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Tracer Gas as an Aid in Mine Ventilation Analysis

UNITED STATES DEPARTMENT OF THE INTERIOR

TRACER GAS AS AN AID IN MINE VENTILATION ANALYSIS

by

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ABSTRACT

The Bureau of Mines has successfully used sulfur hexafluoride (SF_6) as a tracer gas to measure mine air flows under conditions where conventional methods have failed. SF_6 was employed experimentally to measure accurately recirculation of return into intake air caused by leakage through an old stoped area, to check for potential leakage from an adjacent mine, to trace 10,000 cfm of "lost" air from an intake airway, and to measure transit air time through uranium mines. It proved useful as a means of accurately measuring airflow volumes in airways of large cross section and very low flow velocity, and in determining the recirculation resulting from underground cooling plants.

INTRODUCTION

Mine ventilation systems are generally very complex. Many aspects of a mine ventilation network can be studied by conventional anemometer and smoke cloud techniques. However, problems such as recirculation of return into intake air, leakage from adjacent mines, "lost" intake air, uncertain flow quantities in airways of large cross section and low velocity, and unknown transit flow times through stoped areas call for new ways of analyzing airflow underground. Use of SF_6 as a tracer gas can be an effective means of analyzing these ventilation problems. The Bureau of Mines is concerned with finding solutions to these problems in conjunction with its ventilation programs. Various studies have been conducted by the Bureau in several mines in order to show the value of the SF_6 tracer gas.

Organic and inorganic chemicals, and radioactive substances have been used for trace purposes, but most of these materials have inherent disadvantages. Chemical tracers are less easily detected at low concentrations than radioactive substances, and are often highly adsorbed on many surfaces. Radioactive substances, on the other hand, can be detected in low concentrations, but are difficult to handle and are likely to be unacceptable to men working underground. An effective tracer gas must be detectable at low concentrations,

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safe, odorless, have a low background concentration, and be chemically and thermally stable.

Sulfur hexafluoride meets all these essential requirements. It can be detected to very dilute levels by means of gas-solid chromatography using electron-capture detection (1).[3] Saltzman (9) and Niemeyer and McCormick (7) showed SF_6 can be traced down to a concentration of 10^{-5} ppm.

Lester and Greenberg (6) established that SF_6 is safe by keeping rats in an 80-percent SF_6 atmosphere for 24 hours with no ill effects. In addition, it is odorless, chemically and thermally stable, and is convenient to handle and dispense in air (11). Hunt and Moore (5) showed that SF_6 is not measurably adsorbed on reservoir sandstone. Whisman (12) found the same for coal. Finally, SF_6 has the advantage that it does not occur naturally in the atmosphere.

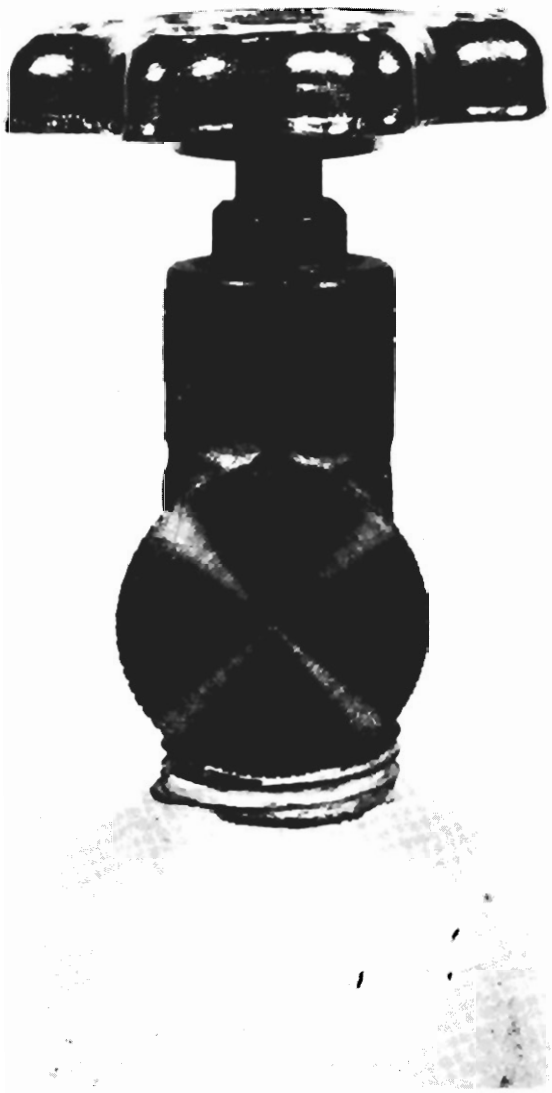

FIGURE 1. - SF_6 lecture bottle with 0.006-inch hole drilled in cap.

Several researchers (2-3, 11) used SF_6 in meteorological studies of moving air masses and the dispersion of airborne pollutants. Drivas (4) used SF_6 as a tracer gas to study ventilation system in buildings, including the ventilation of individual rooms and contamination due to re-entry of fume hood exhaust.

Sulfur hexafluoride has also been employed in Appalachian coal mines to evaluate the effectiveness of the plugging of oil wells penetrating the mines. Rennick (8) introduced sulfur hexafluoride into the oil reservoir before the well was plugged. The success of the plugging technique in preventing reservoir gas from entering the mine atmosphere through the well holes was verified by monitoring the mine air twice daily for indications of the trace gas.

[3]Underlined number in parentheses refer to items in the list of references at the end of this report.

RELEASE AND MEASUREMENT OF SF_6

Methods of releasing SF_6 into the atmosphere were investigated in the Bureau of Mines Safety Research Coal Mine at Bruceton, Pa. (10). The major problem was found to be incomplete mixing of the dense SF_6 with the mine air in airways of low velocity; at high velocities there was no mixing problem.

Good mixing of the SF_6 and mine air is achieved when the SF_6 is released as a jet spray from a pressurized lecture bottle through a small hole (.006-inch drilled through the cap (fig. 1). Mixing is further improved by moving the lecture bottle around the mine airway during release. The volume of SF_6 released is determined from the weight loss of the lecture bottle.

The gas samples are taken in 10-ml glass syringe bottles (fig. 2) sealed with tight-fitting rubber stoppers. The syringe bottles must be airtight since they are often exposed to varying temperatures and pressures, and occasionally to time delays of several days before being tested in the laboratory.[4] The SF_6 concentrations in the syringe sample bottles are measured in a portable electron capture gas chromatograph. This chromatograph operates with an 8.5-foot by 1/8-inch stainless steel column packed with Chromasorb

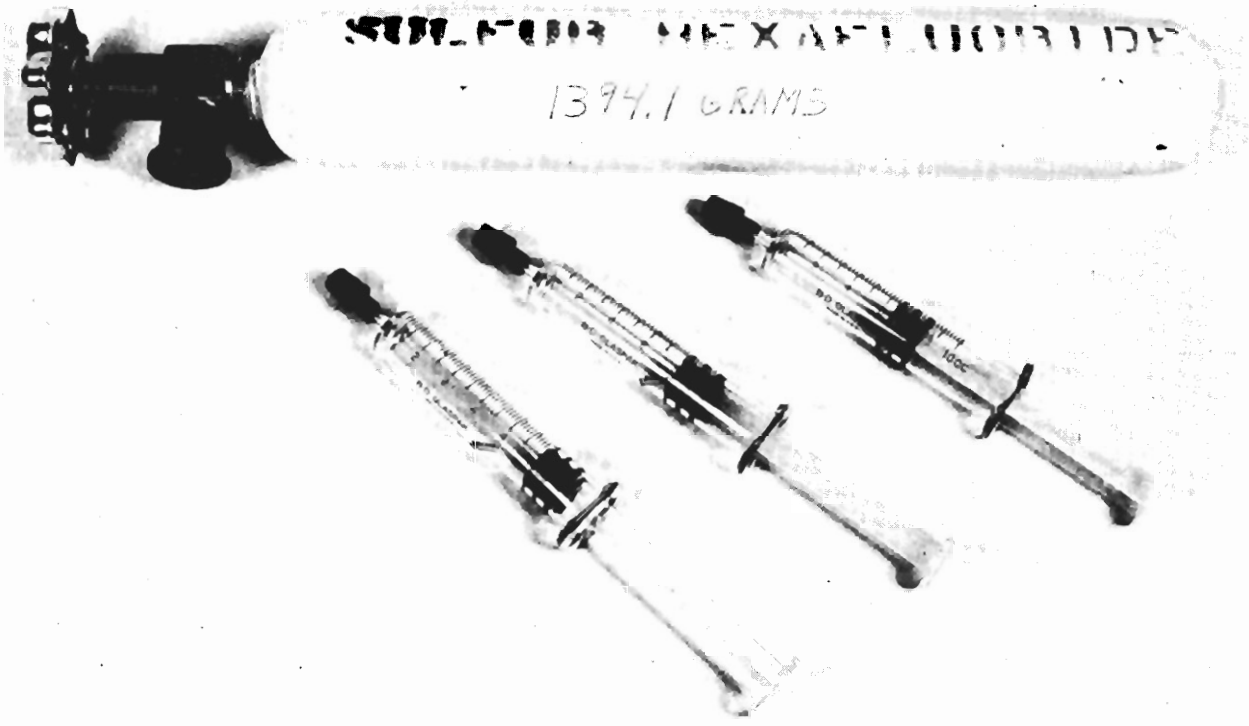

FIGURE 2. - SF_6 lecture bottle and syringe sample bottles.

[4]If the concentration of a given sample appears low as compared with those of the other samples, we check this syringe bottle in the laboratory by filling the bottle with a known amount of SF_6 and measuring its concentration again after several days.

102 (60-80 mesh)[5] that has been treated at 100° C for two hours. The operating temperature is 50° C. The carrier gas is argon with 5 percent methane, flowing at 10 cm^3 per 17 seconds. A 0.1-milliliter gas sample is injected into the chromatograph. The resulting analysis is read by a digital voltmeter and printed out at a rate of 20 readings per second. SF_6 peak heights are used for calibration and analysis. A detailed discussion of the chromatograph calibration procedure is given elsewhere (10).

PRELIMINARY TRACER GAS EXPERIMENTS

To determine if SF_6 could be traced quantitatively underground, preliminary experiments were conducted in the Bureau of Mines Safety Research Coal Mine, located at Bruceton, Pa. This mine (fig. 3) has a single intake and exhaust and is an ideal facility for testing a trace gas. In these experiments a known quantity of SF_6 was released into the intake air at R, and after a few minutes the return air was sampled at S every 2 minutes for a period of 90 minutes. The samples were run on the chromatograph to determine

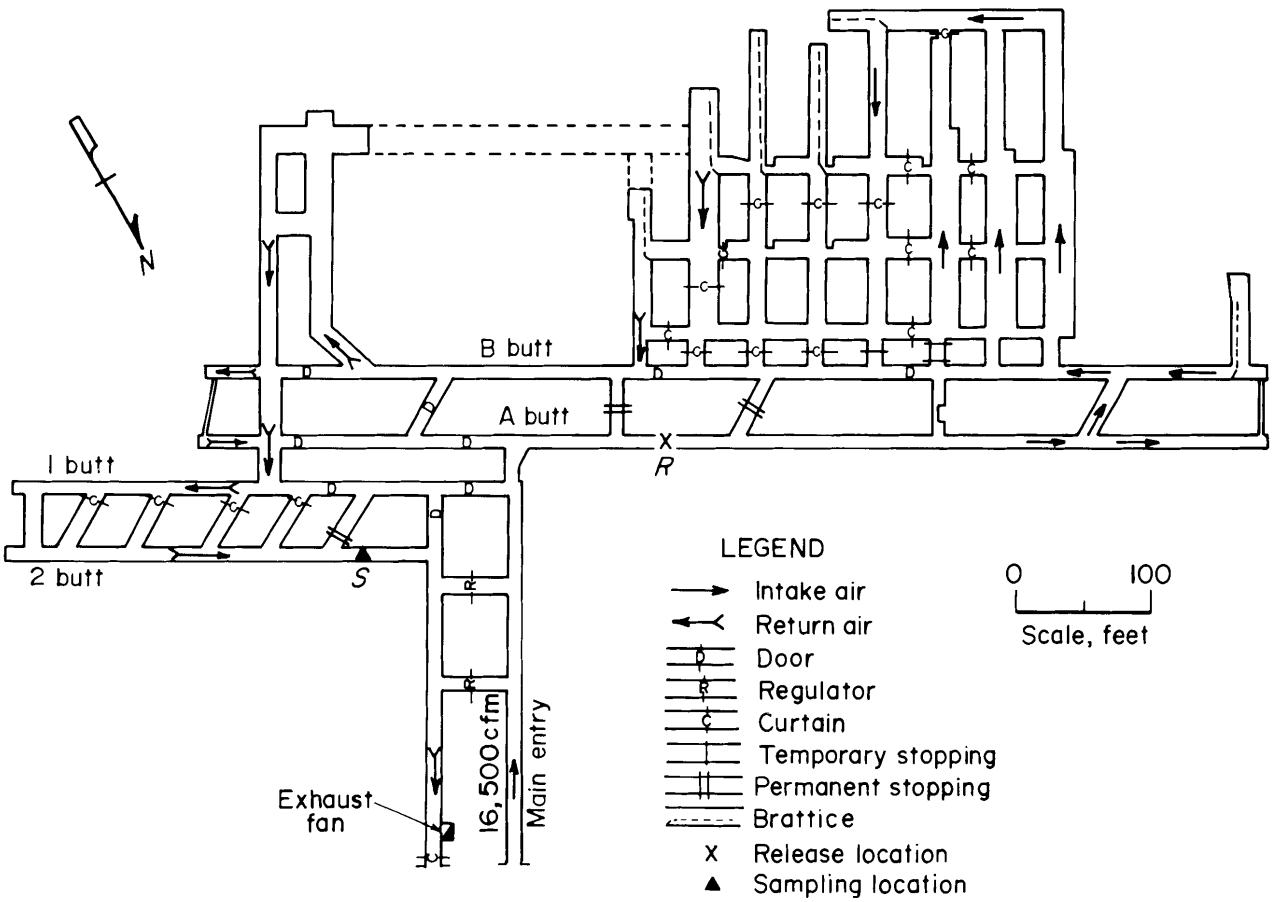

FIGURE 3. - Bureau of Mines safety research coal mine.

[5]Reference to specific trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

the SF_6 concentrations. The quantity of SF_6 passing in the return was estimated by substituting the resulting data into the following equation:

$$Q_{SF_6} = Q_{AIR} \int c\,dt.$$

Here, Q_{SF_6} is the SF_6 volume, Q_{AIR} is the volumetric airflow rate at the sampling point, and c is the SF_6 concentration at time t. Integration of this equation is simply done by multiplying C_{avg}, the average SF_6 concentration in those sample bottles that contain SF_6, by the total time T during which measurable amounts of SF_6 were found in the return air. This total time T is the sampling interval (2 minutes in this case) multiplied by the number of samples with a measurable SF_6 concentration. Thus, the above equation reduces to $Q_{SF_6} = Q_{AIR}\ C_{avg}\ T$.

Results of a typical experiment were as follows: 10.5 liters of SF_6 were released in the intake. Of the 45 air samples taken in the return at 2-minute intervals, 31 contained measurable quantities of SF_6 with an average concentration of 377 parts per billion (pbb). The SF_6 concentration of each sample is assumed to represent the SF_6 concentration at S over a 2-minute interval (from 1 minute before the sample is taken until 1 minute after it is taken). Therefore the 31 samples containing SF_6 indicate the presence of SF_6 in the return for a period of 62 minutes at an average concentration of 377 ppb. The SF_6 concentration in the return is plotted as a function of the time from the release of SF_6 in the intake in figure 4. The return volume airflow was

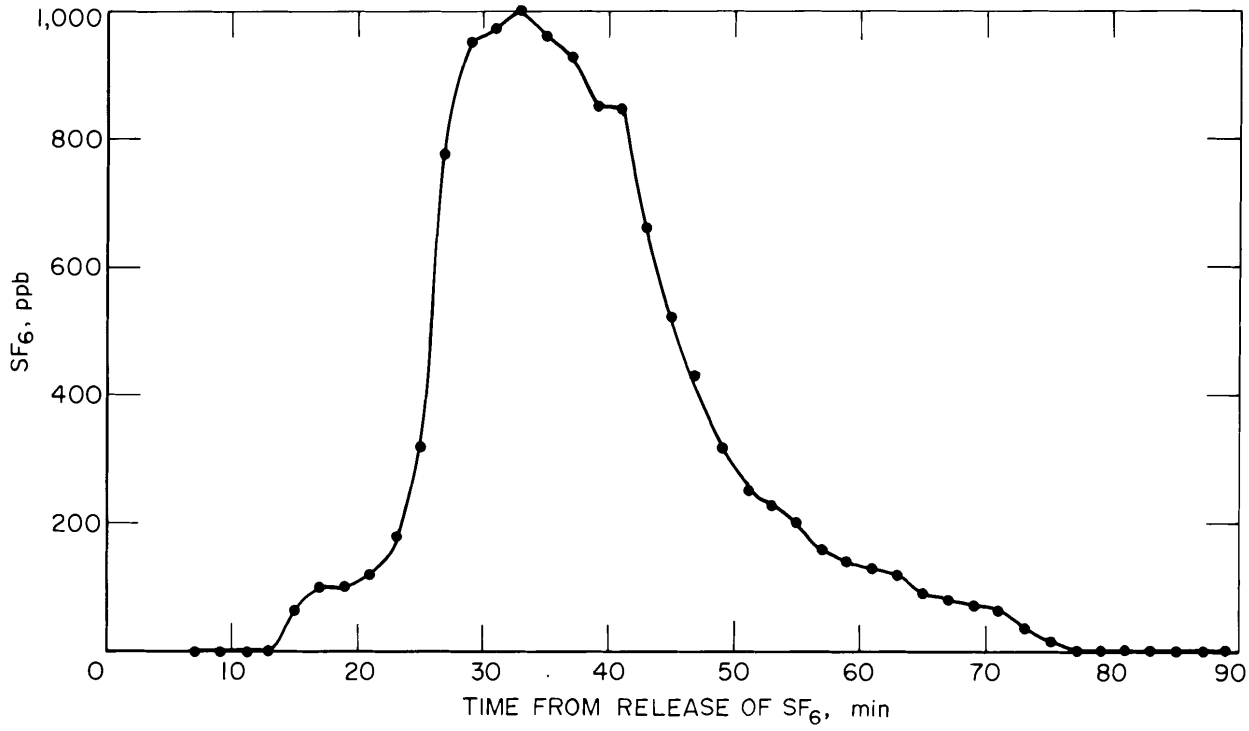

FIGURE 4. - SF_6 concentration in the return as a function of time.

16,280 cfm. Using the continuity equation given above, the calculated quantity of SF_6 in the return is as follows: SF_6 (liters) = (16,280 ft^3 air/min) (377 $\times$ 10^{-9} ft^3 SF_6/ft^3air) (62 min) (28.3 liter/ft^3) = 10.7 liters. This is in good experimental agreement with the original value of 10.5 liters released in the intake. Results with this degree of accuracy were obtainable only if the SF_6 was thoroughly mixed with the mine air.

EFFECT OF DEEP MINING CONDITIONS ON TRACING WITH SF_6

A major concern in the development of the tracer gas technique was that it might not be effective in deep mines, where some of the SF_6 might be washed out by cooling plants or lost in the long multilevel air paths or in stopes. To determine the effect of such conditions, an experiment was conducted in a western copper mine in which most of the ventilation air passed through cooling plants, heavily stoped areas, and over long distances (up to 4 miles) before exiting the mine. This mine has been worked since the 19th century and has an extremely complicated and extensive ventilation network. A simplified schematic of the mine is shown in figure 5. The experiment began with the release of 68.9 liters of SF_6 into the intake air from 9:30 a.m. to

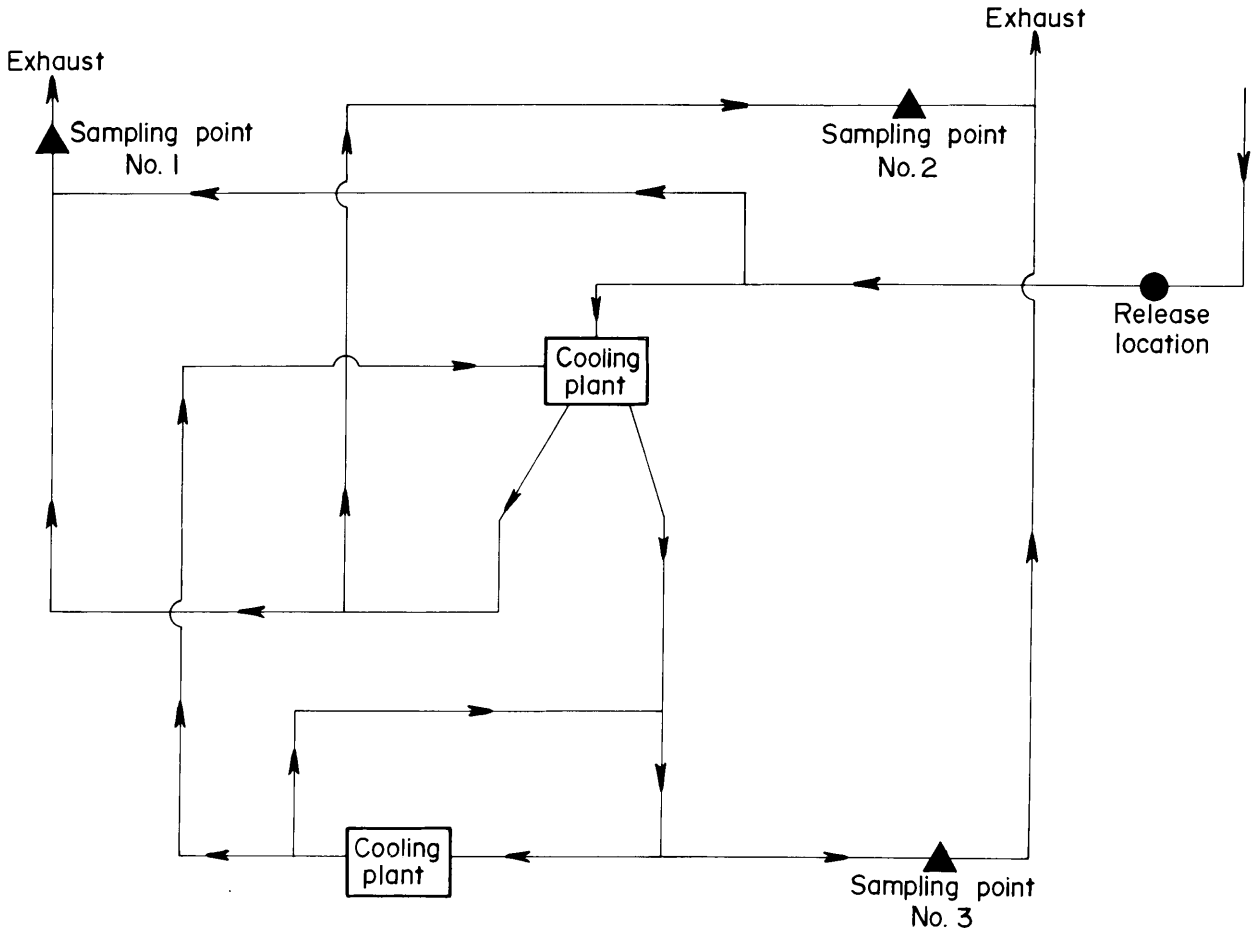

FIGURE 5. - Schematic of copper mine.

9:32 a.m. Air samples were taken at 5-minute intervals from 9:30 a.m. to 12:00 noon at each of three sampling points (fig. 5). Air passing these three locations encompassed the entire exhaust air supply from the mine. The test results are presented in table 1. The total SF_6 from the three exhaust sampling locations is 70.4 liters. The volume of SF_6 released was 68.9 liters, indicating an error of about 2 percent. This indicates the SF_6 gas is not washed out to any measureable extent by passing through cooling plants, and is not lost due to the long air transit time in the mine or by traveling through stoped areas.

TABLE 1. - Results at the three sampling locations in a western copper mine

Sampling location	Air-flow rate, cfm	Arrival time of SF_6[1]	Time of last SF_6 at location	Number of samples containing SF_6	Time SF_6 was present, min (number of samples × 5 min)	Average SF_6, concentration ppb	Total SF_6 to pass this location, liters
1	66,000	9:55 a.m.	11:20 a.m.	16	80	121.8	18.1
2	65,000	9:35 a.m.	11:50 a.m.	28	140	69.5	17.8
3	106,000	9:40 a.m.	11:25 a.m.	22	110	104.3	34.5

[1] SF_6 released from 9:30 to 9:32 a.m.

RECIRCULATION MEASUREMENTS USING SF_6

In multilevel mines, recirculation of return air into intake airways can be a serious problem. Generally, it is due to leakage through stoped areas that are inadequately sealed. In the event of a mine fire, the recirculated air can contaminate the intake escape route with toxic gases. To prevent recirculation, one must first determine the extent to which it occurs and find where the leakage is taking place. Tracer gas can be applied for this purpose.

Two tracer gas experiments were conducted in a western metal mine where recirculation was known to occur (fig. 6). To determine the percentage of the return air leaking through the stopes into the intake, a measured volume of SF_6 was released into the return, and intake air samples were periodically taken. The percentage of the return air recirculated into the intake was calculated from the ratio of SF_6 in the intake to the total SF_6.

In the first experiment, 32.4 liters of SF_6 were released from 10:45 to 11:00 a.m. at R1 in the return, where the air flow was 86,000 cfm. Air samples were collected at 2-minute intervals from 10:45 to 11:37 a.m. at S1, where the flow was 87,000 cfm. Sample analysis showed that SF_6 first appeared at S1 at 10:59 a.m. and continued in measurable concentrations until 11:19 a.m. (fig. 7). The calculated volume of SF_6 to have passed S1 was 2.1 liters, indicating recirculation in this area to be slightly greater than 6 percent.

In the second recirculation experiment, 8.6 liters of SF_6 were released from 1:10 to 1:23 p.m. at R2 in the return. The air flow at R2 was 7,000 cfm

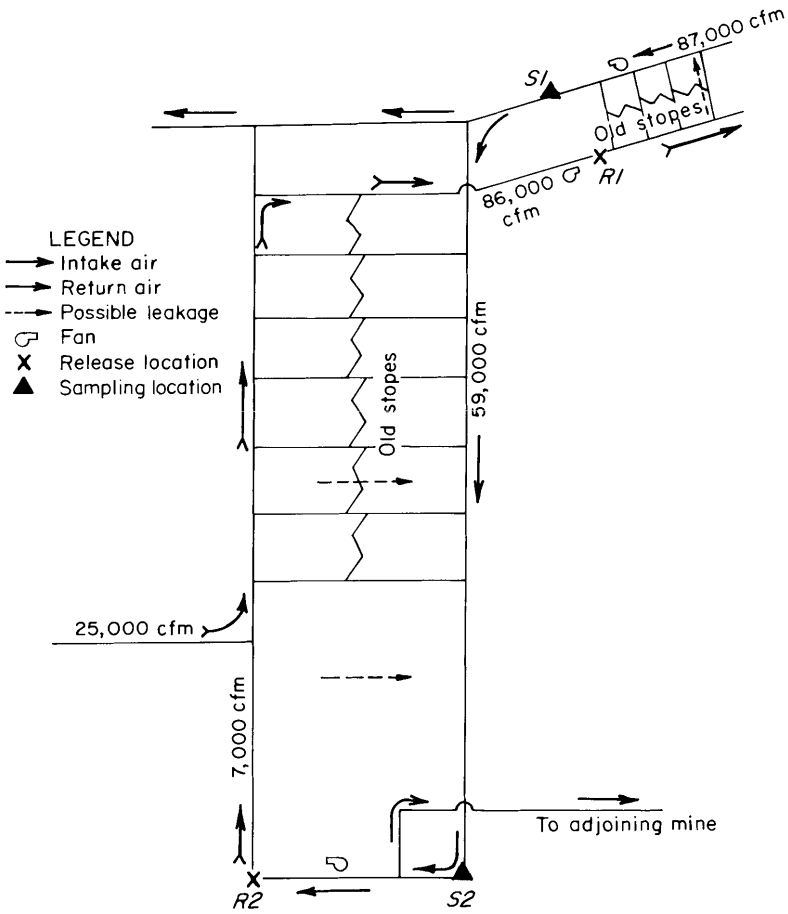

FIGURE 6. - Western metal mine where recirculation experiments were conducted.

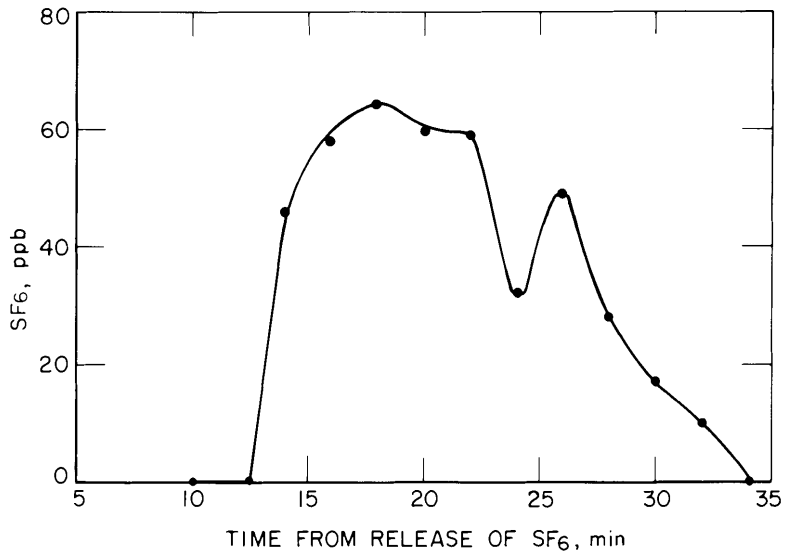

FIGURE 7. - SF_6 concentration in the intake during first recirculation test.

but increased considerably further up the return. Air samples were taken in 5-minute intervals from 1:10 to 2:45 p.m. at S2 in the intake, where the airflow was 58,000 cfm. The first recirculated SF_6 appeared in the sample taken at 1:40 p.m., and varying amounts of SF_6 were found until 2:35 p.m. Figure 8 shows the SF_6 concentration at S2 as a function of time from release. The calculated volume of recirculated SF_6 was 5.3 liters, indicating 61 percent recirculation. Without further experiments, it is impossible to determine if 61 percent of the 7,000 cfm at the release location was recirculated or if 61 percent of some larger volume of return air was recirculated. This depends upon where the leakage occurred. If some leakage occurred above the level where the 25,000 cfm enters the return shaft, then it is 61 percent of a larger air volume. Other tracer gas experiments, with the release or sampling points located further up the shafts, would be required to determine where the leakage occurred.

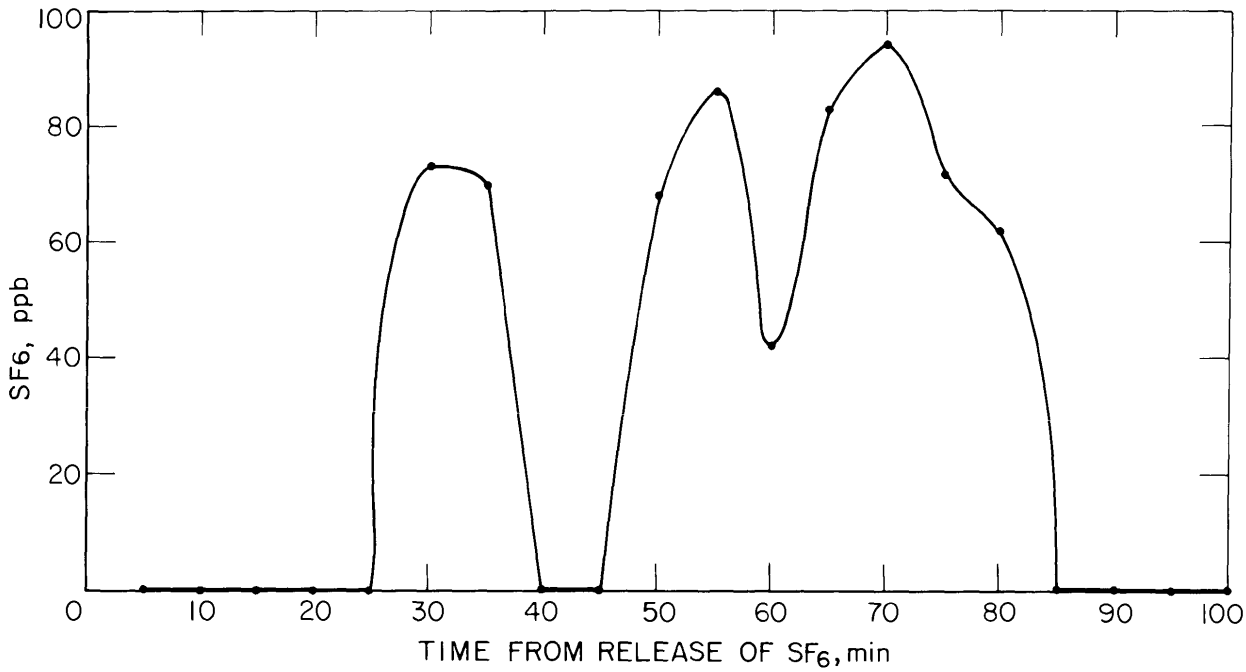

FIGURE 8. - SF_6 concentration in the intake during second recirculation test.

FACE VENTILATION ANALYSIS IN A ROOM-AND-PILLAR MINE

Tracer gas was employed to evaluate face ventilation in a Pennsylvania limestone mine worked by the room-and-pillar method. At the time of the experiment, the last room on the working face was 16 room (fig. 9). Dust and diesel fume concentrations around 16 room were high. It was assumed that intake air was not reaching 16 room in sufficient quantities. To check this assumption, a known amount of SF_6 was released into the intake air and the amount of SF_6 reaching 16 room was measured.

Thirty liters of SF_6 were released in the intake air at 5 room (fig. 9) at 9:54 a.m.; gas sampling began at 9:54 at both the junction of 16 room and 10 butt, and in 9 butt about 50 feet down air from the auxiliary fan mounted between 13 and 14 rooms. The auxiliary fan exhausted the air from the working face. Samples were taken in both locations every minute until 10:30 a.m. The samples taken in 16 room showed slight traces of SF_6 (about 1 ppb) from 10:04 until 10:18 a.m. In 9 butt the samples showed more than 100 ppb SF_6 after only 2 minutes and continued to show these high concentrations throughout the remaining 34 minutes of sampling. Since the SF_6 in the return air in 9 butt generally exceeded 100 ppb and the SF_6 in 16 room was 1 ppb or less, it would appear that only 1 percent or less of the intake air ever reaches 16 room. The auxiliary fan is evidently exhausting the air before it reaches 16 room, resulting in high concentrations of dust and fumes.

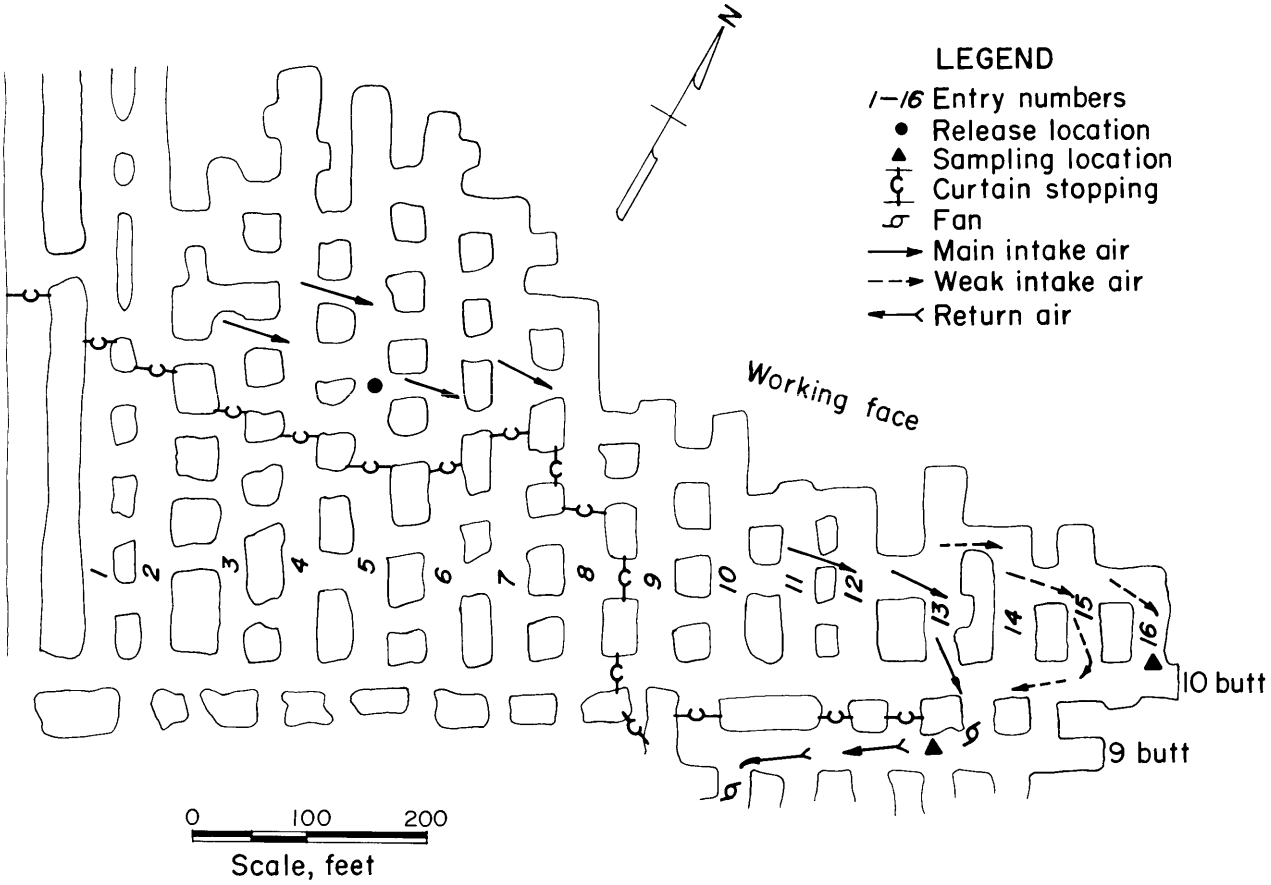

FIGURE 9. - Area of limestone mine where face ventilation experiment was conducted.

USE OF TRACER GAS TO MEASURE AIRFLOWS

One important use of tracer gas is to measure volume flow rates in airways where the cross section in too large and/or the velocity is too low for standard measurements. An experiment of this type was conducted in a Pennsylvania limestone mine with a vertical natural draft intake hole about 70 feet deep and about 20 feet in diameter. The hole carries intake air from the surface down to an airway of about 800 ft^2 cross-section. Since the cross section was too large and the velocity too low to use an anemometer traverse, the volume flow rate down the intake was measured with the tracer gas technique.

Around the surface perimeter of the hole, 12.2 liters of SF_6 were released from a lecture bottle. The gas was released in a jet spray directed down into the hole to insure that all the gas entered the mine. Starting simultaneously with the SF_6 release, samples were taken every minute for 35 minutes at a station in the intake airway located 70 feet from the bottom of the vertical hole. Of the 36 samples taken, 27 contained SF_6 at an average concentration of 470 ppb. Assuming that all the SF_6 released entered the intake hole, the volume airflow rate into the mine from the natural draft intake can be calculated from the continuity equation: $Q_{SF_6} = Q_{AIR}\ C_{avg}\ T$. In this case,

Q_{AIR} is the airflow rate, Q_{SF_6} is the volume of SF_6 released, C_{avg} is the average SF_6 concentration in the 27 samples containing SF_6, and T is the 27-minute time interval that these samples represent. Therefore 12.2 liters = (470 x 10^{-9} $ft^3 SF_6/ft^3$ air) (28.3 liters/ft^3) (27 min) (Q_{AIR}). From this we can calculate Q_{AIR}, the airflow rate, and we find that Q_{AIR} = 34,000 cfm.

AIR LEAKAGE EXPERIMENTS

Multilevel mines with involved ventilation patterns, large stoped areas, and numerous bulkheads are often subject to serious air leakages that are difficult to track down. The tracer gas can be useful here, as was shown in three separate experiments conducted in a western metal mine where several major air leakages were known to exist.

Experiment 1.--Figure 10 is a general schematic of the airflow pattern in the mine. After passing through the stopes the exhaust airflow was about 55,000 cfm. At the top of shaft No. 1, just beyond the inclined shaft junction, the flow was 117,000 cfm. It was about 120,000 cfm at the exhaust shaft, showing an increase in the return air volume of 65,000 cfm, of which 12,000 cfm could be credited to leakage through the bulkhead at the bottom of the inclined shaft. The problem was to account for the other 53,000 cfm. One good possibility was that air was leaking from the old workings of an adjacent mine into No. 1 shaft, which was inaccessable to an anemometer survey.

Almost 70 liters of SF_6 were released into the intake (R1) of the adjacent mine from 11:02 to 11:15 a.m. Air samples were taken at the exhaust fan (S1) of the working mine from 11:30 a.m. to 3:00 p.m. If there was leakage from the old mine, the SF_6 would have shown itself in measurable concentrations by then, as can be seen from the following calculation. The 70 liters of SF_6 was equivalent to about 2.5 ft^3. The airflow in the adjacent mine was around 20,000 cfm. Assuming that the SF_6 spreads itself out in the adjacent mine over a period of 1 hour, then its concentration could be calculated as follows: $\frac{2.5\ ft^3}{20{,}000\ ft^3/min \times 60\ min} = 2.1 \times 10^{-6}$, or 2.1 ppm. If only 1,000 cfm leaks into the working mine and is diluted in 120,000 cfm then the SF_6 concentration in the working mine could be calculated as follows: $2.1 \times 10^{-6} \frac{ft^3\ SF_6}{ft^3\ air} \times \frac{1{,}000\ ft^3\ air}{120{,}000\ ft^3\ air} = 1.75 \times 10^{-8}$, or 17.5 ppb, which would be easily detected. Since no SF_6 showed in any of the samples taken, it can be concluded that the unaccounted for air does not come from the adjacent mine.

Experiment 2.--A second possibility was leakage from the inclined shaft through old stopes and down into No. 1 shaft (fig. 10). To explore this possibility 8.6 liters of SF_6 were released at the top of the inclined shaft at R2 at 8:55 a.m. and sampling was started at the top of No. 1 shaft at S2 and just behind a leaky bulkhead in the inclined shaft on the return air side at S3. Samples were taken at 5-minute intervals until 10:30 a.m. Analysis showed that 4.4 liters of SF_6 showed at S2 and 6.3 liters of SF_6 showed at S3. This is a total of 10.7 liters of SF_6, whereas only 8.6 liters had been released. This discrepancy probably resulted from the fact that SF_6 appreared

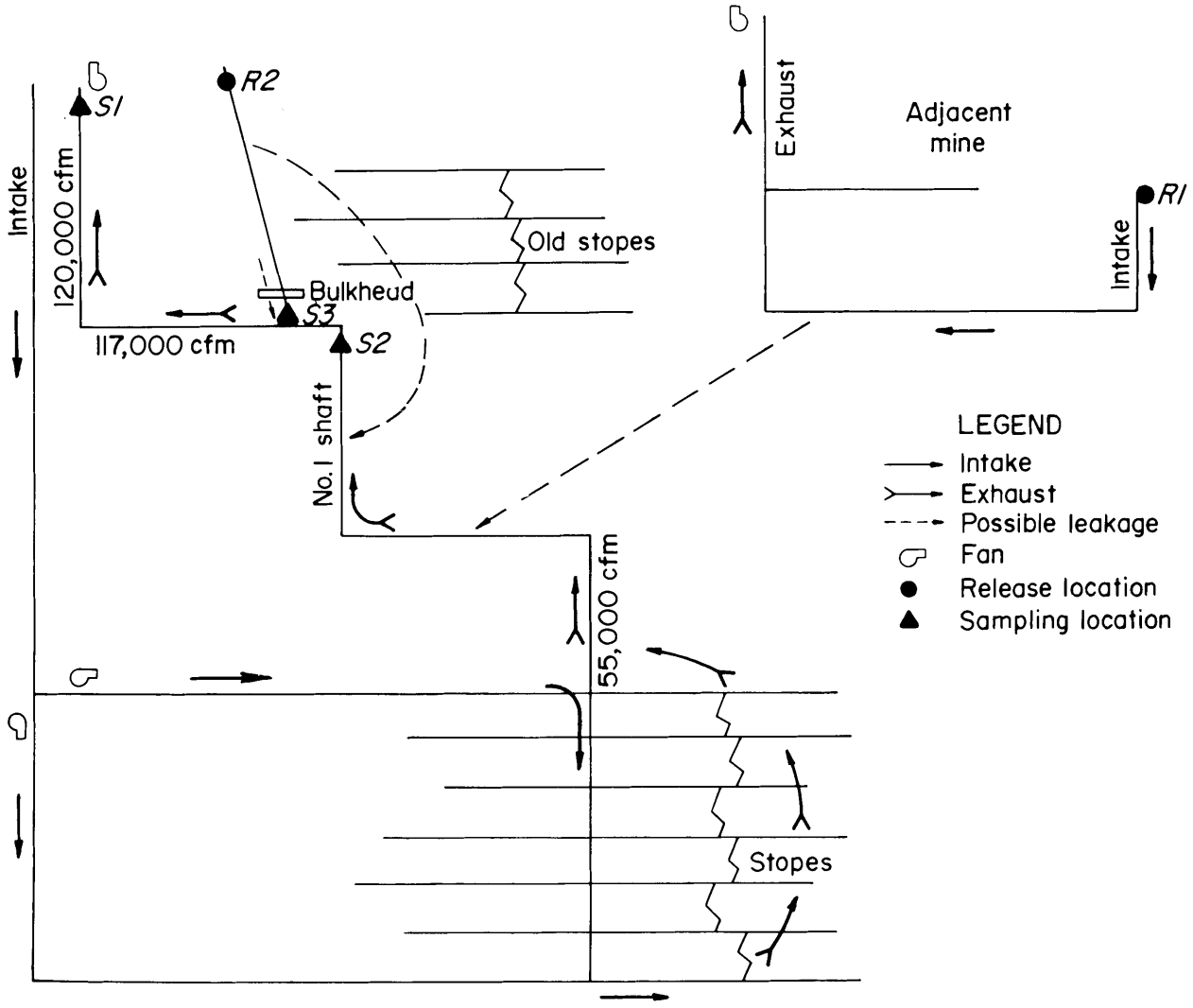

FIGURE 10. - Schematic of mine where leakage tests were conducted.

in only a small number of samples, thus reducing the accuracy of the numerical integration.

Since some SF_6 did show at the top of No. 1 shaft, we know that there is some leakage from the inclined shaft through the old stopes and into the return air somewhere below the top of No. 1 shaft. However, other considerations would indicate that this leakage is small. An anemometer traverse at the top of the inclined shaft at R2 indicated a flow of 2,000 cfm down the shaft at this point. On the other hand, 12,000 cfm was leaking through the bulkhead at S3, indicating, rather surprisingly, that the net leakage in the shaft was in and not out.

The SF_6 travel time between release at R2 and the first appearance at S3 was 50 minutes. The distance traveled down the inclined shaft was 1,700 feet, indicating a velocity of 34 ft/min. If the shaft cross section was 60

ft^2, then the average airflow was 2,040 cfm. This indicates that most of the leakage into the inclined shaft took place near the bottom and very close to S3.

Experiment 3.--This experiment took place in a different portion of the mine. The intake air volume on C level (fig. 11) was 51,500 cfm. At the junction of C level and No. 8 shaft this air volume splits three ways: up and down No. 8 shaft and through the C level doors on the other side of No. 8 shaft. These three air volumes were measured, they totaled to 38,300 cfm, leaving a loss of 13,200 cfm of air somewhere along C level. Leakage through cracks from the C to the B level was suspected.

A known amount of SF_6, 6.6 liters, was released at R on the C level at 11:57 a.m., and sampling began next to No. 8 shaft on the B level (S1) and about 1,500 feet further along B level (S2). The results revealed two significant facts. First, SF_6 arrived at S2 at 12:17 p.m., but did not reach S1 until 12:26 p.m., indicating that some SF_6 did leak from the C to the B level. Second, the total volume of SF_6 passing S2 was 0.5 liter more than the volume passing S1. This 0.5 liter is obviously the volume of SF_6 that leaked through. The lost air volume was 13,200 cfm; if all of this were going to the B level, the SF_6 quantity difference would have been 13,200 cfm/51,500 cfm × 6.6 liters = 1.7 liters. Since only 0.5 liter extra showed up on the

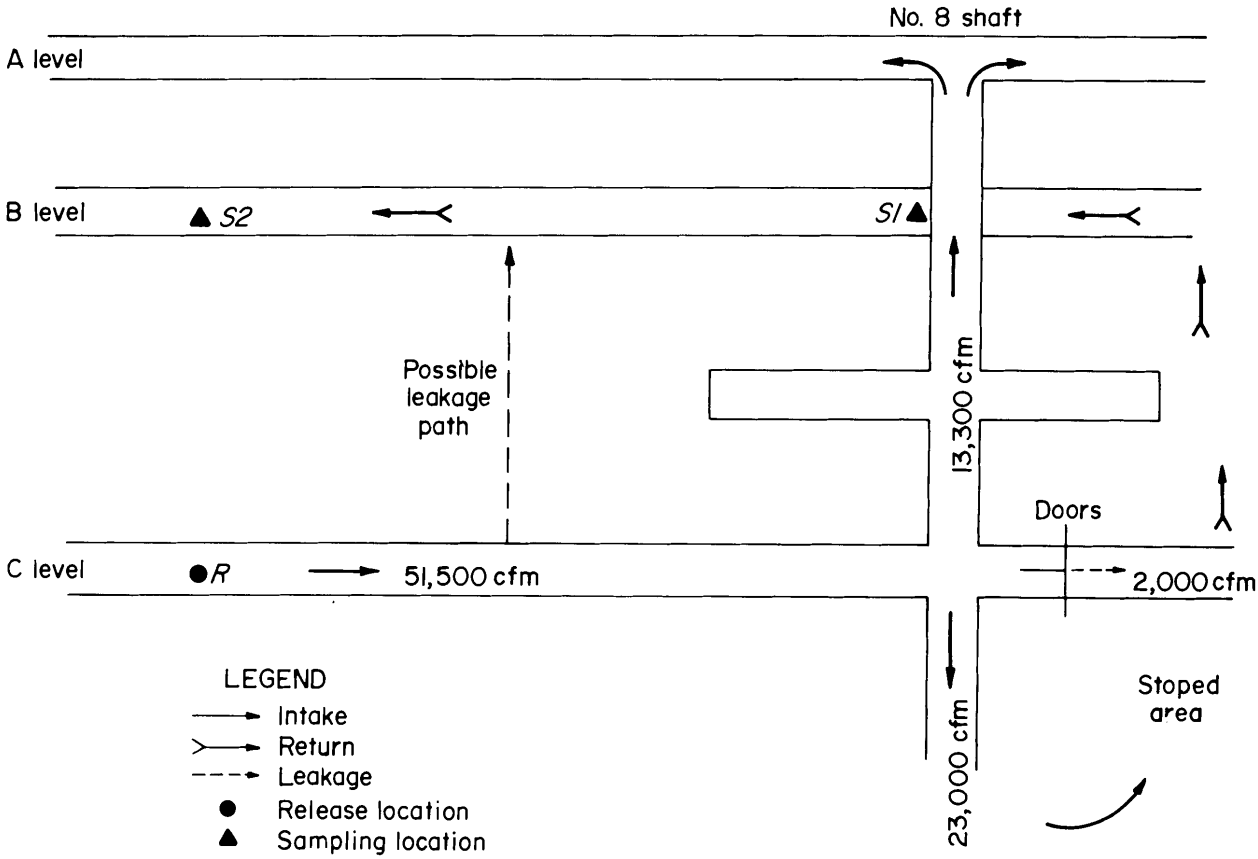

FIGURE 11. - Leakage test on C level.

B level, it would seem that less than one-third of the lost air goes to the B level. The remaining lost air must leak elsewhere.

It is interesting to note that although the straight distance between the C and B levels is only 300 feet, it took 20 minutes for the SF_6 to arrive at S2. If the leakage was about 4,000 cfm, the cross section through which the leakage air passed must be large.

COOLING PLANT RECIRCULATION EXPERIMENTS

In deep mines, the air temperature is maintained at tolerable levels by underground cooling plants that may cause large volumes of air to be recirculated in the mining areas. In case of a mine fire, the cooling plants could recirculate contaminated air. The amount of recirculation occurring at two cooling plants in the western copper mine was determined quantitatively by releasing a given volume of SF_6 into the intake of the cooling plant and monitoring this intake for the next two hours.

If the volume of SF_6 released is R and the fraction recirculated is n, then the volume of SF_6 returning the first time around is nR. The second time around the volume is n^2R, and the third time it is n^3R, and so on. The sum of this series is $A = \left(\frac{n}{1-n} \right) R$, where A is the total volume of SF_6 recirculated. In this case, A is the volume of SF_6 monitored at the cooling plant intake during the experiment.[6] It can be seen from table 2 that approximately 50 percent of the air passing through these cooling plants is recirculated. A concentration-time curve for the second cooling plant is given in figure 12, where the individual peaks most likely represent recirculation along different paths.

TABLE 2. - Results of cooling plant recirculation tests

Cooling plant	SF_6 released (R) liters	Total volume of SF_6 recirculated (A) liters	Recirculation factor (n)
1	19.1	22.9	0.54
2	31.1	26.1	.46

AIR TRANSIT TIMES IN URANIUM MINES

Radon daughter levels in uranium mines are a function of the mine air transit times, since the levels increase with time after mining. Therefore, the shorter the air transit time underground, the lower the radon daughter levels. Unfortunately, the complexity of the air patterns underground makes it difficult to estimate air transit times. The trace gas technique again provides a straightforward solution

[6]This approach was not used in the experiments discussed previously to measure recirculation from return into intake airways because SF_6 monitoring was discontinued before the gas could return a second time.

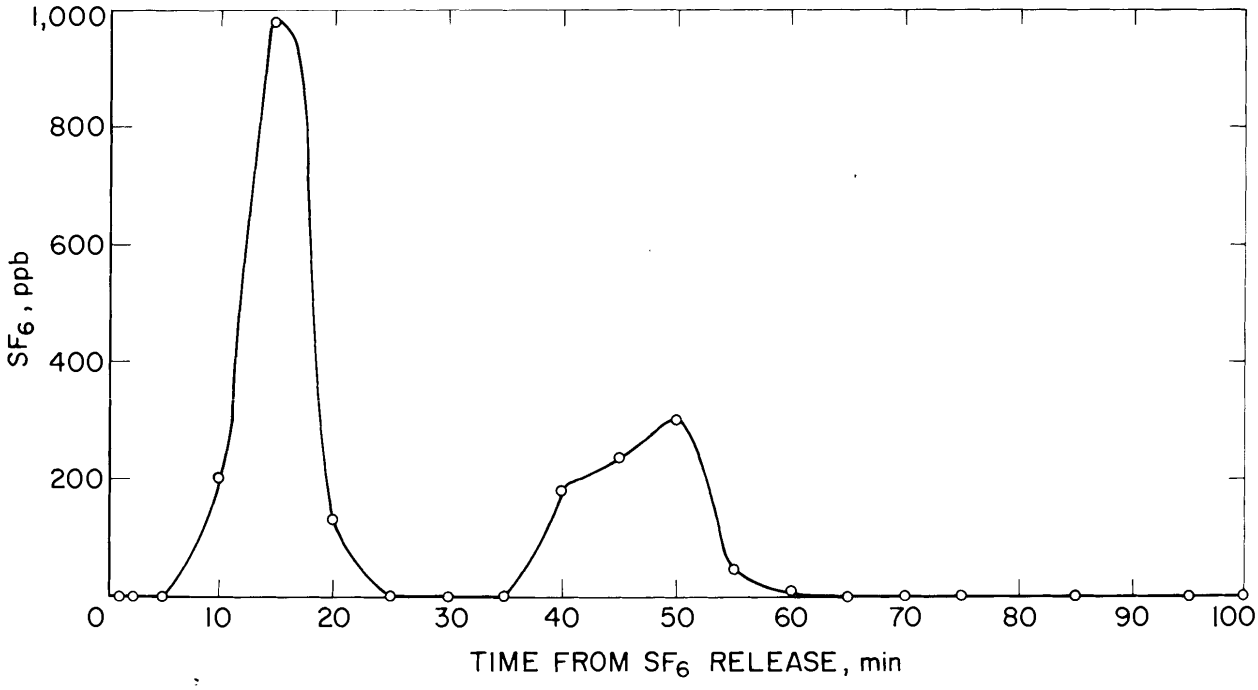

FIGURE 12. - SF_6 concentration versus time for cooling plant test.

Trace gas experiments to determine air transit times were conducted in three southwestern uranium mines, each of which had a major intake with three exhausts (table 3). A known volume of SF_6 was released into the intake shaft on the surface and bottle gas samples were taken at each of the three exhausts for one hour afterwards. Figure 13 shows a concentration curve for the SF_6 exhausting from one of the upcast shafts. This curve is typical in that for all nine of the exhaust shafts monitored, the peak SF_6 concentration appeared in less than 30 minutes; in almost every case some residual SF_6 was still in the mine an hour after release.

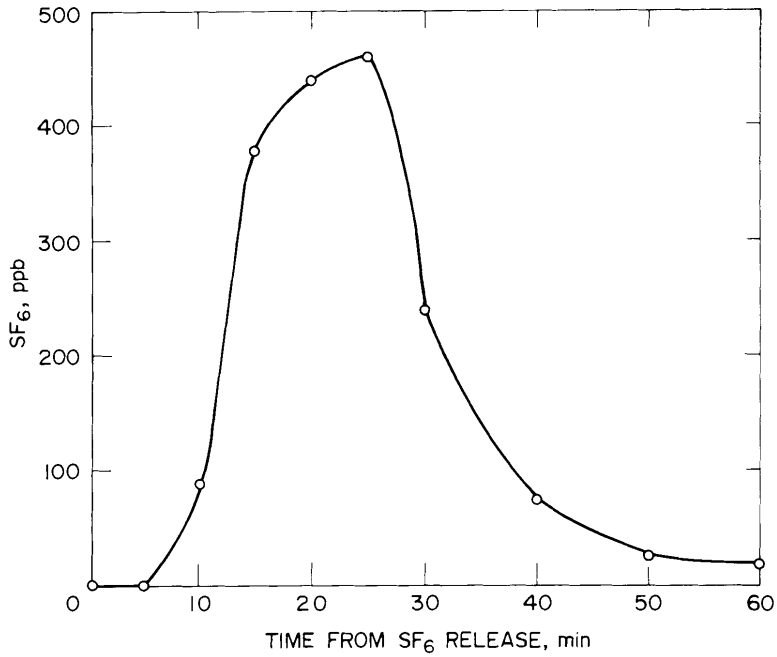

FIGURE 13. - SF_6 concentration curve from a uranium mine exhaust shaft.

Therefore, in all three mines tested the bulk of the SF_6 had exited within an hour after release into the intake. The fact that not

all the tracer gas could be accounted for is probably due to the large number of dead headings in the mines.

TABLE 3. - Results of transit air time tests in uranium mines

Mine and exhaust shaft	SF_6 released, liters	SF_6 exiting, liters	SF_6 not accounted for, liters	Peak concentration		Concentration after 1 hour, ppb
				Time after release, min	Ppb	
Mine 1:						
Exhaust shaft 1-1..	-	6 4	-	5	350	0
Exhaust shaft 1-2..	-	12.2	-	15	270	5
Exhaust shaft 1-3..	-	4.0	-	15	330	3
Total.....	25.2	22.6	2.6	-	-	-
Mine 2:						
Exhaust shaft 2-1..	-	0.6	-	25	100	2
Exhaust shaft 2-2..	-	23.1	-	20	560	43
Exhaust shaft 2-3..	-	4.8	-	20	145	12
Total.....	31.3	28.5	2.8	-	-	-
Mine 3:						
Exhaust shaft 3-1..	-	12.5	-	25	620	13
Exhaust shaft 3-2..	-	12.3	-	25	460	24
Exhaust shaft 3-3..	-	1.1	-	20	180	32
Total.....	29.2	25.9	3.3	-	-	-

CONCLUSIONS

The SF_6 tracer gas has shown itself to be a useful and versatile tool for studying mine ventilation systems. The Bureau of Mines has successfully employed SF_6 to measure and identify ventilation problems such as air leakage through old stopes, doors, and cracks; air recirculation caused by leakage and cooling plants; airflow rates in airways of large cross sections and low velocities; air exchange rates in poorly ventilated areas; and air transit times underground. The simplicity and accuracy of the tracer gas technique in studying ventilation systems where conventional methods fail warrants serious consideration of adopting the tracer gas as a standard ventilation tool.

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