IC 9109

Bureau of Mines Information Circular/1986

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UNITED STATES DEPARTMENT OF THE INTERIOR

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BUREAU OF MINES
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Library of Congress Cataloging in Publication Data:

Timko, Robert J
Evaluating ventilation parameters of three coal mine gobs.

(Information circular ; 9109)

Bibliography: p. 16.

Supt. of Docs. no.: I 28.27: 9109.

1. Mine ventilation. 2. Mine gases. 3. Coal mines and mining - Safety measures. 4. Mine shafts. I. Kissell, Fred N. II. Thimons, Edward D. III. Title. IV. Series: Information circular (United States. Bureau of Mines) ; 9109.

TN295.U4 [TN301] 622 s [622'.8] 86-600132

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	in w.g.	inch, water gauge
ft^3	cubic foot	min	minute
ft^3/h	cubic foot per hour	ppb	part per billion
ft/min	foot per minute	ppm	part per million
ft^3/min	cubic foot per minute	pct	percent
h	hour	psi	pound per square inch

EVALUATING VENTILATION PARAMETERS OF THREE COAL MINE GOBS

By R. J. Timko,[1] F. N. Kissell,[2] and E. D. Thimons[3]

ABSTRACT

The Bureau of Mines used sulfur hexafluoride (SF_6) tracer gas to evaluate the effectiveness of gob ventilation and/or sealing practices at three coal mines, each having different problems associated with their mined-out areas. The purpose of these ventilation studies was to better understand whether current techniques employed for ventilation or sealing are successful at minimizing the potential for gob fires and explosions. The work performed at each mine is discussed: One is a longwall operation that uses ventilation to carry off hazardous gases, and two are room-and-pillar operations, each with far different concerns, that seal off the gobs to isolate them from the main mine ventilation. In all cases employment of the Bureau's SF_6 tracer gas technique resulted in answers to questions raised by the mine operators concerning the effectiveness of their gob ventilation or sealing practices in preventing mine fires.

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INTRODUCTION

Coal mining involves the fracturing and removal of a certain portion of the coal seam; a production goal is to remove the maximum amount of coal without compromising safety of the miners. High extraction techniques, such as longwalls, have become common. In room-and-pillar operations, retreat or second mining is frequently performed. This involves systematic removal of coal pillars that remain after the primary mining cycle, which results in controlled caving of the strata above the mined-out area, or gob.

To prevent the mixing of explosive concentrations of methane (5 to 15 pct CH_4 in air) and oxygen-rich mine air, mine operators may employ one of two techniques: (1) continue to ventilate the gob to keep the methane concentration low, or (2) seal off the section to isolate it from the main mine ventilation. The Mine Safety and Health Administration (MSHA) has regulations or specifications regarding either technique. For ventilation, MSHA requires that sufficient air be used to carry off hazardous gases (5).[4]

MSHA's specifications for gob sealing require that seals be made of substantial and incombustible materials that are strong enough to prevent explosion propagation. Because of varying pressure differentials, mineral friability, and strata convergence, seals are never completely airtight. Their purpose is to reduce the potential for combustion. On the one hand, they restrict the passage of mine air containing high quantities of oxygen into gobs that have a potential for spontaneous combustion; on the other hand, they reduce the passage of explosive gases liberated from the gob to the areas of the active mine.

If ingassing of mine air to the gob occurs, fires can be started through spontaneous combustion, which usually begins slowly but can accelerate to hazardous proportions before detection. If outgassing of gob gas into active areas occurs, explosions can happen where sufficient quantities of methane (5 to 15 pct in air) are present. Even without the presence of methane, problems can occur if blackdamp (CO_2) and/or whitedamp (CO) leak through permeable seals.

This report gives an overview of investigations at three different coal mines having very different gobs.

1. At Mine A, which employs mainly longwall extraction techniques, it was necessary to ventilate the remaining gob. Research determined the permeability as well as average air velocities through the gob.

2. At Mine B, which uses room-and-pillar extraction, the gobs were sealed. The operators had been taking gas samples from two seals in the same small gob. They were concerned because sample analyses did not agree. Research was performed to determine if continuity existed across the gob and to evaluate the performance of the seals.

3. At Mine C, which also uses the room-and-pillar method, the mined-out gobs were sealed. The particular gob studied was very large, with three separate but interconnected sections, having a total of 18 seals separating it from the active mine. The coal seam pitched downward so that the methane concentration was different behind each set of seals. These tests examined the potential interconnection of the gob entries as well as the performance of the section seals.

Sulfur hexafluoride (SF_6) was the tracer gas used in all gob evaluation work. SF_6 is a colorless, odorless, and tasteless gas having a threshold limit value-time weighted average of 1,000 ppm. This low toxicity means that workers can be repeatedly exposed to 1,000 ppm of SF_6 for a normal 8-h day and 40-h week without encountering adverse effects (1).

SF_6 is stored in small, low-pressure (300-psi), metal lecture bottles. The gas has a volume of approximately 1.5 ft^3 at atmospheric pressure. The Bureau has developed techniques for releasing and sampling SF_6, as well as for reducing the data obtained (3-4). Typically, the SF_6 is released, then sampled by puncturing air-evacuating sampling tubes, which are

[4]Underlined numbers in parentheses refer to items in the list of references at the end of this report

similar to tubes used for blood collection. These tubes are then returned to the laboratory where actual gas concentrations are determined through electron-capture gas chromatographic analysis.

MINE A

BACKGROUND

Mine A, located in southwestern Pennsylvania, was required to ventilate, rather than seal, the gobs remaining after longwall mining. The gob area comprised four longwall panels whose perimeters contained entries to properly ventilate the gob. The longwall gob being evaluated was in the second developed panel, which was 490 ft wide and 3,900 ft long. Typical seam height in this mine was 60 in.

At times, gob outgassing of methane in Mine A was a problem. Therefore, the mine had begun sinking boreholes into the longwall panels prior to mining. The topography above the mine made actual borehole placement difficult. The borehole in this gob was driven to the centerline of the gob, approximately 500 ft from the eastern bleeder entries.

The objective of this investigation was to measure gas velocities through the caved gob. This was accomplished by capping the borehole and injecting SF_6 down a tube through the borehole into the gob. Several underground sampling locations around the perimeter of the gob were set up to detect the SF_6. The total time required for the SF_6 to traverse the gob and enter the ventilation airstream could be converted to an average velocity, expressed in feet per minute.

BOREHOLE EXAMINATION

Prior to beginning the evaluation, the flame arrester and check valve were removed from the borehole. The borehole was then capped and 0.25-in-ID, semirigid tubing was lowered through the cap into the hole. The tubing served two purposes. First, it was used to release the SF_6 just above the caved gob. Second, SF_6 samples were taken from the tubing at specific intervals during the test.

Static pressure at the top of the borehole was 3.0 in w.g. The pressure difference between the top of the borehole and the bottom of the tube was measured as the tubing was lowered down the hole. Two hoses were connected to a Dwyer[5] Magnehelic pressure gauge: one from the borehole top, and another from the fixed end of the tube descending the borehole. Table 1 shows that pressure difference increased somewhat linearly from 0 in w.g. at the borehole top to 0.08 in w.g. at 500 ft.

At 570 ft, or approximately 200 ft above the coal seam, an obstruction was encountered, and the pressure differential began to climb rapidly. The tubing was then raised slightly to return the pressure differential to its original value (0.08 in w.g.).

SF_6 was then injected through the tubing. To ensure that the SF_6 would be released into the gob and not remain in the tubing, the tube was then purged with nitrogen. However, problems were encountered with the nitrogen purge, and SF_6 release was not completed until approximately 3.5 h after the release start. This was the official start time of the test. Sampling took place at 15-min intervals at nine underground bleeder entry stations at the gob perimeter, as well as at the borehole.

[5]Reference to specific manufacturers does not imply endorsement by the Bureau of Mines.

TABLE 1. - Differential pressure change with depth

Depth, ft:	Pressure differential, in w.g.	Depth, ft:	Pressure differential, in w.g.
Surface.....	[1]0.00	300.....	0.04
100.....	.04	400.....	.08
200.....	.04	500.....	.08

[1]Actual values were limited by the resolution of the instrument.

To determine initial results, samples taken during the first 3 h at the borehole bottom were analyzed immediately. Results showed that the SF_6 in the borehole was not diffusing very rapidly. Therefore, sampling frequencies were reduced to one sample every 30 min, and the test time extended.

Borehole samples were again analyzed on the following day to determine if SF_6 dispersion was increasing. After 27 h of sampling, SF_6 concentrations at the borehole bottom had been reduced from approximately 20,000 ppb to just above 100 ppb. Sampling continued, but at a reduced frequency of one sample per hour, for 1 week (168 h).

Figure 1 is a ventilation schematic of the gob being evaluated, showing bleeder entry sampling stations *1-9* and the borehole. Position *A* denotes the shortest two-dimensional path from the borehole to a bleeder entry. Also shown are approximate two-dimensional distances from the borehole to each sampling station.

Stations were divided into three groups: (a) no SF_6 detected (b) detection within 3 h, and (c) detection between 40 and 57 h. Only station *1* detected no SF_6, probably because the borehole was between it and the fan. Stations *2-6* detected SF_6 within 3 h after gas release. Stations *7-9* first detected SF_6 between 40 and 57 h after the test began. Sampling was halted after 144 h.

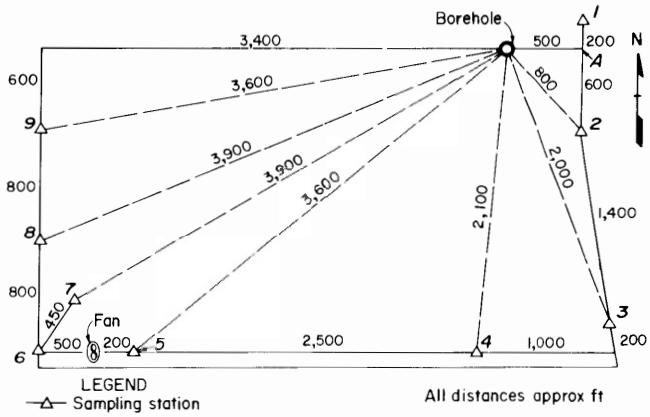

FIGURE 1.—Ventilation schematic and sampling stations of Mine A gob.

RESULTS

Table 2 shows the approximate time from test start to detection of SF_6 at each station (except station *1*). Average gas velocity ($\bar{V}$) was determined for both the last sampling time prior to gas detection and the first sampling for which SF_6 was detected at the station, according to the equation

$$\bar{V} = D/T,$$

where $\bar{V}$ = average gas velocity, ft/min,

D = distance from borehole to station, ft,

and T = detection time, min.

TABLE 2. - SF_6 detection time and average gas velocity through the gob from the borehole to sampling stations *2-9*, Mine A

SF_6 flow from borehole to--	2-dimensional distance, ft	Last sampling before detection		1st sampling showing SF_6	
		Time, min	Gas velocity, ft/min	Time, min	Gas velocity, ft/min
East side:					
Station *2*...	800	NAp	NAp	45	17.78
Station *3*...	2,000	30	66.67	90	22.22
Station *4*...	2,100	45	46.67	105	20.00
Station *5*...	3,600	30	120.00	90	40.00
Station *6*...	[1]4,350	105	41.43	165	26.36
West side:					
Station *7*...	3,900	2,395	1.63	3,397	1.15
Station *8*...	3,900	2,430	1.58	2,741	1.42
Station *9*...	3,600	2,725	1.32	3,420	1.05

[1]Indirect path, via station *7*.

Looking at only stations *7-9* (on the west side of the gob), one might assume that the overall $\bar{V}$ was no more than 1.63 ft/min. However, the wide range in $\bar{V}$ at stations *2-6* (18 to 120 ft/min) indicated that the SF_6 was not traveling directly to those stations through the gob but must have entered the bleeder entries at some point and was carried along the airway to these sampling stations. If SF_6 was to take the shortest two-dimensional path to the bleeder entries (500 ft), it would enter the bleeder airstream at position *A* in figure 1. If $\bar{V}$ for stations *7-9* had been realistic, travel time from the borehole to position *A* should have been approximately 6 h; but in actual testing SF_6 was detected at station *2*, just downstream from position *A*, after only 45 min.

Bleeder entry air velocity was measured using an anemometer at 300 ft/min, and travel time from station *1* to station *6* was as follows:

From	To	Time, min
Station *1*.....	Station *2*.....	2.7
Station *2*.....	Station *3*.....	4.7
Station *3*.....	Station *4*.....	4.0
Station *4*.....	Station *5*.....	8.3
Station *5*.....	Station *6*.....	2.3
Station *1*.....	Station *6*.....	22.0

From this information, it was possible to approximate the gas velocity through the gob to position *A*. Since ventilation air traveled from position *A* to station *2* in only 2 min, then the maximum time for the gas to move through the gob to the bleeder entry (at position *A*) is 43 min; this results in a $\bar{V}$ through the gob of 12.8 ft/min, which is a minimum figure. This is approximately 10 times the velocity toward the west side of the gob (range 1.05 to 1.63 ft/min). The wide variation from the east to west sides of the gob may be due to several factors, including gob caving, proximity to the bleeder, borehole position, and atmospheric pressure differences in the surrounding bleeder entries.

Once SF_6 entered the bleeder entries, it acquired entry velocity and moved toward the fan. SF_6 was detected at stations *2-6* within the same sampling interval, indicating that the gas took the shortest possible path from the borehole to point *A*. The SF_6 concentrations peaked rapidly, then reapproached zero asymptotically. No "second spike" or subsequent increase in SF_6 concentration was ever recorded at stations *2-6*; such a change would have indicated a direct flow of SF_6 from the borehole, through the gob, to that station and could have given researchers an average gas velocity throughout the entire gob.

Assuming that the true gob velocity was 12.8 ft/min, the ventilation paths to the western bleeder sampling stations (*7-9*)[6] may have been so tortuous that the air required a greater time to permeate the gob. In an attempt to place a third dimension in the gob, the equation $D = R \times T$ was used where R was 12.8 ft/min, T was the gas detection time (min), and D was the total distance (ft). From table 3, it is apparent that the distances derived were unrealistically large. This confirms the results of table 2. The velocities in the western side of the gob were significantly lower than those of the eastern side.

CONCLUSIONS

The objective was to determine the ability of ventilation air to adequately enter and ventilate a caved gob. The lone exhausting borehole was capped and a small-diameter tube placed down the hole from the surface to a position just above the actual caving. SF_6, followed by an inert purge gas, was released into the gob. Nine underground bleeder evaluation stations, in addition to the borehole location, were sampled for SF_6 over a total of 6 days. SF_6 was detected in less than 3 h at the eastern sampling points (nearer the borehole), whereas detection required 2 days at the western sampling points farthest from the borehole.

[6]As shown in figure 1, the path of SF_6 to station *6* was not through the gob (hence, not via station *7*), and could not have been through the bleeder entry from station *5*, but was likely through a parallel bleeder entry (shown).

TABLE 3. - Distances from borehole to western sampling points

	Gas detection time, min	Distance from borehole, ft	
		2-dimensional	3-dimensional
Station 7:			
Minimum.....	2,395	3,900	30,656
Maximum.....	3,397	3,900	43,481
Station 8:			
Minimum.....	2,430	3,850	31,104
Maximum.....	2,741	3,850	35,084
Station 9:			
Minimum.....	2,725	4,000	34,880
Maximum.....	3,420	4,000	43,776

The following conclusions were derived regarding the permeability of the caved gob. This gob was permeable, since SF_6 was detected after a short sampling time. The location of the borehole tended to enhance gas escape toward the eastern working areas even though mine atmospheric pressures were lower on the western side of the gob. If air quantities from the respective entries remained the same when the borehole was reopened, then one side of the gob was being ventilated more efficiently than the other.

The location of the borehole appeared to be a critical factor in the performance of this gob. Multiple boreholes in each panel, or possibly a more strategic location of the single borehole, would improve gob ventilation.

If multiple boreholes are not feasible, an alternative would be to ensure that a measurable pressure differential existed across the gob, and that a perceptible quantity of air was actually flowing into the gob. Since air movement is directly related to pressure differential, if a differential exists across the gob, some air movement will take place. There was a pressure differential across the gob in Mine A. This, in conjunction with the borehole, was apparently sufficient to minimize problems associated with gob ventilation.

MINE B

BACKGROUND

Research at Mine B, an underground coal mine in western Colorado, was performed on a sealed gob. The coal in this particular seam is prone to spontaneous combustion. The gob was in a section driven 90° westward from the mains for approximately 700 ft before executing a 90° right turn and continuing development parallel to the main entries. Initially, five entries were driven; two intakes, two returns, and one belt entry. After the 90° right turn, only four entries were driven for just under 400 ft, after which the section was expanded to seven entries (fig. 2).

Approximately 700 ft past the 90° right turn, a vertical fault was encountered. Due to the extent of the vertical displacement, the development was halted, and the section was retreat-pillar-mined back to the four-entry area. Seals were then installed in each of the four entries. Because of the quantity of overburden and the resultant strata convergence, each seal had to be constructed of wood blocks. These pine blocks were built to an approximate thickness of 3 ft. Sprayed-on rigid urethane foam was applied to the seal faces as well as to the ribs and roof for 10 to 15 ft outby (fig. 3). Sampling ports in seals *A* and

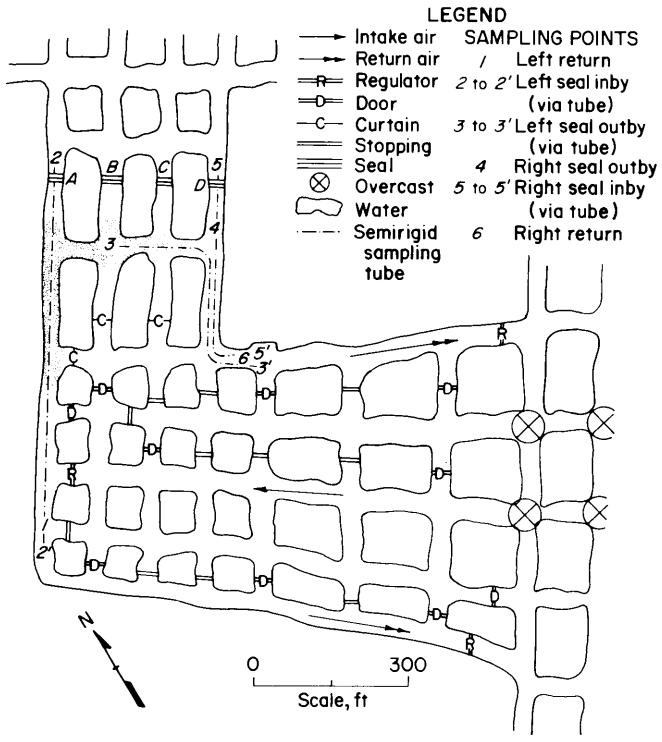

FIGURE 2.—Sealed gob and sampling stations of Mine B.

D made it possible to take gob samples remotely via tubing.

The objective of these tests was to determine why the oxygen concentration at sampling point *5* was much higher than expected. This was a concern because of the potential for spontaneous combustion. SF_6 was released directly into seal *D* through the sampling port. To determine seal performance and possible migration of SF_6, gob air samples were taken behind the seals from the sampling ports at points *2* and *5*. Additionally, SF_6 samples were taken from positions just outby the left and right seals (points *3* and *4*, respectively), and from the left and right returns (points *1* and *6*, respectively).

Prior to this research, another SF_6 tracer gas survey at the same location had been conducted by an MSHA technical support group. MSHA found that detectable SF_6 was neither permeating the large vertical fault that had previously halted mining in the section, nor entering a nearby return entry. Because of the proximity of the main return to the sealed section, a large pressure differential existed between the two. Had SF_6 been detected in the return, it would have indicated that the area was actively being ventilated rather than being sealed.

Two unknowns were investigated: (1) the performance of the seals in prohibiting ingassing and outgassing, and (2) the potential for the voids inby the seals to be directly interconnected, thus enabling gas to migrate from one seal to another. Since oxygen inflow is directly related to seal performance, solving the first unknown would enable researchers to reach conclusions about the high oxygen concentrations.

Underground sampling took place at six different locations (fig. 2). Any SF_6 that escaped from behind the seals would be detected at one or possibly two sampling points (*1* or *6*). A considerable amount of standing water in front of seals *A-C* (fig. 4) made it difficult to examine seal *A* for air leakage. A solution to this problem was to connect sampling tubing to the seal port and extend this tubing approximately 500 ft outby the seal (from point *2* to point *2'*). This length of tubing also allowed the sampling station to be on the return side of the intake air split, eliminating the possibility of SF_6 reentrainment. To sample for SF_6 behind seal *A*, mine personnel aspirated the tubing, then began sampling gob air.

Tubing was also used to sample from seal *A* outby (point *3* to point *3'*) and seal *D* inby (point *5* to point *5'*) positions. This was done to avoid overlapping of SF_6 samples at different positions. Personal sampling pumps were used to continually pull air through the flexible tubing in all cases.

FIRST GOB EVALUATION

Once SF_6 was released behind seal *D*, sampling began. A problem immediately surfaced at point *5*. The rate at which the sampling pump was pulling air suggested the tubing had a restriction somewhere in-line. Shortly thereafter, water was visible in the flexible tubing. SF_6 samples taken at this position were considered unreliable because of the large quantity of water that was collecting

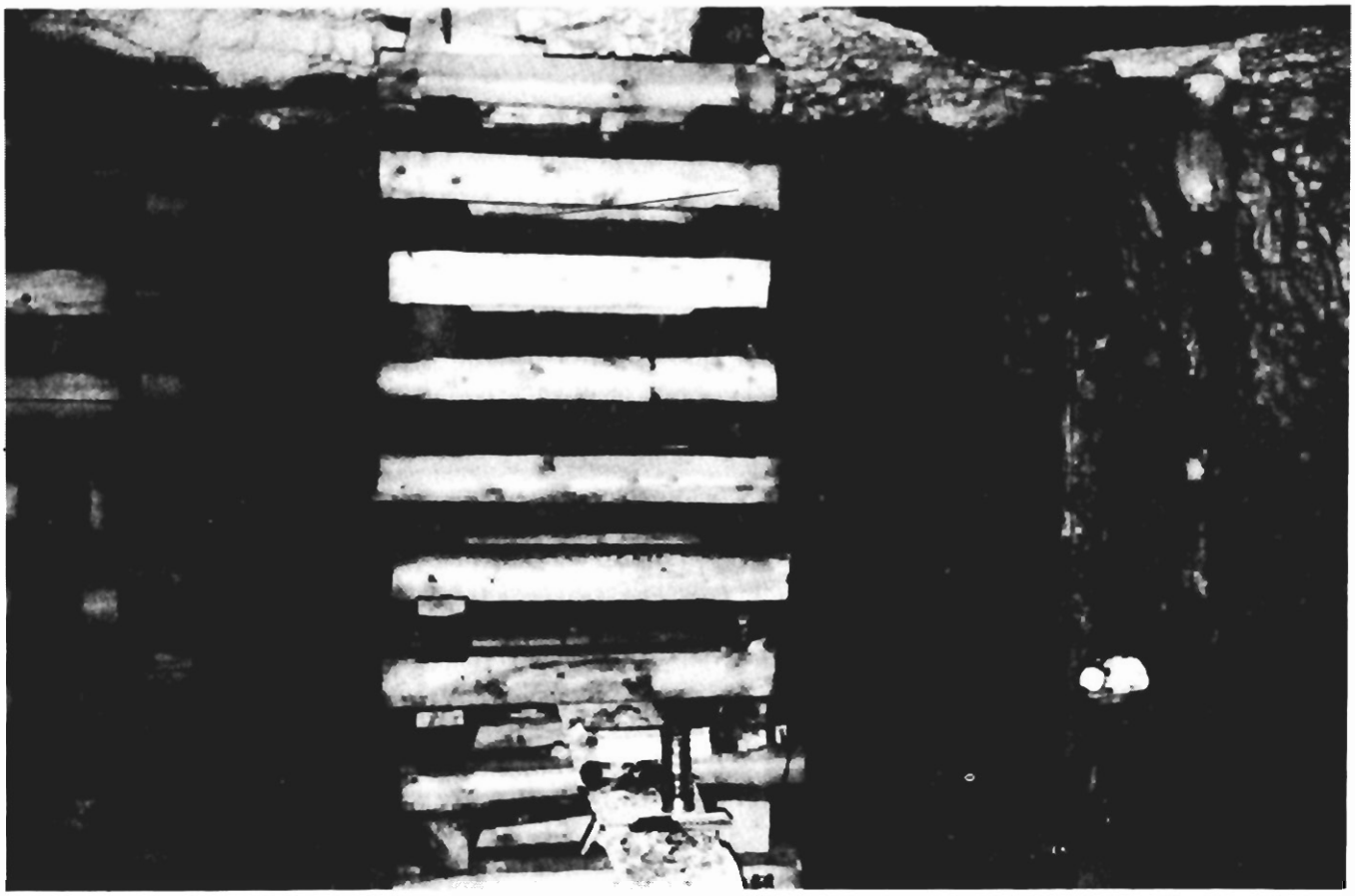

FIGURE 3.—Mine B seals with urethane foam seal outby on roof and ribs.

inside the tubing. This implied that not all of the SF_6 was injected behind the seal.

Within 30 min after SF_6 was released behind seal *D*, 60 pct of the tracer gas had already passed sampling point *6*. Because of this rapid recovery of SF_6, it appeared that much of the SF_6 was released outby the seal (at point *4*) as a result of the restriction.

At sampling points *2*, *4*, and *6*, results were obtained for approximately 30 min. Sampling point *4*, closest to the SF_6 release, showed an extremely high SF_6 concentration immediately following the SF_6 injection into seal *D*. SF_6 concentrations at points *6* and *3* (via *3'*) peaked shortly after point *4*. No SF_6 was detected at sample point *2* (via *2'*).

The quantity of SF_6 recovered was determined by the equation:

$$Q_{SF_6} = C\bar{x}_{SF_6} TQ_{air} \qquad (1)$$

where Q_{SF_6} = quantity of SF_6 recovered (ft^3)

$C\bar{x}_{SF_6}$ = mean concentration of SF_6 in one part of air

T = sampling time (min)

and Q_{air} = airflow (ft^3/min)

At point *6*, considered the most reliable sampling position, 0.67 ft^3 or 60 pct of the SF_6 released was detected within 35 min. Concentrations at points *3* and *4* averaged 23 ppb (sampled for 30 min) and 9,800 ppb (sampled for 65 min), respectively. The air quantities flowing past each sampling point were unknown. No SF_6 was detected at point *1*. Since all SF_6 exiting the section had to pass sampling point *6*, the sum of air quantities at points *3* and *4* should have equaled the

FIGURE 4.—Standing water located outby Mine B seals.

0.67 ft^3 found in the return. Modifying equation 1 slightly enables solving it for airflow, rather than for SF_6 recovered. The calculated average airflow passing the right and left outby positions was 1,050 ft^3/min.

Because of injection problems, the results obtained in this portion of the test were limited. However, it was seen that no SF_6 migrated to point *1* or from seal *D* inby (point *5*) to seal *A* inby (point *2*).

SECOND GOB EVALUATION

Because of the obvious sampling problems at point *5*, researchers examined the copper tubing extending through seal *D* into the gob. The inby end of the tube was found to be almost totally collapsed and under water. The copper tube was repaired and reinserted into seal *D*, and a second bottle of SF_6 was injected into the seal. Again, air sampling took place at all six sampling positions. This time, SF_6 concentrations at point *4* averaged 320 ppb for 35 min. At point *6*, mean SF_6 concentrations were 90 ppb for 105 sampling minutes.

After the second release, point *6* showed only a 29-pct recovery of the total SF_6 injected. Assuming that the air quantity previously determined at point *4* (1,050 ft/min) was correct, now only 4.5 pct of the SF_6 released was recovered at that point. Therefore, point *4* was sampling less gas than the return. Since point *4* was within the urethane-sealed roof and rib area, SF_6 injected into the gob was probably leaking around the urethane seal and into the return.

No SF_6 was detected at point *2* throughout both these tests. Again, any air migration from point *5* to point *2* was either extremely slow or nil.

After the release, the concentration at sampling point *5* remained almost constant (slope 0.02). Knowing this, an

assumption was made about the relative size of the void behind seal *D*. Mean SF_6 concentration averaged 2.6 vol pct. The actual quantity of SF_6 released was 1.01 ft^3. By proportion, the approximate size of the void behind seal *D* was determined to be 39 ft^3.

Results of this second phase of testing provided more information. Assuming that the derived volume behind seal *D* was correct, the likelihood of gas migration from one entry to another was very remote. Therefore, there was little chance that SF_6 released inby seal *D* would be detected in any other gob location.

GAS ANALYSES OF LEFT AND RIGHT INBY POSITIONS

In addition to the SF_6 evaluations, gas concentrations behind both seals *A* and *D* were examined. Again, there appeared to be little correlation between data received from the two inby seal positions (points *2* and *5*, respectively). Seal *A* exhibited characteristics commonly found in sealed gobs--depressed O_2 and N_2 and elevated quantities of CO_2 and hydrocarbons (table 4). The air behind seal *A* appeared to be part of the gob atmosphere.

Sampling behind seal *D* did not produce the same results. Initially, O_2 samples resembled the ambient mine atmosphere. Samples obtained through the repaired sampling port during the second gob evaluation, which started at 10:30 a.m., showed a decrease in O_2 and an increase in CO_2 and the hydrocarbons. Although the concentrations of various gases linked to gob atmospheres did increase, the elevated quantities were still low enough to support the belief that air was probably leaking through seal *D*. Since hydrocarbon concentrations remained relatively low, caving behind the seal must have been complete and very close to the seal. Only a remote connection, due to slightly elevated CO_2 and CH_4, appeared to exist between the void and the overall gob volume.

CONCLUSIONS

In Mine B, after mining had been completed, standard practice was to seal the section to eliminate the potential for spontaneous combustion. Seals were made of pine blocks, hitched into the floor and ribs, and coated with spray-applied, rigid urethane foam. In addition, to reduce the possibility of gob gas escape into the working areas of the mine, extensive sealing was performed on the roof and ribs outby the seals.

In the particular section examined, four seals separated the gob from the active workings. The two outside seals had sampling ports through which gob gas was sampled.

TABLE 4. - Gas concentrations behind seal *A* and seal *D*, Mine B

Time	Concentration, pct						Concentration, ppm			
	O_2	Ar	N_2	CO_2	CO	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}
SEAL *A*										
10:15.....	9.0	0.71	59.9	8.4	ND	21.9	200	95	150	60
10:55.....	8.4	.70	59.0	8.8	ND	23.0	210	100	165	65
11:30.....	8.1	.70	58.8	8.9	ND	23.4	200	100	165	65
13:00.....	8.0	.70	58.8	8.9	ND	23.5	200	100	165	65
14:30.....	8.9	.70	59.7	8.5	ND	22.1	190	90	155	60
SEAL *D*										
10:15.....	20.8	0.93	78.1	0.1	ND	ND	ND	ND	ND	ND
10:40.....	19.3	.91	76.4	1.3	ND	2.1	15	9	15	7
10:55.....	19.0	.89	75.0	1.8	ND	3.3	20	12	22	9
11:30.....	17.0	.89	74.4	2.7	ND	5.0	10	10	25	10
13:00.....	16.6	.89	74.4	3.0	ND	5.1	10	8	20	10
14:30.....	18.7	.91	76.1	1.8	ND	2.5	20	5	12	6

ND No gas detected.

The objective was to determine why gas samples taken from the two outside seals differed so radically, one exhibiting high methane and low oxygen, the other just the opposite.

A sampling strategy was developed. In both tests, SF_6 was injected inby the seal displaying ambient air properties (seal *D*). The results of these tests indicated the presence of an extensive cave-in just inby that seal. This caving was tight enough to separate the area immediately behind the seal from the rest of the gob. Gas analyses showed only a remote connection between the space inby seal *D* and the rest of the gob. Samples taken inby seal *D* showed gas concentrations close to those in ambient air. Those samples taken inby seal *A* were more typical of gob gas samples in that they had higher concentrations of hydrocarbon gases and CO_2, and depressed quantities of O_2. This implied that the area immediately inby seal *D* was almost completely isolated from the rest of the gob.

MINE C

BACKGROUND

In Mine C, unanticipated gob gas problems were occurring behind gob seals that separated three different, supposedly interconnected, mine sections from the working areas of a coal mine. Each section had several seals, one of which had a port for gob gas sampling. Section 2 South exhibited high methane (approx. 50 pct), section 3 South had methane concentrations just above the explosive range (approx. 17 pct), and section 4 South approximated ambient air. Because of the potential danger associated with section 3 South, the Bureau of Mines was asked to perform SF_6 ventilation tests on all three sections. The objectives were to determine seal performance and attempt to verify the existence of an air interconnection between the three sections.

Mine C is located in southeastern Colorado. Sections 2 South, 3 South, and 4 South (fig. 5) are located in a coal seam 4 to 11 ft thick, which pitches down toward the southwest at a 7-pct slope.

The main entry (not shown) was driven in a westward direction. Several sections were developed southward from the main. The three sections to be examined appeared to be interconnected by an east-west development, referred to as Panel A.[7] Panel A development took place at the southerly termination of all three sections.

Development, and some retreat pillar mining had been completed in the 3 South and 4 South sections before they were sealed. Approximately 800 ft of the southernmost portion of 2 South was also sealed. The enclosed gob encompassed nearly 6.5 million ft^3. An active section still existed in the 2 South development, just north of the sealed gob. This subsection was being developed westward and was referred to as Panel B.

The gob was isolated from the active mine by 16-in-thick concrete block seals. A cementitious sealant was applied to the outby and inby faces. Rigid urethane foam was spray-applied to the perimeter of each seal for added tightness. A 2-in ball valve was located in the far left and right seals of each section. A 0.25-in-OD copper tube for gob gas sampling was also located in the left or No. 1 seal of each section. It was estimated that the copper tubes extended into the gob for at least 50 ft.

All three sealed sections were ventilated on return air. An intake split from the main entry ventilated Panel B, then ventilated the seals across 2 South. Both 3 and 4 South seals were ventilated by the south leg of the main entry returns. Brattice-wing curtains, just outby each seal, forced return air to sweep the seal face, helping to ensure proper seal ventilation.

To start the evaluation, on separate days SF_6 was released into the No. 1 seal

[7]The gob area associated with Panel A was where all examinations in this report took place. This area will be referred to as the gob.

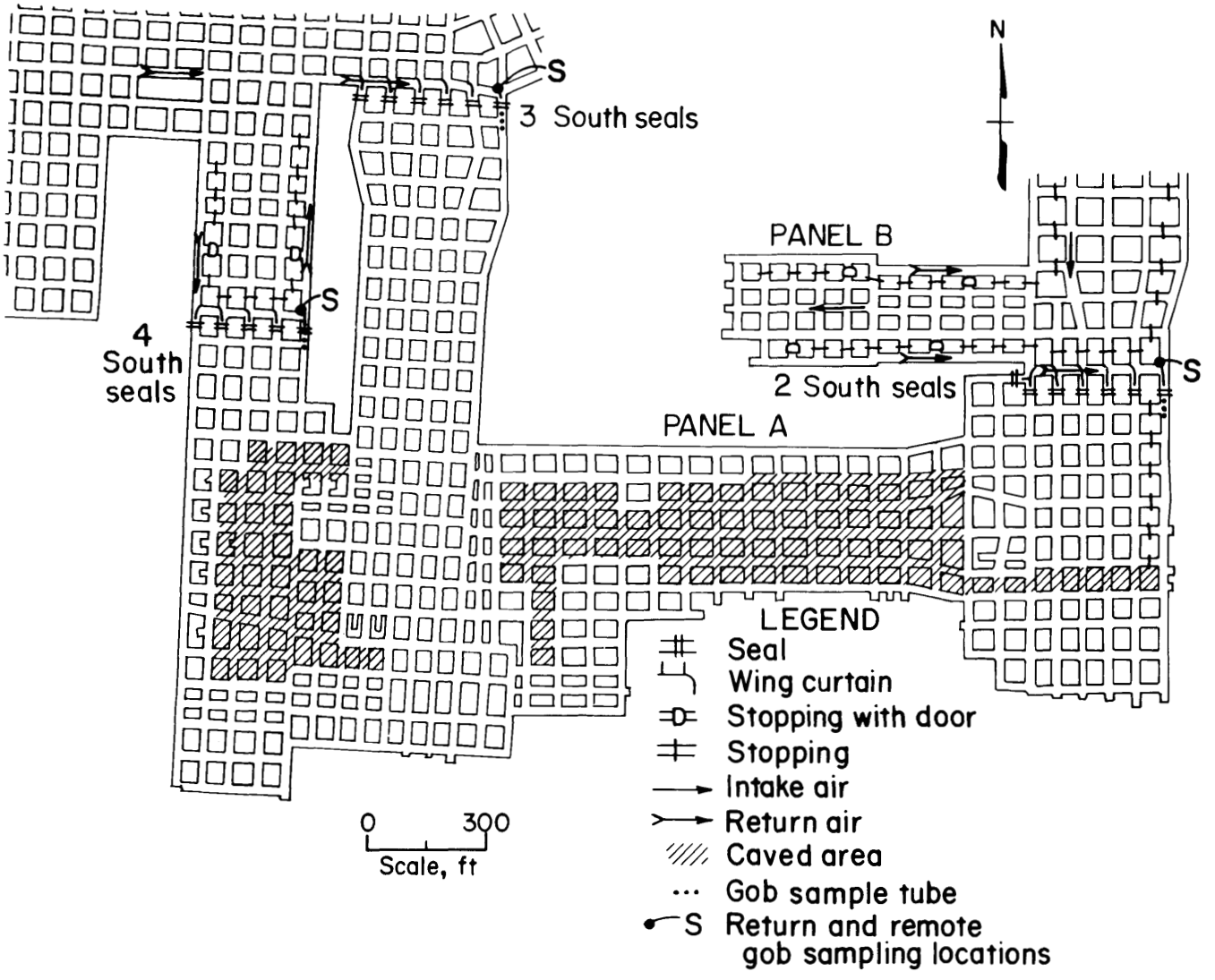

FIGURE 5.—Sealed gob and sampling stations of Mine C.

of each of the three sections through the 0.25-in gas sampling tube. On the first day of testing, SF_6 was injected into 4 South; on the second day, into 3 South; and on the third, into 2 South. Immediately following the SF_6 release, a positive displacement pump, approved by MSHA for sampling in methane atmospheres, was connected to each tube and run until the line was completely purged. This ensured that the SF_6 samples would be drawn from the gob atmosphere and not from the tube itself.

For these tests, samples were collected in two different ways--direct sampling by evaluating ambient air in the returns, and remote sampling, using a personal sampling pump to pull air from inby the seals through the gob sampling port. Semirigid tubing was connected to the gas sampling port that protruded from the seal. The sampling pump was connected to the outby end of the tubing.

An in-line plastic tee was placed in the tubing at an arbitrary distance between the seal and pump. The semirigid tubing was connected to two legs of the tee. The third leg had an airtight septum, through which samples would be extracted at previously arranged specific time intervals.

EVALUATION

4 South

In the 4 South section, 1.16 ft^3 of SF_6 was released behind the No. 1 seal. The seal was ingassing as the SF_6 was being released. The SF_6 concentration at this location showed little change over the entire sampling period. The gas concentrations measured at this point indicated a very low rate of diffusion.

The 4 South return sampling position began indicating the presence of SF_6 117 min after release and then continuously for the remainder of the test. The quantity of SF_6 leaking through the seals during the test averaged 0.06 ft^3/h.

Thirty minutes after the 4 South return began detecting SF_6, it was also found in the 3 South return. The average SF_6 flow volume at the 3 South return for the test was 0.01 ft^3/h. This yields a dilution ratio of 6:1 (from 4 South to 3 South), which enabled researchers to determine the contribution of 4 South air leakage when the 3 South seals were evaluated the following day. No SF_6 was detected in the 3 South gob; thus, it was highly unlikely that any SF_6 found in the 3 South return was leaking through the 3 South seals. For the remainder of the test, SF_6 was detected at both the 4 South and 3 South return positions, with values at 3 South roughly trailing 4 South peaks by 20 min.

3 South

On the second day, 1.15 ft^3 of SF_6 was released behind the No. 1 seal of the 3 South section, which outgassed throughout the SF_6 release. SF_6 concentrations behind the No. 1 seal in 3 South were initially fairly low and increased throughout the sampling period. This was contrary to what had been expected, since diffusion caused by the kinetic energy of the gases at the molecular level should tend to dilute the gases and thus reduce the concentrations.

SF_6 was detected in the 3 South return immediately after release. Average SF_6 flow rate through 3 South seals was 0.04 ft^3/h. Because of the low SF_6 concentration detected in the 4 South return during this evaluation, all SF_6 sampled in the 3 South return was considered to be leaking through 3 South seals. If this leak rate had continued unchanged, all the SF_6 in the 3 South gob should have been depleted in just under 26 h. However, as the 3 South section approached equilibrium,[8] leakage through the seals rapidly diminished.

Average air leakage from the 3 South seals was 1,525 ft^3/min. If SF_6 was leaking evenly through all six seals, the average air leakage was slightly more than 250 ft^3/min per seal.

Remote gob samples taken behind the 4 South seals showed that SF_6 concentrations decreased by a factor of 1,500 over a 24-h period. This large reduction took place even though very little concentration change was noted throughout the second day's sampling time.

2 South

On the third day, 1.13 ft^3 of SF_6 was released behind the 2 South seal. This seal also was outgassing during the SF_6 release. Again, the average SF_6 concentration began at a low value and increased throughout the test. Assuming that the highest concentration attained signified equilibrium in the gob, the 2 South gob appeared to equilibrate much faster than the 3 South gob.

As in the 3 South test, SF_6 was detected in the 2 South return immediately after release. Return concentrations remained high throughout the test. Average SF_6 flow rate through the seals was 0.18 ft^3/h. At this rate, SF_6 was projected to fully deplete in slightly over 6 h. Again, as the gob air began to approach equilibrium, SF_6 flow through the seals diminished rapidly.

The air leakage through the seals was calculated by comparing the concentrations behind and in front of the

[8]Equilibrium in this context means the sampling time in which SF_6 concentrations fall, then maintain a constant value, with no measurable additional diffusion taking place.

seals. If the SF_6 was leaking through only the one seal with the sampling port, leakage was 3,569 ft^3/min. If all seven seals were leaking, the average airflow was 509 ft^3/min.

Remote gob samples taken inby the 3 South seals were surprising, in that the average SF_6 concentration increased, rather than decreased, compared with levels from samples taken the previous day. In fact, the values were almost twice as high as the day before. At the same time, remote gob samples also showed that the concentration in the 4 South gob continued to decrease very slowly. In both cases, the concentration changed very little during sampling, showing little additional gas dilution throughout the gob.

CONCLUSIONS

4 South

Because the SF_6 concentration behind the 4 South seal did not decline measurably throughout the first-day test, the gas was apparently being released into a problem area, probably into some tightly caved or blind area where little mixing was able to take place. However, since SF_6 leakage did occur through the seals, the air in the gob was moving. The sample probe, therefore, may have been poorly located and may not have indicated what was actually happening in the gob.

Following the first day of sampling, only very small quantities of SF_6 were detected in the 4 South returns. During initial SF_6 release, the seal was ingassing, but it began outgassing during the next two sampling days. It was probable that, during hours when no SF_6 sampling was taking place, more SF_6 outgassed into the return. Mine conditions did not appear to be sufficiently severe to cause pressure changes that would have created an appreciable change in the mine atmosphere.

Twenty-four hours after the SF_6 release in 4 South, samples detected no SF_6 in the 3 South gob. Even after more than 48 h, the 2 South gob sampling position still had not detected any SF_6 from 4 South. Based on this, there appeared to have been no low-resistance air interconnection between sections.

The seals themselves appeared adequately constructed to preclude large-scale gob gas leakage. However, a periodic visual inspection was recommended to ensure that the seals, and especially their mortar sealants, remained solid.

3 South

It was not determined why, after SF_6 was released behind the 3 South seal, the concentration increased throughout the sampling period. According to gas diffusion laws, because of the random motion of molecules and their associated kinetic energy, the net flow of gas is from high concentrations to low. One explanation proposed was that if the sampling probe was at the roof and the gob atmosphere was static, the SF_6, which is more than 4 times as dense as air, would require a long time to dilute back to the probe. However, this would be valid only if there was little air movement in the gob; the immediate detection of SF_6 in the 3 South return suggests air movement behind the seals.

During the 2 South evaluation, SF_6 concentrations in the 3 South gob were stable but approximately twice as high as the initial peak when SF_6 was released into 3 South. SF_6 continued to increase from the time gas was released into the section until equilibrium was established. Since no SF_6 change occurred in 3 South during sampling the day after SF_6 release in 3 South, the gob was considered to be at equilibrium.

Again, an open interconnection between 4 South and 3 South did not appear to exist. No SF_6 was detected in 3 South even as late as 24 h after its release in 4 South. The distance from the release point in 4 South to the sample point in 3 South was approximately 1,300 ft. Thus, a diffusion rate of less than 1 ft/min was required to detect SF_6 in the 3 South gob. Still, no SF_6 was found.

Initially, it was thought that the increase in SF_6 concentration 24 h after release into 3 South was due to the

mixing of gas in 3 South and 4 South sections. No reasonable explanation could be given for the large difference in concentrations between the two sections. It seemed logical that, if the sections were readily interconnected, equilibrium would have provided a common SF_6 value for both locations.

The seals associated with the 3 South section also appeared to be well constructed. During testing, their leakage values approximated what was expected from most concrete block seals. Although appreciable quantities of SF_6 existed behind the seals, only minute quantities were sampled in the return.

2 South

As in the 3 South gob, SF_6 released into 2 South gob also exhibited characteristics that cannot be readily explained by gas diffusion laws. The SF_6 concentrations behind the seal appeared to stabilize near the end of the test. This equilibration occurred much faster in 2 South than in other sections. The inference here was that the unobstructed volume behind 2 South appeared to be less than the volume behind 3 South seals. Looking at the mine map, this theory might be valid if all stoppings shown in 2 South were still in place.

No SF_6 was detected in the 2 South gob prior to gas release in that section. Since the first release of SF_6 was 48 h earlier, it was evident that no readily accessible passageway existed between the 4 South and 2 South sections. The average air velocity required for transmission of SF_6 from 4 South to 2 South within 48 h would have been slightly more than 1 ft/min.

Section 2 South was apparently not as well sealed as the other two sections, as proven by the higher average air leakage through the seals. At several places across the seal face, small areas of high (greater than 10 pct) methane concentrations were detected. These data bore out suppositions based on prior visual inspection. Recoating these seals with a sealant would probably have eliminated the additional leakage.

SUMMARY

Two options, ventilating or sealing, are available to mines having abandoned areas. If the gob is to be ventilated after abandonment, there should be several bleeder entries around the gob, as well as a pressure differential across the gob, to ensure adequate air movement. To further enhance gob ventilation, at least one borehole should be driven into the section before or after mining.

Gobs that liberate excessive quantities of methane, or are prone to spontaneous combustion, are usually sealed (2). Seals must be constructed of substantial, incombustible material and must be able to arrest an explosion. A section that is to be sealed after mining should have a minimum number of entries, consistent with good health and safety practices. Seals are not 100 pct efficient; therefore, minimizing their number reduces the potential for gob leakage. Boreholes also enhance the performance of sealed gobs. These are developed vertically from the surface, or horizontally through a seal to the return.

Each mine examined was faced with a different situation that required specific information to determine gob performance. All of the research was performed using sulfur hexafluoride (SF_6) gas as the primary air tracer. Mine A ventilated its gobs; research determined both the average gob air velocity and the locations around the gob that were more thoroughly ventilated. Mine B sealed its gobs, but was receiving conflicting gas sampling results from two seals isolating the same gob; research found a restriction behind one seal that altered sampled gas concentrations. Mine C has a large gob, containing three sections with a total of 18 seals. This gob was experiencing different methane concentrations in each section; results showed that the

individual sections were not interconnected. Average leak rates through the seals in each section were also determined.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1986—605-017/40,098

INT.-BU.OF MINES,PGH.,PA. 28367