape and perforated paper tape. Generally, a 10-channel system is configured to have five radon monitors and one each for working level, absolute pressure, temperature, air velocity, and relative humidity.

A radon detector and data acquisition unit are shown in figure 1. For safekeeping and ease of servicing, the DAS is usually placed on the surface, and multiplexers connected to the monitors underground.

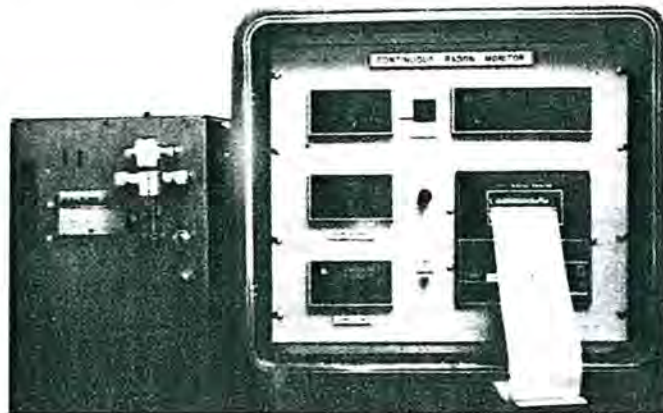


FIGURE 1. Radon detector and data acquisition system (DAS).

The perforated paper tape allows us to feed the data directly into a computer for conversion and plotting. A van-mounted mini-computer, located at the mine site, is used for daily analysis and plotting.

All Bureau data discussed in this paper were taken using the DAS.

VENTILATION

The actual radon and radon daughter concentrations in the mine atmosphere are affected by many things: ventilation pressure, barometric pressure, ventilation quantity (fan shutdowns or losses through bulkheads), mining activity, and ventilation quality (temperature and residence time). Problems in controlling the radon and radon daughter in uranium mines have been the subject of many papers. Rock (17) discusses mine planning to facilitate radon control and the problems associated in preplanning ventilation for uranium mines. Schroeder (18,19) discusses uranium mine ventilation with particular emphasis on positive pressure with radon sinks.

Exhausting Versus Blowing

The U.S. Bureau of Mines has conducted two tests comparing exhausting to blowing ventilation. In the first test, pressure control bulkheads were constructed in the two portals of a small inactive mine. To maintain the same airflow direction during the exhausting and blowing periods, the fan was installed first in the exhaust portal and then in the intake portal. Ten radon detectors, two working level monitors, three absolute pressure transducers, two each temperature and air-velocity indicators, and one relative humidity indicator were placed to continuously monitor the airflow throughout the mine.

Figure 2 shows the radon concentration for total intake and exhaust air during the last portion of the exhausting period. Starting on Julian day 230, the exhaust fan was shut down and moved to the intake portal bulkhead.

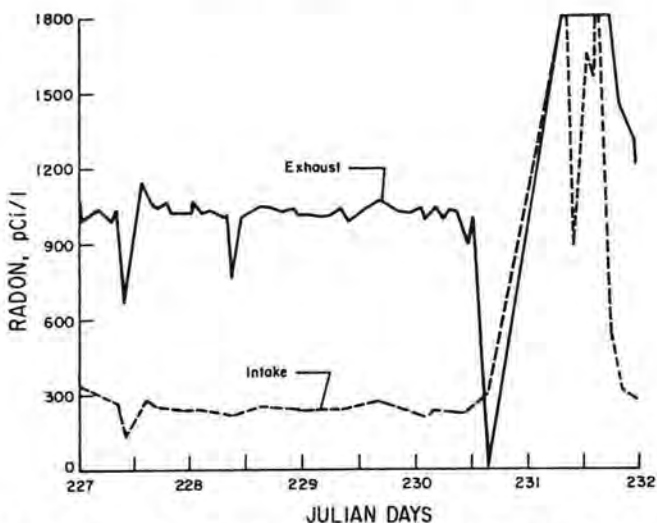


FIGURE 2. Radon concentration with exhausting ventilation, -2.1-inch water-gage pressure.

Figure 3 shows the same detectors during the blow-

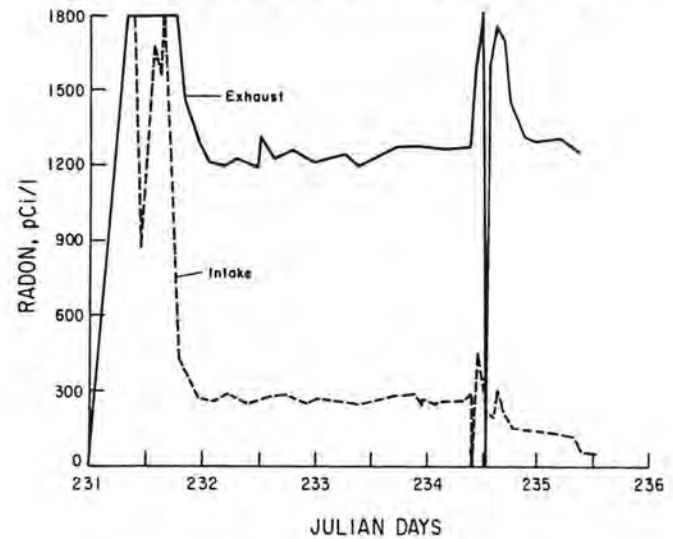


FIGURE 3. Radon concentration with blowing ventilation, 1.6-inch water-gage pressure.

ing period, prior to terminating the experiment. The increase seen on day 234 resulted from a cavein that changed airflow patterns in the back part of the mine. Average daily radon production for each period, prior to the caveins, shows a 20 percent reduction, blowing versus exhausting (table 1).

TABLE 1. Daily radon production, exhausting versus blowing ventilation

	Pressure, inches water-gage	kN/m^2	Rn production, curies/day
Exhausting	-2.1	-0.52	0.24
Blowing	1.6	0.42	0.19
Difference	3.7	0.94	0.05

The second test was conducted in a mine using a push-pull ventilation system with an overall positive pressure. The area under investigation was ventilated by two downcast fans and one upcast fan. During a 3-day shutdown of the mine, the two downcast fans were shut off, changing the test area from a positive to a negative pressure. Radon mass flows for two radon stations are given in table 2.

Days 246 through 248 are the negative pressure period, while days 251 and 252 represent a positive pressure period with a steady barometer. The radon mass flows at stations 3 and 4 were 25 and 21 percent higher, respectively, during the negative period.

Immediately downstream of station 3, the air split into two passages with 18 percent going through an unmonitored drift and 82 percent going through the test area. After correcting the radon mass flows for this air split and dividing by the surface area, the increase from station 3 to 4 gives the radon emanation. The average emanation for 3 days of negative ventilation is 6.0×10^{-14} Ci/cm²/sec, while for the positive ventilation period it is 5.0×10^{-14} Ci/cm²/sec. The increase in emanation caused by negative pressure was

TABLE 2. Radon mass flows for two monitoring stations during positive and negative pressure ventilation

Day	Station 3, Ci/min $\times 10^{-4}$	Station 4, Ci/min $\times 10^{-4}$	Pressure mm Hg	Air volume, m^3/min
246	7.6 ± 0.1	7.5 ± 0.1	570.9 ± 0.2	$1,171 \pm 4.0$
247	8.2 ± 0.2	8.1 ± 0.2	570.3 ± 0.4	$1,164 \pm 4.0$
248	8.9 ± 0.2	8.2 ± 0.2	569.3 ± 0.2	$1,236 \pm 10.0$
251	5.7 ± 0.1	5.8 ± 0.1	568.3 ± 0.2	$1,424 \pm 4.0$
252	5.7 ± 0.1	5.8 ± 0.1	569.3 ± 0.1	$1,402 \pm 8.0$

¹Standard deviation of the mean.

20 percent. The average pressure change (caused by changing ventilation) is 1.3 mm Hg for these two periods.

An unscheduled fan shutdown occurred during another weekend. During this weekend, the upcast fan was off 42 hours which resulted in a higher positive pressure, and the results are reported in table 3. Radon emanations calculated for the high and normal pressures were 2.1×10^{-14} and 3.8×10^{-14} Ci/cm²/sec, respectively.

Diurnal Changes

For years radon concentration changes have been noted in relation to atmospheric changes (1,14-16). Diurnal changes in radon concentrations generally follow an inverse correlation with barometric pressure; although, at times, it is possible that a direct correlation will occur due possibly to a shift in radon concentration with respect to time (16).

TABLE 3. Radon mass flows for two monitoring stations during normal and increased pressure

Day	Station 3, Ci/min $\times 10^{-4}$	Station 4, Ci/min $\times 10^{-4}$	Pressure, mm Hg	Air volume, m^3/min
Fans 1, 2, and 4 on normal mine pressure				
286	5.5 ± 0.1	5.3 ± 0.1	572.2 ± 0.2	$1,661 \pm 5.0$
287	5.4 ± 0.2	5.2 ± 0.2	574.4 ± 0.1	$1,652 \pm 5.0$
Fans 1 and 2 on fan 4 off increased pressure				
288	1.8 ± 0.02	2.0 ± 0.02	573.7 ± 0.1	237 ± 2.0

¹Standard deviation of the mean.

Radon emanation has been measured in several additional areas; table 4 shows these measurements along

TABLE 4. Emanation rate measurements

No.	Mine	Location	Ventilation system	Pressure	Days measured	Emanation Ci/cm ² /S $\times 10^{-14}$
1	A	Haulage	P-P	Slightly positive	3	5.0
2	A	..do...	..do..	Negative	2	6.0
3	A	..do...	..do..	Slightly positive	2	3.8
4	A	..do...	..do..	Positive	1	2.1
5	A	Side drift	..do..	...do...	3	1.7
6	B ₁	Haulage	..do..	...do...	12	2.8
7	C ¹	Total mine	Exhaust	Negative	9	1.9
8	D	Side drift	..do..	...do...	16	12.2
9	Utah ²	-	-	-	-	0.5
10	New Mexico ²	-	-	-	-	5.0

¹Reference 9.

²Reference 20.

with the above measurements. A single emanation number cannot be derived for all cases, since for a given case, the emanation depends on the ventilation overpressure and changes in barometric pressure. For example, data in lines 1 and 3, table 4, were from the same haulageway with about the same ventilation, but the absolute pressure (barometric plus ventilation pressure) increased from 568 to 573 mm Hg. Many other factors come into play between different mines or parts of mines: ore grade, emanation coefficient, porosity, permeability, fracturing, moisture content, etc.

Continuous monitoring data (collected for other purposes) can be used to demonstrate the inverse relationship, table 5. The data were taken in a dead-end, bulkheaded drift with a bleeder pipe to maintain a slight negative pressure behind the bulkheads. The correlation coefficient expresses the degree of interrelationship between variables. With 96 measurements each day, an absolute value of 0.25 is significant at the 99 percentile.

TABLE 5. Correlation between radon concentration and absolute pressure

Day	Correlation coefficient	Day	Correlation coefficient
1	-0.68	13	-0.74
2	-0.70	14	-0.73
3	-0.50	15	-0.80
4	-0.20	16	-0.74
5	-0.48	17	-0.67
6	-0.45	18	-0.44
7	-0.86	19	-0.85
8	-0.01	20	-0.80
9	-0.70	21	-0.47
10	-0.93	22	-0.55
11	-0.80	23	-0.54
12	+0.01		

The poor correlation for days 4 and 8 could have resulted from instrumentation "spikes," but there was no obvious reason for the low correlation on day 12. In figure 4, the radon concentration and absolute pressure are plotted for 1 day. The correlation coefficient is -0.70.

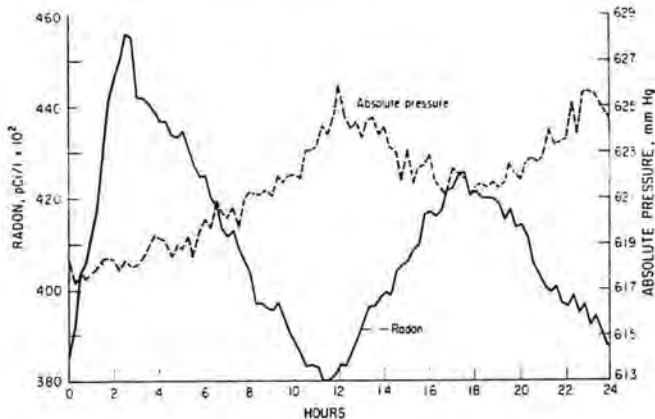


FIGURE 4. Radon concentration versus absolute pressure.

Fan Shutdown

Shutting off surface fans has a drastic effect on the radon concentration; a 1,600 percent increase in 3 hours (11) was measured in one stope. In a negative pressure mine, 16 fan shutdowns had an average duration of 2.2 hours. The average length of effect, after restarting the fan, was 4.48 hours. This means, for every hour that the fan is off, it takes 2 hours for the radon concentration to return to its original state. In one positive pressure mine studied, the factor appeared to be 1 to 4. The readings in this mine were taken only twice an hour. This means that a shutdown could show up for one reading, but might have lasted between 10 and 30 minutes. However, on the average, for a 30 minute or less shutdown, it took about 2 hours for the radon concentration to return to its original state.

For one event, the average concentration for five readings before fan shutdown, was 330 pCi/l. At the midpoint time of the fan shutdown, the average radon concentration was 860 pCi/l, and it peaked at 2,012 pCi/l.

An example of one fan shutdown in a negative pressure mine is shown in figure 5. Drawing a line

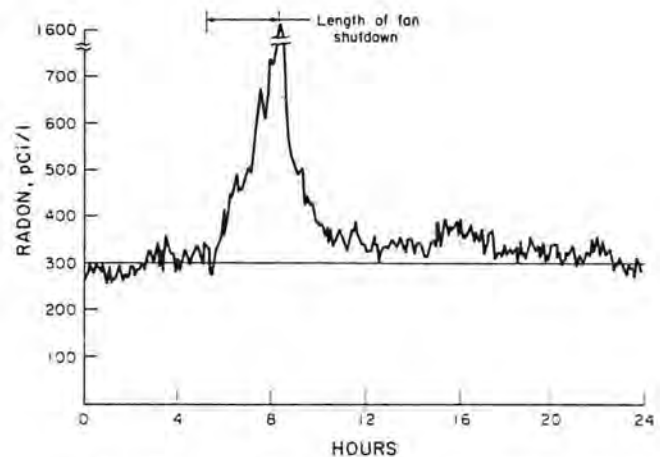


FIGURE 5. Effect of a fan shutdown on exhaust air in a negative pressure mine.

through the readings before the fan shutdown to obtain the average, shows that it took almost 16 hours for the radon to return to the previous average. The length of time of fan shutdown was determined by the change in absolute pressure.

Mining Activities

Blasting also has a large, short-term effect on radon concentration. A continuous monitoring system setup in two interconnecting stopes was used to monitor the effect of blasting and other mining activity. Generally, the peak concentration rose and dropped quickly; however, the radon contamination in the exhaust air remained considerably higher than normal for some time after the blast. Table 6 reports the radon concentrations for a radon sampling of stope blasts. As shown, the changes ranged from 17 to 160 percent for stope air, and 8 to 150 percent for the exhaust air. This range varies due to the size and proximity of the blast.

After the short-duration release of interstitial radon by blasting, the fractured rock provides a source for elevated radon emanation. Washington (22) indicates that the total surface area within a muck site is more important to radon release than the amount of material slushed. Slushing, however, does create additional surfaces and insures that most of the available radon is released to the mine atmosphere. To examine the magnitude of this increase, the radon concentrations during slushing were compared to the nearest preceding non-work period. Data for 10 days are given in table 7. The change in radon concentration ranged from 2 to 67 percent.

Frequently, in mining situations, a "clean" analysis of a single activity cannot be performed because of multiple events. Figures 6 and 7 show two interesting combinations: (a) blasting, then slushing; and (b) fan shutdown, blasting, and slushing. Note, radon and temperature increases following blasting.

Bulkheads

Bulkheading is the second most important radon control measure in uranium mines. Properly installed bulkheads can isolate inactive workings from the ventilating air and thereby, improve conditions for the

TABLE 6. Radon concentration for normal and blasting conditions

Stope air			Exhaust air		
Average pCi/l	Maximum reading pCi/l	Percentage change	Average pCi/l	Maximum reading pCi/l	Percentage change
205	293	43	298	418	40
176	336	91	275	690	150
267	323	21	270	343	27
206	387	88	277	623	125
189	440	132	276	552	100
194	399	105	278	503	81
248	644	160	308	683	122
247	608	146	323	623	93
239	321	34	380	492	30
319	424	33	424	545	28
268	314	17	443	518	17
318	531	68	412	444	8
312	432	38	451	522	16
213	340	60	376	424	13
225	396	76	463	629	36
182	318	74	378	444	17
184	222	20	364	498	37
230	318	38	362	485	34
208	293	40	338	544	61
219	304	38	340	655	93

TABLE 7. Radon concentration for normal and slushing conditions

Base average pCi/l	Average during slushing pCi/l	Percent change
225	375	67
275	300	9
275	280	2
275	300	9
275	280	2
275	290	6
325	450	40
375	400	7
230	260	13
330	370	12
420	430	3

this to 0.04 working level. Placing a 1/4-hp fan on the bleeder pipe guarantees that any leakage is inward (fig. 8, days 168 to 185). Bulkhead construction costs can be reduced by using expanded metal lath, inorganic cements, and a bleeder pipe (\$185 estimated) instead of timber and urethane foam (\$400 estimated) (12).

SEALANTS

Using sealants to prevent radon from entering the mine atmosphere would be the ideal way to control radiation hazards. However, to seal the entire mine is impractical, if not impossible. Intake airways, shops, lunchrooms, and any high-emanating areas are candidates for sealing.

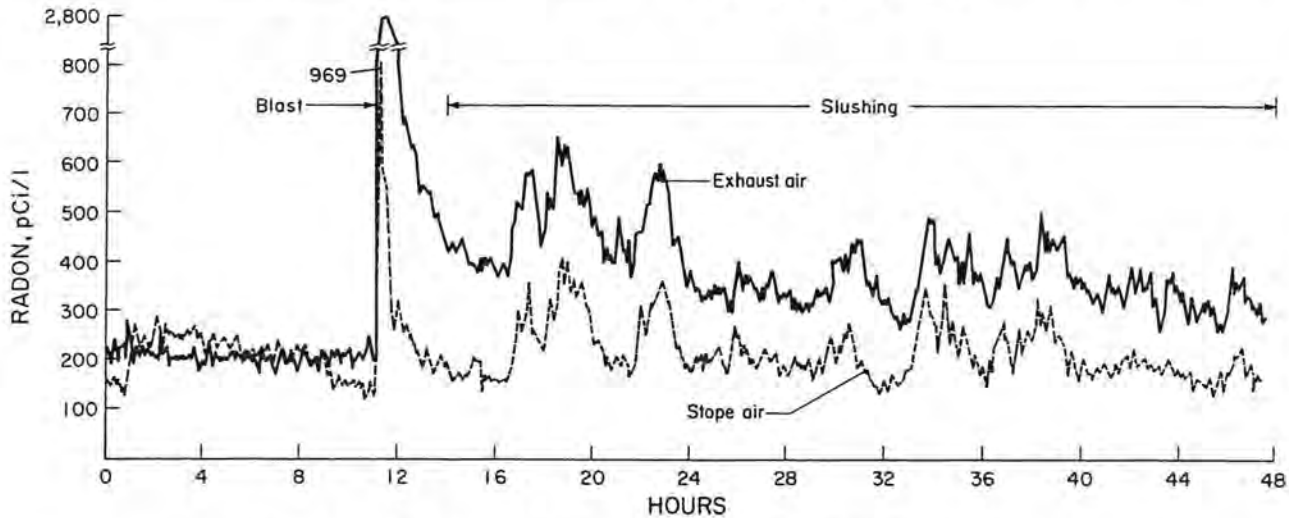


FIGURE 6. Effect of a blast and slushing on radon concentration.

miner. The effect of a leaky bulkhead is shown in figure 8. Contaminated air from behind the bulkhead (probably over 100 working levels) raised the intake airstream to an average 0.22 working level (days 154 to 156). Correcting the leaks and connecting a bleeder pipe to the exhaust airway (1,12) reduced

Laboratory studies (1,2,6,7) have shown that polymeric sealant materials are capable of stopping up to 100 percent of radon emission of uranium ore. Radon barrier properties of 86 various materials were measured in the laboratory. Those materials stopping more than 50 percent of the radon emission were evaluated

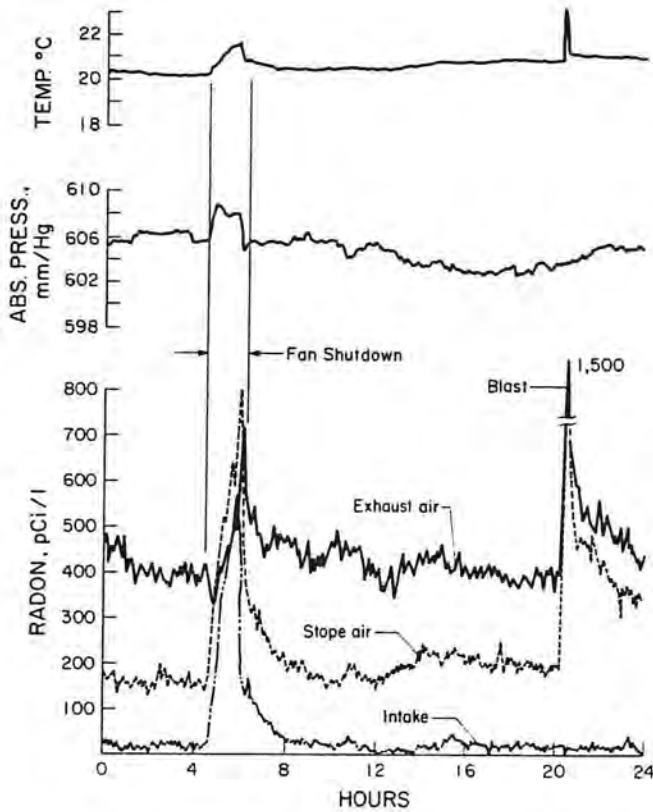


FIGURE 7. Effect of a fan shutdown and a blast, followed by slushing.

for flammability, toxicity, and other health hazards. Out of these, six materials have been field tested, with results ranging from 44 to 75 percent stoppage. Because of the very irregular mine surfaces, filler materials were needed to provide a suitable surface for the application of the polymeric materials. Costs for materials ranged from \$0.30 to \$1.19 (1975 dollars) per square foot.

CONCLUSIONS

The control of radiation hazards in uranium mines is a very difficult task for the ventilation engineer. So many conditions effect radon emanation that ventilation alone cannot be relied on for radon/radon daughter control. The ventilation engineer has to use additional techniques, such as bulkheads, sealants, and backfilling, to reduce the demands on the ventilation system.

In a shallow mine, it was found that blowing ventilation reduces radon emanation by 20 percent as opposed to exhausting.

Measured emanation rates ranged from 1.7×10^{-14} to 12.2×10^{-14} Ci/cm²/sec.

Blasting causes sharp increases in radon concentration. Even though this concentration quickly diminishes, care should be taken that miners do not return too soon.

Elevated radon concentrations have been observed during slushing operations; so extra checking of the miner's environment is advisable to insure against overexposure.

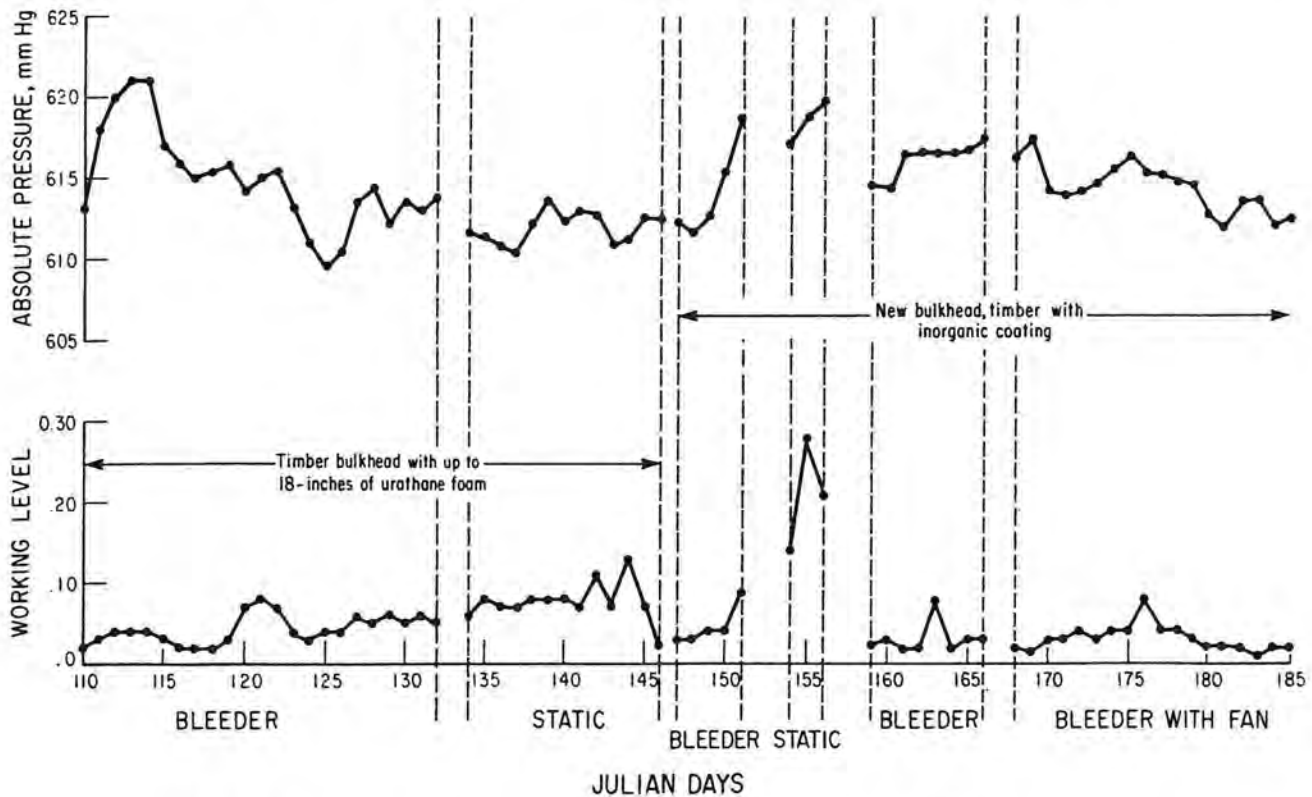


FIGURE 8. Working level and absolute pressure under various bulkheaded conditions.

Two hours of ventilating for each hour of fan shut-down should be set as a minimum.

Since the radon/radon daughter concentration can vary widely, ventilation must be given a high priority during both pre-mine planning and actual operation.

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