

EMERALD MINE FIELD STUDY

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**UTILIZING MULTIPLE TRACER GAS RELEASES
TO DEFINE AIR MOVEMENT IN GOB AREAS**

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EXECUTIVE SUMMARY

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UTILIZING MULTIPLE TRACER GAS RELEASES TO DEFINE AIR MOVEMENT IN GOB AREAS

STUDY OBJECTIVE	Measure gas migration characteristics associated with longwall gobs for use in optimizing methane control strategies.
TEST SUMMARY	Eight tracer gas releases (7 underground and 1 gob gas venthole injection) were completed. Gob gas venthole and bleeder fan methane production trends have been evaluated.
MAJOR FINDINGS	The bleeders and gob gas venthole methane control systems generally acted independently. Flow paths for tracer gas in both the bleeders (former gate roads) and the longwall gobs were to the back (start-up) end of the panels. All three gob gas ventholes on G panel were in communication. Production interruptions at one gob gas venthole on a panel may influence airflows within the panel and out of the panel. Gob gas ventholes located at the start-up end of the panels produced methane at higher rates for a longer time than holes located in the central or completion end of the panels. The bleeder fans generally produced more gas than the active gob gas ventholes during the same time intervals. Tracer gas studies can be a valuable tool to study ventilation airflows associated with longwall gobs, bleeders, and gob gas ventholes.

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UTILIZING MULTIPLE TRACER GAS RELEASES TO DEFINE AIR MOVEMENT IN GOB AREAS

INTRODUCTION

STUDY BACKGROUND

A study designed to investigate airflow in longwall gob areas utilizing tracer gas was initiated at Cyprus Emerald Resources Corporation's Emerald Mine with an "Opening Meeting" on March 31, 1997. In attendance at the meeting were representatives of the National Institute for Occupational Safety and Health (NIOSH), mine management, union safety committee, MSHA, and the PA Bureau of Deep Mine Safety. A Progress Report was presented at the Emerald Mine on November 25, 1997.

A previous study that utilized SF₆ tracer gas to investigate the distribution of air moving through the active G Panel tailgate to Bleeder Fans 2 and 3 (BF2 and BF3) was completed at the Emerald Mine with a "Closing Meeting" and report on February 28, 1997. The release point for the tracer gas was just inby the longwall face in the number 2 tailgate entry (figure 1). At the time of the study, the face on G Panel was about 250 ft inby gob gas venthole G2, and 6,000 ft inby the longwall take-out room. This previous study showed that approximately 79 percent of the ventilation airflow associated with the release point went to BF2, 19 percent went to BF3, and 2 percent was not recovered. This experiment demonstrated that tracer gas evaluation methods have a high degree of sensitivity in characterizing airflow movements in areas of underground mines, such as longwall gob areas, where access is limited or impossible.

OVERVIEW OF EMERALD MINE OPERATIONS

The Emerald Mine operates a single longwall section in the Pittsburgh Coalbed in Greene County, PA. The mine employed approximately 500 workers and produced 4.7 million st of coal in 1997. Three continuous miner sections are active during the three daily production shifts. The mine generally uses a three-entry gateroad system, except near the start-up (back) end of the panels near the bleeders, and near the submains at the completion (front) end of the panels where four entries are commonly used. Entries are nominally 16 ft wide and 7 ft high.

Longwall panels in the study area (figure 1) were generally about 780 ft wide initially (panels A+ through E) and were increased to 1,000 ft starting with F panel. Panel lengths were variable, generally increasing with each successive panel. G panel at the

southern end of the study area where the SF₆ borehole injection experiment and two of the seven underground releases were conducted was approximately 12,000 ft in length.

The ventilation configuration on active panels has intake air on the headgate side of the panel. The air traverses the face, then splits in the tailgate with a fraction of the air going towards the bleeders at the back of the panel and the remainder moving towards the submains at the front of the panel. Bleeder Fans 2 and 3 are designed to remove a substantial portion of the gas produced by the large gob area formed by the mined-out panels, as well as the active panel (figure 1). The bleeder fan installations consist of a 6 ft diameter shaft with a primary and secondary (back-up) fan unit. Overburden depths to the top of the Pittsburgh Coalbed are 604 and 762 ft respectively for BF2 and BF3.

Gob gas ventholes are also used to control gas in the gobs, with three holes commonly drilled on the tailgate side of each panel. Generally, the surface installation for a gob gas venthole includes a gate valve for shutting-in the hole when necessary, an exhaustor (powered by the produced gas) to withdraw gob gas, a one way check valve, flame arrestor, and flare stack. When an exhaustor is removed from a gob gas venthole, the hole is generally allowed to free flow until the methane concentration falls below the 25% limit specified in the ventilation plan, at which point it is shut-in. During the free flow period, the one-way check valve prevents the inflow of air into the gob.

STUDY OBJECTIVE

The objective of the Emerald Mine tracer gas study was to measure gas migration characteristics associated with longwall gobs for use in optimizing methane control strategies. This objective was approached in two ways utilizing tracer gas releases from various locations within the mine environment. The first investigated communication (or the lack thereof) between gob gas ventholes and the ventilation system, and between individual gob gas ventholes on the same longwall panel. The second determined the overall distribution pattern and average velocities of the tracer gas movement in the gob and old workings.

TEST PROCEDURES AND EQUIPMENT

GENERAL

The general concept of the gas flow characterization experiments is to release a defined volume of tracer gas into the ventilation airflow or longwall gob, and then monitor (obtain gas samples) all potential exit points for the gas. By determining the tracer gas concentration (if any) in the periodic gas samples taken at the various

monitoring locations, and measuring the associated gas flow rate, the volume of tracer gas passing through each monitoring site can be calculated. Thus, the relative distribution of gas flow to the various outlet points can be determined. The velocities associated with the identified gas flow pathways can be calculated knowing the path length and travel times (first arrival, peak concentration, and tail) for tracer gas flow at each monitoring location. These are the basic gas flow characterization data required for optimizing longwall gob methane control strategies.

For the underground releases, most of the ventilation air was expected to flow to one or both of the bleeder fans. In addition to monitoring the bleeder fans, operating gob gas ventholes that were in the vicinity of the expected general flow path for the ventilation airflow towards the bleeder fans were also monitored. In several cases, underground SF₆ monitoring was conducted to determine if any ventilation airflow recirculated around the inlet evaluation point (IEP) release location(s) towards the main fan shaft. Migration pathways for the tracer gas introduced directly into the gob from the surface via the gob gas venthole was more speculative than that for the underground releases. Therefore, monitoring locations for the borehole injection experiment included the other two producing gob gas ventholes on the study panel, one venthole on the previously mined panel to the north, the two bleeder fans, and underground locations which would intercept any tracer gas that might migrate towards the main fan shaft.

GAS SAMPLING PROCEDURES AND EQUIPMENT

The periodic gas samples necessary to determine the presence (or absence) of the released tracer gas at the monitoring stations were collected in 20 ml Vacutainer glass sample tubes. These evacuated sample tubes draw in a sample of the gas to be sampled when the rubber stopper is punctured with a syringe needle or when a valve assembly attached to the needle is mechanically activated. Gas samples were obtained in two ways during the experiments. Primary sampling was accomplished with an automated gas sampling (AGS) system. The automated system was supplemented with manual sampling during critical time periods, primarily just after a tracer gas release, to better identify the first arrival of the tracer gas at a monitoring site.

The AGS device consists of a battery powered chart drive attached to a protective cylindrical metal housing containing twelve 20 ml Vacutainer sample tubes (figure 2). The Vacutainer sample tubes are inserted onto syringe needles, which are attached to Clippard Minimatic whisker valves on the external surface of the sample housing base plate. The normally closed vertical whisker valve/syringe needle assemblies are arranged equidistantly around the perimeter of the circular base plate. A horizontal actuating arm is attached with an adjustable collar to the vertical shaft of the chart drive positioned above the vertical whisker valves. A sample of the atmosphere inside the AGS housing is obtained when the rotating actuating arm deflects and opens a whisker valve, allowing the attached Vacutainer tube to draw in a sample.

The sample interval time is controlled by the rotational cycle time of the chart drive shaft, and the number and position of the Vacutainer sample tubes used. Each AGS housing had 15 pre-drilled potential sampling ports on the base plate. The standard configuration for the AGS devices during this study was to equip 12 consecutive sampling ports with Vacutainers, leaving 3 consecutive open ports (figure 2). This configuration allowed for the actuating arm to be set back one port position at the initiation of a sampling cycle, so that there was a delay equal to the desired sampling interval prior to the first sample being taken. The remaining two open ports were positioned at the end of the sampling cycle, so that there was additional time after the 12 periodic samples were taken, in case there were delays in retrieving the samples. It was important to retrieve the samples before the actuating arm (which would continue to rotate unless manually shut-off) reactivated the needle valves with the previously taken Vacutainer samples still attached, possibly contaminating the original sample.

The AGS system allowed for gas samples to be taken automatically at programable intervals, with the interval between samples commonly ranging from 6.4 minutes to 11.2 hours. The shorter sampling intervals (6.4 min) were generally used early in the experiments, just after a release, in an effort to document the first arrival of tracer gas at the various monitoring locations. The shorter sampling intervals also better characterized short duration peaks, in particular the maximum tracer gas concentration, as well as the tail. Longer sampling intervals (48 min) were used overnight during the first few days of each individual tracer gas release, and 3.2 and 11.2 h sampling intervals were used over weekends and later in the experiments when personnel were not available to change-out sampling tubes more frequently, as would be required for the shorter duration sampling intervals.

Operationally, the complete AGS system consisted of the automated gas sampling device sealed inside an air-tight container, and a Gilian GILAIR-5 permissible, programmable air sampling pump, external to the sealed container (figures 2 and 3). The intake side of the pump was connected via tubing to the air-tight container, which in turn was connected to the mine air/gas production point to be monitored, i.e., either the bleeder fan housing (figure 4), or the piping system of a gob gas venthole (figure 5). Thus, when the air sampling pump was on, the atmosphere inside the air-tight container was evacuated, pulling the mine air/gas production to be sampled into the container.

For atmospheric sampling applications underground, it was not necessary to use the air sampling pump and sealed container, since the AGS device (permissible) was sampling mine air directly. The cycling time of the air sampling pump and the AGS device were coordinated so that the pump was on and evacuating the air-tight container housing the AGS device prior to each Vacutainer gas sample being taken. This was done to obtain a fresh sample from the gas source being monitored each time a Vacutainer atmosphere sample was taken. It was calculated that the air sampling pump (operating

at 4L/min) would change-out the atmosphere in the container housing the AGS device in approximately 3 to 4 min. Therefore, approximately 2 to 7 atmosphere changes should occur in the AGS housing before each new sample was taken, depending on the sampling interval time.

GAS SAMPLE ANALYSIS

Two gas chromatographs (GC's) were used to generate the SF₆ data in this study. One GC was a bench-scale unit located at NIOSH's Pittsburgh Research Laboratory's (PRL) analytical lab in Bruceton, PA, and the second was a portable unit which was used primarily in the field at the Emerald Mine study site. The laboratory GC was used as the primary means to quantify SF₆ analysis in this study. This GC has a 6 ft millipore packed analytical column and an electron capture detector (ECD). Samples were introduced either via on-column syringe injection or through a 10 microliter 6-port sample loop. Of the two GC's used in this study, the laboratory unit has the lower detection limit (0.12 ppb SF₆). This value was used for the experimental minimum detection limit in this study. Consequently, the laboratory GC was used to define the arrivals and tails of the SF₆ tracer gas when SF₆ concentrations were below about 1 ppb. At SF₆ concentrations below 0.12 ppb, the data are considered to be non-quantitative, and are reported as zero concentration values. Since each individual tracer gas test in this study began with essentially 0% SF₆ in the air, reached a peak concentration, and then declined back to a concentration of 0 % SF₆, the range of SF₆ concentrations between 0 % and 0.12 ppb constitutes experimental error. This error is most significant at the bleeder fan monitoring sites where air flows were relatively high (in excess of 100,000 cfm).

The portable GC (figure 6) was acquired to serve primarily as a field unit to improve the quality of the SF₆ tracer gas tests and secondarily to supplement the analytical determinations being performed on the laboratory bench-scale unit. Gas sampling strategies in the field were modified based on the SF₆ results being determined on the portable GC. Once an SF₆ arrival was identified at one of the monitoring sites, the time interval between samples collected by the AGS's was reduced. The time interval between samples was also kept to a minimum at apparent inflection points on the SF₆ concentration versus time plots, and at a maximum between inflection points. This strategy was designed to maximize the SF₆ recovery percentage for each test, and to reduce the demands on field crews by avoiding the collection of numerous, short time interval gas samples prior to the first arrival of the SF₆ tracer gas.

The portable GC has a 6 ft Millipore packed analytical column, a 1 ft pre-column and an ECD. The portable GC also has a 10 port sampling valve which was equipped with a 1 ml sample loop. During this investigation, all SF₆ samples analyzed on the portable GC were introduced via on-column syringe injections. The SF₆ detection limit for the portable GC was found to be at a higher concentration than that of the laboratory bench

scale unit. Based on data from this study, the minimum detection limit for the portable GC was estimated to be 0.3 ppb and possibly as low as about 0.28 ppb. In this low ppb range, the portable GC was underestimating the actual SF₆ concentrations (based on the comparative results from the bench-scale GC). Results measured in this low concentration range on the portable GC were verified by additional concentration determinations performed on the same or similar gas samples using the laboratory bench-scale unit.

Gas samples were collected in 20 ml Vacutainer tubes and analyzed by one or both GC's to determine the concentration of specified chemical constituents. The majority of gas samples were quantitatively analyzed for the concentration of SF₆ tracer gas. A qualitative evaluation of oxygen concentrations was frequently made on this suite of gas samples as an internal check for experimental irregularities. The laboratory bench-scale GC was used to determine the overall composition of gas samples periodically retrieved from the surface borehole monitoring sites. These data were used as a supplement to the standard SF₆ tracer gas monitoring data, and to confirm experimental conditions at the various surface borehole monitoring sites.

UNDERGROUND RELEASES

GENERAL

Seven underground SF₆ tracer gas releases were conducted as part of this research effort. The majority of the underground releases were conducted at the IEP's located at the completion ends of the subject panels, as indicated on figure 1. In cases where the airflow velocities were low, or the airflow paths were not absolutely certain, releases were made at multiple IEP's for a panel to ensure that airflow associated with that set of entries would be completely evaluated. Two of the releases (Test 2-0 and Test 2-5) were conducted in the No. 2 entry, in by the active face on the tailgate side of G Panel. The location of these two tracer gas releases is approximately 4,000 ft west of the release point for the previous study concluded in February of 1997.

The locations for the underground SF₆ releases were chosen to assess a complete geographic distribution of gas flows from the 218 Mains area of the Emerald Mine. The releases were conducted at the completion (west) ends of the panels because the ventilation airflow for this part of the mine was to the back (east) ends of the panels where the two bleeder fans are located. Prior to the underground tracer gas releases, ventilation surveys were conducted throughout the underground study area to determine the airflow volumes and velocities in the vicinity of the proposed release sites. These data were used to design each individual release, including tracer gas volume and release method, i.e., fast versus slow, as summarized in table 1. The ventilation surveys were also used to determine possible recirculation areas where tracer gas might

travel outby the release points, which would require underground monitoring for the presence of tracer gas.

RELEASE SPECIFICATIONS

The SF₆ tracer gas used in the releases was 99.99 % pure and was contained in lecture bottles of various volumes ranging from 1.1 to 2.3 ft³ at standard temperature and pressure (STP) conditions (760 mm Hg, 0° C). Two methods of tracer gas release (fast or slow) are generally used for underground airflow studies such as those conducted as part of this research effort. A fast release would empty a standard 1.3 ft³ lecture bottle in as little as 30 seconds, producing a high peak concentration in the air stream at the release point and subsequently, a shorter duration, high concentration peak at the monitoring locations. It commonly took about 3 minutes to release two 1.3 ft³ lecture bottles for the underground releases conducted in this study. Previous research has suggested a maximum allowable limit of 100 ppm of SF₆ in air for this tracer gas to simulate the movement of the host air stream. The results of the work conducted as part of this current study determined that a velocity of 2,000 ft/min was generally the minimum airflow acceptable for a successful fast release of tracer gas from two lecture bottles. Most of the releases in this series of experiments were fast (table 1).

Primarily due to low airflow conditions at the release point, the slow release method was used for one underground release (Test 2-0, table 1), in an effort to stay below a 100 ppm maximum concentration. The slow release method empties a standard 1.3 ft³ lecture bottle in about 20 minutes. The slower release method is generally expected to produce a longer duration, lower concentration peak at the monitoring locations than would be observed with a fast release. The general wider dispersal expected from a slow release can be advantageous under circumstances where the tracer gas might disperse more completely and follow low-flow air courses.

MONITORING

The two bleeder fans (figure 1) were monitored for all underground tracer gas release experiments since most of the tracer gas was expected to flow through the bleeders to these fans. In addition, active gob gas ventholes that were geographically between the release points and the bleeder fans were monitored. Finally, if the ventilation surveys indicated a possibility of gas traveling outby the release point, underground locations along the potential recirculation path(s) were also monitored.

SPECIFICATIONS AND RESULTS OF INDIVIDUAL UNDERGROUND SF₆ RELEASES

Test 2-0

The first test was designated Test 2-0. This test was designed and performed by Emerald Mine personnel, with technical assistance provided by the NIOSH research staff. The SF₆ release was located in the F Panel bleeder and former headgate, just inby the G Panel face (figure 7). The test configuration called for a simultaneous release of two lecture bottles of SF₆ (table 1). At the time of the tracer gas release, G Panel was active and the face location is given in figure 7. Tracer gas monitoring sites included Bleeder Fans 2 and 3, and gob gas ventholes G1, G2, and G3 (figure 1). All three gob gas ventholes were equipped with surface exhausters. However, the exhauster on G1 was not operating due to mechanical problems, and the exhauster on G3 was operating with a tank of propane gas as a fuel source. The exhauster at G3 was started just before the test began and ran out of fuel less than 1 hour after the cessation of tracer gas monitoring.

The automated gas sampling system was not used for tracer gas monitoring during Test 2-0. Tracer gas monitoring for this test consisted of manual hand sampling at the surface sites. No tracer gas was present in any of the samples from any of the monitored locations on the day of the release. Samples collected the following day at the same locations by mine personnel showed evidence of tracer gas above detectable limits at all of the monitoring locations except for G1 (figure 1, table 1). At the time of gas sample collection on the day following the tracer gas release, the exhauster on gob gas venthole G2 was running, and the exhausters on G1 and G3 were idle, but the holes appeared to be free flowing gas.

No determinations of recovered tracer gas volumes could be made for Test 2-0. Test 2-0 consisted of essentially only a single data point in time that was above the SF₆ detection limit at each monitoring location. A significant result from this limited data collection test is the determination of travel time that was required for the tracer gas to reach the monitoring locations where it was detected. It took over 24 hours for the tracer gas to reach BF2, BF3, G2, and G3 (figure 1). A second important aspect of the test results is that the tracer gas migrated from the release point in the underground bleeder system to gob gas ventholes G2 and G3 (figure 7). Unfortunately, it is not possible with the limited data to estimate how much of the tracer gas volume may have actually migrated to these gob gas ventholes from the underground release into the ventilation airflow.

Test 2-1

Test 2-1 was designed and conducted by NIOSH with assistance from the Emerald Mine engineering staff. It represented the initiation of a PRL field study utilizing standard NIOSH research protocol, which includes a tripartite (regulatory agencies, organized labor, and mine management) Opening and Closing Meetings for the research study, and this Closing Report. Test 2-1 was conducted on the A+ Panel (figure 1), with two releases of tracer gas (table 1) from the IEP locations designated 1 North No. 1 and 1 North No. 2 (figure 8). One lecture bottle was first released from the IEP-1 North No. 1 followed by a second release 1 hour and 45 minutes later from the IEP-1 North No. 2.

The AGS system was installed at all surface monitoring sites during Test 2-1, and all surface monitoring sites in subsequent tests, except where only manual sampling is specifically indicated. However, available equipment limited the number of automated monitoring stations to three sites for this test, and subsequent Tests 2-2, and 2-3. Tracer gas monitoring was conducted at gob gas venthole A+1, and Bleeder Fans 2 and 3 (figure 1). It was recognized that BF3 was not a likely outlet point for SF₆ migration from the Test 2-1 tracer gas release due to the ventilation pattern in the 218 Mains area of the mine. However, due to the high ventilation airflows to Bleeder Fans 2 and 3, and the low detection limit for SF₆, it was decided to incorporate tracer gas monitoring at both bleeder fan sites for this and all other tracer gas tests. The exhaustor on gob gas venthole A+1 was not operational during the test but a free flow of gas from the borehole was observed.

Figure 9 shows a plot of sulfur hexafluoride (SF₆) concentration versus time for Test 2-1. The SF₆ concentration peaked at about 595 ppb. Figure 10 shows a plot of the cumulative SF₆ recovered over time during Test 2-1. The total recovery of SF₆ during tracer gas monitoring was about 66% of the released volume (table 1).

The tracer gas release into the two IEP's was designed to address multiple airflow pathways in the bleeders. The delay between releases was incorporated in attempt to distinguish the two slugs of SF₆ which were anticipated to have potentially different travel times. The twin peak form was preserved and is clearly visible in figure 9. The relatively high airflow rates, particularly in IEP-1 North No. 2, probably limited the amount of mixing from the two releases and enhanced the preservation of the double peak form. The arrival of SF₆ at BF2 occurred just 45 minutes after the initial release and the tail was identified at 14.5 hours (figure 9). The inflection point on the cumulative recovery curve shown in figure 10 corresponds to the trough between the two SF₆ concentration peaks shown in figure 9. The relatively low SF₆ recovery rate (given the rapid travel times in Test 2-1) and high concentration of the SF₆ arrival (figure 9) may indicate that some of the initial tracer gas slug was missed, perhaps due to a problem with the monitoring apparatus at the BF2 monitoring site.

Test 2-2

The tracer gas release for Test 2-2 was located on B Panel (figure 1). The release location was in the IEP-B Panel (figure 8), where two lecture bottles of SF₆ were simultaneously released (table 1). Tracer gas monitoring during this test was conducted at the gob gas venthole A+1, and Bleeder Fans 2 and 3. The exhauster on gob gas venthole A+1 was not operational during the test but the hole was free flowing gas.

The only arrival of the tracer occurred at BF2, at about 5½ hours after the initial release (figure 11). The SF₆ peak (31 ppb) occurred about 10 hours after the release, followed by the tracer gas tail at approximately 3 days. The 89% recovery of the released tracer gas volume at BF3 (figure 12, table 1) indicates that the monitoring system was successful in detecting a high percentage of the released gas from the available migration pathways.

Test 2-3

Test 2-3 was performed on A Panel (figure 1). The test plan specified two release locations, IEP-A Panel and IEP-A+ Panel No. 1 (figure 8). The first release was made in the IEP-A Panel location, followed by the second release about 1½ hours later, in the IEP-A+ Panel No. 1 location (table 1). Tracer gas monitoring was conducted at BF2 and BF3, and the A+1 gob gas venthole (figure 1). The exhauster on gob gas venthole A+1 was not operational during the test, but the hole was free flowing gas. SF₆ was recovered from the A+1 borehole (figure 13) and BF2 (figures 14 and 15). The peak concentration of recovered SF₆ was about 57 ppb from BF2 (figure 14). The recovery from BF2 was about 55% of the released tracer gas volume.

Test 2-3 is one of four tracer gas tests performed in this study which demonstrated some interaction between the ventilation system/bleeder network and the gob gas ventholes (the other tests which displayed similar interactions are Test 2-0, Test 2-5 and Test 3-1). Only two gas samples retrieved from gob gas venthole A+1 contained concentrations of SF₆ over the 0.12 ppb detection limit (figure 13). Although the AGS monitoring system was not particularly well suited for obtaining gas samples from gob gas ventholes producing gas under free flow conditions, the recovered volume of SF₆ from the A+1 gob gas venthole is estimated to be only a few ten-thousandths of a percent of the released tracer gas volume. Although it is possible that gas monitoring could have missed some of the SF₆ volume at this location, the low magnitude of the peak concentration and the steepness of the rise and fall of the gas concentration over time suggests this was a very short duration, low volume, tracer gas recovery site (figures 13 and 15).

The graph of SF₆ concentration against time for BF2 during Test 2-3 (figure 14) seems to display some of the twin peak configuration indicative of the time delay between

lecture bottle releases, similar to that observed in Test 2-1 (figure 9). The first arrival of the tracer gas occurred two hours and 10 minutes after the release (figure 14). The two peaks occurring between about 4½ and 5½ hours and the tail at 4 days, 3 hours. The overall tracer gas recovery for Test 2-3 was less than 60% of the released gas (figure 15, table 1).

Test 2-4

Test 2-4 was conducted on C Panel and included two underground tracer gas release points (figure 7). The two release point locations were IEP-C Panel No. 1 and IEP-C Panel No. 2. Two lecture bottles were released from IEP-C Panel No. 1 and about 1:30 hours later, one lecture bottle was released from IEP-C Panel No. 2 (figure 7, table 1). Tracer gas monitoring sites during Test 2-4 were BF2, BF3, D1, E1, and F1 (figure 1). Due to concerns about the low airflow velocities at the release points and potential for tracer gas recirculation, an underground tracer gas monitoring site was incorporated and was designated UG-CBR (figure 7). During the monitoring period, gob gas ventholes E1 and F1 were producing gas via their exhausters. The D1 exhauster was not operating, however flow measurements indicated it was free flowing gas. Figure 16 shows the concentration of the tracer recovered at the underground monitoring location UG-CBR, which accounts for about 0.7% of the released tracer gas volume. The only other monitoring site for Test 2-4 where tracer gas was detected was BF2 at a peak concentration of about 10 ppb (figure 17). About 85% of the released tracer gas volume was recovered at BF2 (figure 18).

The underground monitoring site at UG-CBR during Test 2-4 indicates a relatively high peak of about 150 ppb (figure 16). This was a relatively short lived peak (arrival at 37 minutes and a peak at 42 minutes), with the tracer gas concentrations returning to near background levels within the monitoring period. At BF2, the tracer gas slug arrived at about 7 hours, attained a relatively low peak at about 34 hours, and the tail was detected at slightly over eight days (figure 17). The total tracer gas recovery was about 86% of the released gas (figure 18, table 1). The underground tracer gas recovery was attributed to the SF₆ dispersal technique, which may have allowed some of the tracer gas to be “oversprayed” outside the margins of the IEP opening, which then recirculated in the underground workings.

Test 2-5

Test 2-5 was conducted in the bleeder which comprised the former F Panel headgate (figure 1). The release was made in the center entry and the release point was just outby the final position of the F Panel face (figure 19). Four lecture bottles were utilized in two pairs of 2-bottle simultaneous releases (table 1). Due to the low airflow velocity in the entry designated for the release, underground manual tracer gas monitoring was included in the test procedure at locations UG-F1 and UG-F5 (figure 19). Surface tracer

gas monitoring locations included BF2, BF3, G1, G2, G3, and F1 (figure 1). Of the gob gas ventholes, G2 and F1 were producing gas with operating exhausters; the exhausters at G1 and G3 were not operating but the boreholes had the potential to free flow gob gas. Tracer gas was detected at UG-F5, BF2, BF3, and at G2 (figures 20 - 23). Both BF3 and UG-F5 recovered slightly more than 1% of the released SF₆. The BF2 site recovered just over 56% of the released gas (table 1).

The results from the underground monitoring indicated that during Test 2-5, tracer gas did reach the UG-F5 location shown in figure 20 (no tracer gas was detected at the other underground monitoring site UG-F1). The arrival of SF₆ at UG-F5 occurred at 65 minutes and the peak at 90 minutes. Analysis of the underground sampling indicates that sample collection (manual) was terminated before the SF₆ tail reached the UG-F5 monitoring site (figure 20). Therefore, the SF₆ recovery data underestimates the true volume of tracer gas that flowed through this monitoring site (table 1), because of the inadvertent termination of the UG-F5 monitoring when SF₆ concentrations of roughly 40 ppb were still present in the airstream. Ventilation system changes during recovery operations at the former G Panel face are thought to be the primary reason for the observed tracer gas recirculation.

Gob gas venthole G2 had a tracer gas arrival at about 15.5 hours, a peak at about 28.5 hours, and a tail at just over 23 days (figure 21). Figure 23 is a cumulative plot of the relative amount of tracer gas recovered at all monitoring sites where tracer gas was detected during Test 2-5. The G2 site accounted for about 0.74 % of the recovered tracer (table 1). At BF3, there was a tracer gas arrival at 9 hours 40 minutes, a peak at 12.5 hours, and a tail at about 28 hours (figure 22). The recovery of tracer gas at BF3 was between 1.1 and 1.2 % of the total released gas volume. Most of the tracer gas recovery from this test (56%) was recovered at BF2 (figure 23). The tracer gas arrival at BF2 occurred at slightly over 14 hours, the peak at just over 1 day, and the tail at just over 6 days.

Test 2-5 (figure 19) was very similar in design to Test 2-0 (figure 7). The major operational differences between the two tests were: 1) Test 2-0 was performed before G Panel had been completely mined out, and Test 2-5 was performed about 1.5 months after the panel was completed and after some degree of gob consolidation; 2) Test 2-5 utilized a variety of modern gas monitoring and analytical equipment (including the first field use of the portable GC), which facilitated quantitative SF₆ determinations in the field on nearly a real time basis, to characterize the movement of the tracer gas slug; and 3) ventilation system changes related to the longwall move from G to H Panel and the recovery operations at the completion (outby) end of G Panel.

The most significant variation in results between Test 2-5 and Test 2-0 are; 1) the arrival of tracer gas at the G3 gob gas venthole during Test 2-0 and, 2) the arrival of tracer gas at an underground monitoring station during Test 2-5, presumably due to recirculation of

some tracer gas in the ventilation air. The two months that transpired between Test 2-0 and Test 2-5 may have produced an increased degree of gob consolidation. However, there is no tracer gas evidence from a comparison of the two sets of test results to support this conclusion.

A review of the ventilation practices in use on G Panel during Tests 2-0 and 2-5 suggests a potential cause for the tracer gas recirculation during Test 2-5. Figure 24 shows the ventilation system design that was in use during Test 2-0 when the G Panel face was still retreating under normal mine production conditions. As previously described, the G Panel intake air flowed from the submains down the headgate, and was split at the headgate corner with the majority of the air crossing the face and the remainder continuing down the headgate into the bleeders at the back of the panel, and ultimately to BF3. The air crossing the face is split at the tailgate corner with part of the air flowing in an outby direction in the tailgate and the remainder flowing inby between the mined-out F and G panel blocks.

During Test 2-5, G panel was mined out. The ventilation system had also been modified which produced more negative differential pressures at the regulators in the former G Panel tailgate gateroad (figure 25). The completion of G Panel, and the removal of all longwall shield supports left a highly rubblized zone (gob) between the G Panel headgate and tailgate, whereas, in Test 2-0, an open airway had existed between the shields and the longwall shearer. The release locations for Test 2-0 and 2-5 were very similar (figure 19). The tracer gas release in Test 2-0 allowed the gas to migrate in an inby direction and initially between the two mined out F Panel and G Panel longwall blocks (figure 24). Tracer gas release Test 2-5 began in the same way, however, the airflow from the G Panel headgate to tailgate was now greatly reduced due to the formation of the G Panel gob and the resulting increased airflow resistance following the longwall move out of G Panel (figure 25). The enhanced negative pressure (compared to Test 2-0) outby the release location in the G panel headgate and limited flow across the former G Panel face tended to pull the tracer gas from Test 2-5 back out of the gob and towards the submains. The recirculation of tracer gas during Test 2-5 appears to reflect the actual movement of some of the ventilation air during the test, and is probably not representative of procedural problems during the Test 2-5 release.

Test 2-6

Test 2-6 was conducted on E Panel (figure 1) and the release point was in IEP-E Panel (figure 7). The tracer gas release included four lecture bottles of SF₆ in two pairs of 2-bottle simultaneous releases (table 1). The tracer gas monitoring locations included BF2, BF3, D1, E1, and F1. Two underground locations for manual tracer gas monitoring were included and designated UG-E1 and UG-E2. Tracer gas was detected only at BF2. Results from Test 2-6 indicate that the slug of tracer gas was relatively slow moving, with its arrival at BF2 occurring about 8 hours after the release (figure 26). The

peak concentration during this test was measured at 28.5 hours, and the tail at 6 days, 20 hours, and 50 minutes. The total recovery just below 69%.

AIRFLOW VELOCITY DETERMINATIONS FOR UNDERGROUND RELEASES

Migration velocities for the movement of SF₆ slugs associated with the underground tracer gas tests are shown in table 2. This table shows the migration velocity of the SF₆ arrivals from the release location to each monitoring location where detectable levels of the tracer gas were measured. No velocity determinations could be made using the data from Test 2-0. Velocity determinations can also be made relative to either the occurrence of the tracer gas peak or the tail. These values are not included in table 2, but are proportional to the arrival times, only slower, with velocities 1 to 2 orders of magnitude lower than the arrival time velocity data.

Table 2 shows that the highest migration velocity based on the arrival time data is on the order of 260 ft/min to the BF2 monitoring site during Test 2-1. The slowest moving slug of SF₆ which migrated to the BF2 monitoring site, was 17 ft/min during Test 2-5. The monitoring sites at BF3, A+1, and G2 each yielded only 1 tracer gas show during the various underground tracer gas release tests. The migration of tracer gas to G2 during Test 2-5 produced a velocity of 5 ft/min, the slowest measured for this suite of tests.

Table 3 shows the duration of tracer gas flows for each monitoring site where SF₆ was detected. The shortest flow duration was measured at the underground monitoring location during Test 2-4. The underground tracer gas monitoring data from Test 2-5 does not represent the duration of the complete tracer gas slug because tracer gas monitoring was terminated prematurely. The longest duration of tracer gas flow was 22.4 days to the G2 monitoring site during the Test 2-5.

G3 BOREHOLE INJECTION

GENERAL

The final tracer gas release experiment conducted at the Emerald Mine test site in 1997 was an injection into gob gas venthole G3. The hole is located on the completion (west) end of G panel, approximately 150 ft off the centerline (tailgate side of the 1,000 ft wide panel), 1,300 ft from the longwall take-out room and 8,500 ft from the start-up end (figure 27). An injection of tracer gas directly into the gob and subsequent monitoring of probable outlet points would provide significant insight to the migration of gas through the gob. At the time of the release on July 21, 1997, it had been approximately 5 months since hole G3 had been mined through, and 3.6 months since G panel had been completed. The adjoining H panel longwall face was approximately 2,300 ft east of hole G3 and 180 ft west of hole G2 at the time of the injection (figure 27). Hole G3 was

inactive at the time of the injection, and had not produced gob gas for 2.3 months. The hole was shut-in, but when opened, it would intake into the gob. These conditions were ideal for dispersal of the tracer gas into the gob. Had there been a positive flow of gas out of the borehole, the injection experiment would have been significantly more complicated.

All well-head equipment, except for the gate valve, were removed from gob gas venthole G3 prior to the injection experiment. A new well head assembly that would facilitate the tracer gas injection and subsequent monitoring of the shut-in borehole was installed (figure 28). The depth to the Pittsburgh Coalbed at the G3 site was 628 ft. The borehole (figure 29) was originally drilled to a depth of 587 ft, and 7-in casing with 200 ft of slotted pipe on the bottom was installed. The pipe above the slotted casing was cemented in place. The slots were approximately 2 in x 1 ft, oriented vertically, with 4 rows (2 slots/row) for each 20 ft length of pipe in the 200 ft slotted interval. Approximately 45 ft of rock was present between the bottom of casing and the top of the Pittsburgh Coalbed prior to this location being intercepted by mining, and the subsequent collapse of the overburden into the mine void.

RELEASE SPECIFICATIONS

The original concept for the borehole injection experiment was to inject the tracer gas into the borehole via tubing, at a point near the bottom of the borehole. However, prior to releasing the tracer gas, gob gas venthole G3 was probed with a weighted wire line. An obstruction was encountered at 137 ft, limiting the depth for the release. Two 1/8-in-ID polyethylene lines were installed in the hole, one to a depth of 120 ft to release the tracer gas, and the other to a depth of 110 ft for periodic monitoring of the SF_6 concentration after the release. After the injection was completed, a 0 - 1 psi range pressure transducer was attached (at the surface) to the polyethylene line installed to the 120 ft depth to continuously monitor the shut-in pressure of gob gas venthole G3 (figure 28). The shut-in pressure was measured every 30 sec, and the 15 minute average was stored on an electronic data logger.

The tracer gas release into gob gas venthole G3 was the largest (by volume) of the study, with 9.62 ft³ (STP) of SF_6 being release over a 25 min time interval. To conduct the borehole tracer gas release, certain procedural changes were incorporated based upon the findings from the previous underground tracer gas releases. The underground tracer gas releases into areas of low airflow velocity had produced relatively low recovery rates. In an attempt to enhance the recovery of the SF_6 during the borehole injection experiment, the decision was made to significantly increase the volume of the tracer gas release over that of the prior underground releases. A single large tank containing the high purity SF_6 was utilized for the borehole injection experiment instead of the smaller lecture bottles used in the underground releases. Due to the limited free space available in the injection borehole and large volume of tracer gas injected, it was

not possible to keep the tracer gas concentration below the recommended 100 ppm concentration in air.

Gob gas venthole G3 was open and intaking for a short time before and after the SF₆ release to aid in dispersing the tracer gas into the gob. The hole was intaking for approximately 35 min at 66 cfm during the release. The intake volume of about 2,300 ft³ was sufficient to displace the volume of the borehole 100 times, helping to ensure that the tracer gas was dispersed into the gob. In addition, the release tubing line was flushed with approximately 50 ft³ of nitrogen, a volume sufficient to displace the tubing volume 30 times. At the end of the injection, the hole was shut-in, and wellbore pressure monitoring was initiated.

MONITORING

The monitoring strategy for the borehole injection experiment included all outlet points for the most likely migration path(s) for gas released into the gob from the location of gob gas venthole G3. The probable migration pathways were determined by evaluating a combination of factors, including ventilation surveys, methane drainage system configuration, and results from the previous underground releases. The available data indicated that the most likely direction of flow for the tracer gas released into G3 was towards the back (start-up) end of the panel, primarily due to the influence of the two bleeder fans and the two other producing gob gas ventholes on the panel (figure 27). The two additional gob gas ventholes on G panel (G2 and G1), as-well-as producing gob gas venthole F1 on the adjoining panel, and the two bleeder fans (BF2 and BF3) were equipped with AGS systems. In addition, monitoring stations were established in F and G returns underground (figure 27) in the event any of the tracer gas was recirculated back to the main fan(s). These underground stations were monitored for approximately 2 1/2 weeks.

RESULTS

The presence of tracer gas was not detected at either of the underground monitoring locations or at gob gas venthole F1. The first arrival of tracer gas after the release into gob gas venthole G3 was at gob gas venthole G2, the closest inby producing hole on the same panel (figure 27). Tracer gas was first detected in gas samples 1.1 days (27 h) after the release, at concentrations of 0.5 ppb (figure 30). Table 4 shows calculated velocities for tracer gas flows to the various detection points monitored for the borehole injection experiment. The path lengths include the distances traveled vertically in the boreholes/fan shaft, as well as the horizontal distance through the gob/mine entries. The velocity (first arrival) of tracer gas flow from the release point in G3 to the measurement point at the surface on hole G2 is 2.4 ft/min. Peak concentration was 1,309 ppb, 7.1 days after the release. As can be seen on figure 30, hole G2 was taken off production on day 25, before tracer gas had completely cleared this location. The

hole was shut-in due to insufficient methane concentrations to run the methane fueled engine that powered the exhauster. At the time hole G2 was taken off production, 23.9 days after the SF₆ tracer gas was first detected, 75.3% of the injected gas had been recovered at this location (figure 31, table 1), and the SF₆ concentration was still at 111 ppb.

The second monitored location where SF₆ tracer gas was detected was gob gas venthole G1, the next inby producing hole on the same panel (figure 27). Tracer gas was first detected in gas samples 15.3 days after the release at concentrations of 0.43 ppb (figure 32). Peak SF₆ concentration was 43.65 ppb, 25.1 days after the release. The significantly lower peak concentration level, as compared to that at hole G2, is an indication that the injected gas had become much more widely dispersed in the gob atmosphere as it migrated inby past hole G2. Flow velocity (first arrival) to this location was 0.36 ft/min, significantly slower than the 2.4 ft/min observed for flow to G2 (table 4). It is important to note that the exhauster on hole G1 stopped running late on the first day of the release due to mechanical problems, and was not back on production until day 9. It seems likely that if gob gas venthole G1 had been on production the entire time, tracer gas would have migrated to this location in a shorter time. Total SF₆ recovery (288 days duration) from G1 was 3.2% (figure 31, table 1).

The only other confirmed location to which tracer gas migrated from the G3 borehole injection experiment was Bleeder Fan 2 (figure 27). Tracer gas arrived at this location on day 30 after the release (figure 33). Tracer gas was detected at BF2 only four days after gob gas venthole G2 went off production on day 26 of the test. It is possible that the tracer gas was able to migrate out of the gob to the mine's ventilation system due to the disruption of the primary gob gas flow path towards the diminishing low pressure sink of G2 when this hole went off production. Peak concentration at BF2 was only 0.25 ppb on day 35, or about 2x the analytical lab's SF₆ detection limit (figure 33). The low concentration level at the bleeder fan, as compared to the gob gas ventholes, is due to the significantly larger volume of mine air in which the tracer gas volume is diluted. At the time of the borehole injection experiment in July of 1997, the total flow from BF2 ranged from about 120,000 to 150,000 cfm, compared to only about 330 cfm at G2 and G1. The duration of tracer gas at BF2 was 9.2 days, for a total recovery of 4.5% (figure 31, table 1).

The shut-in injection hole (G3), was also periodically monitored to determine if the tracer gas was being dispersed into the gob, and at what point it had completely flushed from this area of the gob. The SF₆ concentration at the measurement location, 110 ft below the surface in G3 peaked at 30.47 ppb approximately 4 hours after the tracer gas injection (figure 34). The SF₆ concentration then gradually declined to a level of ≤ 1.0 ppb at a test time of 7.2 days. A second short duration peak (14.13 ppb) in the SF₆ occurred 81 days, and a third, longer duration elevated level of SF₆ began on test day 121.

In an attempt to clear the remaining SF₆ from the G panel gob, hole G3 was opened to the atmosphere for 5 hours on March 10, 1998, day 232 after the tracer gas injection (figure 34). The procedure for this operation was conducted as approved by MSHA. The hole was on intake after opening, and approximately 14,000 ft³ of air was allowed to flow into the gob. Gas samples immediately proceeding the opening of the hole indicated a very low concentration of SF₆ (≤ 0.12 ppb), although concentrations 4 days earlier had been over 2.0 ppb. Immediately following the flushing operation, SF₆ concentrations remained low (maximum of 0.57 ppb). SF₆ concentrations climbed to over 3.0 ppb, 21 days after the flush (day 253 of the study). The volume of air calculated to have entered the gob during the flush was probably not sufficient to efficiently and quickly move the remaining tracer gas from the void space in the gob. SF₆ concentrations at G3 did not fall below the 0.12 ppb detection limit of the laboratory based GC until July 13, 1998, 125 days after the flush (day 357 of the study).

DISCUSSION OF BOREHOLE INJECTION TEST RESULTS

The primary findings from the borehole injection experiment were: 1) most of the tracer gas that was injected into the gob stayed in the gob, and was recovered from the ventholes in by the injection borehole, and 2) all three gob gas ventholes on the test panel were in communication with each other. Approximately 83.0% of the tracer gas injected into gob gas venthole G3 was recovered through day 303 of the borehole injection experiment (figure 31). Only 4.5% of the released gas was recovered at a location (BF2) outside the longwall panel. Tracer gas was first observed at BF2 on day 30 of the experiment (figure 33), approximately 4 days after gob gas venthole G2 went off production. SF₆ was present at BF2 for nine days.

It is speculated that the presence of tracer gas in the ventilation system is a direct result of G2 going off production. In addition to the time coincidence factor noted above, the close proximity of the gob gas venthole locations to the gateroads on the tailgate side of the panel provides additional support for a connection between the arrival of the tracer gas at BF2 shortly after the loss of active gas production at G2. Injection hole G3 is only about 300 ft from gateroads on the tailgate side of the panel, a considerably shorter flow path than the 2,500 ft between G3 and G2. If the pressure sink created by active gob gas production aided by the exhaustor at G2 had not been so dominating, it would seem likely that tracer gas would have been able to flow the relatively short distance to the gateroads from G3 in a shorter time than the observed 30 days. Therefore, when G2 went off production, tracer gas flow from the vicinity of G3 was eventually influenced by the pressure sink of the ventilation system. As the pressure sink in the gob diminished in vicinity of G2, some of the remaining tracer gas at the completion end of G panel was able to migrate to the ventilation system, and was eventually detected at BF2. No other occurrence of tracer gas was observed at any location outside the longwall panel.

One important caution must be noted at this point relative the observations of gas flow paths discussed above. At the time the borehole injection experiment was conducted, G panel had been completed for 3.6 months, and considerable gas had already been removed from the panel via the 3 gob gas ventholes. It does not necessarily follow that similar results, i.e., minimal gas flow into the ventilation system from the gob would be observed when the longwall was active. During active mining on the panel, a higher (but at this point unknown) portion of the gob gas probably does reach the ventilation system, along with gas emissions from the face. It is also possible that gob gas may enter the ventilation system on the headgate side of the panel during longwall mining, since the gob gas ventholes are placed on the tailgate side of the panel. The gas flow patterns in the gob during active longwall mining are an important unknown that should be addressed in subsequent investigations.

All three gob gas ventholes on G panel were shown to be in communication with each other, as shown by the detection of the tracer gas injected into G3 at both of the inby ventholes. A second line of evidence that supports the communication between the three gob gas ventholes on the study panel is that variations in gas production at G1 and G2 influenced the shut-in pressure at G3 (figure 35), and in some instances, production from each other. As can be seen on figure 35, at the start of the borehole injection experiment and the shutting-in of G3, both G1 and G2 were producing gob gas. The shut-in pressure at G3 was decreasing, as would be expected with the extraction of gas from the gob with the aid of an exhausters via holes G1 and G2. However, at day 0.9 of the experiment, G1 went off production. Concurrently, the shut-in pressure at G3 began to rise. G1 was off production for approximately 8 days, during which time the shut-in pressure at G3 stabilized at about -7.5 in water gauge, and gas production from G2 rose slightly. On day 9, production was restored on G1 for about 4 days, before going off production again for 2 days. The shut-in pressure at G3 declined again due to the extraction of gob gas from G1 during the 4 days of production, and gob gas production from G2 declined. During the short time (2 days) that G1 was off production again, the shut-in pressure at G3 increased, as did the production from G2. When G1 came back on production on day 15, the shut-in pressure at G3 and gas production from G2 once again decreased.

The SF₆ migration time (first arrival) from the injection point in G3 to the next gob gas venthole inby the release point was relatively quick (1.1 days) considering that it had been approximately 5 months and 6 months, respectively, since G3 and G2, had been mined through. With this amount of time for compaction to have taken place in the gob between G3 and G2, and the obstruction at 137 ft in the injection borehole, it is a little surprising that a velocity (first arrival) of 2.4 ft/min was observed between these 2 gob gas ventholes. The maximum migration path length (3,888 ft) includes the 518 ft from the injection point in G3 to the top of the coalbed at that location, the horizontal distance between G3 and G2 (2,500 ft), and the 870 ft from the bottom of G2 to the surface measuring location. If one were to assume that the time for the tracer gas to travel up

borehole G2 was essentially instantaneous, then the migration path length is 3,018 ft, and the resultant velocity is somewhat lower at 1.86 ft/min (table 4). It is also possible that tracer gas flowed at a horizon shallower than the mined-out Pittsburgh Coalbed, again resulting in a lower calculated velocity.

As mentioned previously, gob gas venthole G1 was off production for approximately 8 days, beginning at 0.9 days after the tracer gas release. The calculated velocity (first arrival) for the 15.3 days of total elapsed travel time for the tracer gas from the injection point in G3 to the surface monitoring location at G1 is 0.36 ft/min (table 4). However, if the time G1 was off production (and the velocity presumably reduced), is subtracted from the total test time before the first arrival of SF₆ at G1, then a velocity of 0.77 ft/min is calculated as an estimate for gas flow to gob gas venthole G1, if it had remained on production early in the experiment. The maximum migration path length (8,036 ft) includes the 518 ft from the injection point in G3 to the top of the coalbed at that location, the horizontal distance between G3 and G1 (6,800 ft), and the 718 ft from the bottom of G1 to the surface measuring location. If one were to assume that the time for the tracer gas to travel up borehole G1 was essentially instantaneous, then the migration path length is 7,318 ft, and the resultant velocity is 0.70 ft/min.

G2 was off production for approximately 2 days starting on day 20 of the experiment, at which time the shut-in pressure at G3 rose by about 7-in water gauge. This is a significantly greater influence on the shut-in pressure at G3 as compared to the pressure increases observed when G1 was not producing. This is due to G1 being 4,300 ft further away from G3 than is G2. Finally, on day 26, G2 was off production for the rest of the experiment, causing a permanent rise in shut-in pressure at G3 to an average of about -4-in water gauge. There was also a slight rise in average gas production from G1 after G2 was off production.

EVALUATION OF GOB GAS VENTHOLE PERFORMANCE

Since the ultimate goal of the gob gas characterization studies is to optimize methane control strategies for longwall gobs, it was necessary to document the baseline performance of the current gob gas ventholes at the Emerald Mine. These baseline data would then be one benchmark against which the success of any suggested optimization strategies could be judged. The gob gas venthole production data necessary for this part of the study was supplied by the mine operator. The time interval for the gas flow data for the gob gas ventholes was widely spaced, typically reported every two weeks. These widely spaced data made it difficult to correlate the gob gas production to specific mining events.

Initially, a qualitative (relative performance) scale was applied to the gob gas venthole production data for all the panels in the 218 Mains area of the mine. This qualitative

scale was based on a combination of methane production rate and sustained production time (table 5). The results of this evaluation are shown in table 6. Inspection of the results of the qualitative ranking suggested that the gob gas ventholes on the start-up ends of the panels performed the best, especially on the later panels (D through G, figure 1) in this area of the mine. To quantify this observation, the average gob gas venthole cumulative methane production by location on the panel (start-up end, center, and completion end) was plotted (figure 36). It is quite evident that the average cumulative methane production from gob gas ventholes on the start-up end of the panels is by far the highest of the three general hole locations. The average cumulative methane production of approximately 146 MMcf for the holes on the start-up end of the panels is nearly three and one half times the production from the holes located near the center of the panels, and more than 6 times the production from the holes located at the completion end of the panels.

A combination of factors probably contributes to the high level of methane production from holes on the start-up end of the panels. Being on the start-up end of the panels obviously means that these are the first holes to come on production, therefore they have a time advantage for longer term gas production, which generally results in higher cumulative gas production. Also, a general flow direction for gas in the gob and ventilation airflow towards the start-up end of the panels is established early by the presence of the first gob gas venthole on this end of the panels as well as the bleeder fans located at the back end of the panels. In contrast to the gob gas production trends established at the Emerald Mine study site, USBM studies at the Cambria 33 Mine operating in the Lower Kittanning coalbed, Cambria County, PA, showed that gob gas ventholes on both ends of the panels produced at the highest rates. The Cambria 33 Mine study demonstrated that given enough time, cumulative gob gas production from the holes on the completion end of the panels eventually caught up to that of holes on the start-up end of the panels. The primary difference between these two mine sites is that the Cambria 33 Mine did not use bleeder fans on the back ends of the panels were not used at.

Based on the evaluation results for gob gas venthole performance, it would appear that optimizing the performance of gob gas ventholes outby those on the start-up end of the panels would probably have the greatest impact. Additional data on gob gas flow characteristics during active mining would be helpful for research efforts relative to improving the performance of these gob gas ventholes.

EVALUATION OF BLEEDER FAN PERFORMANCE

To complete the evaluation of the overall methane control system in the Emerald Mine study area, methane vented by the two bleeder fans was also tabulated. Gas flow data for the bleeder fans was supplied by the mine operator. Like the gob gas venthole data,

the bleeder fan flow data were taken at widely spaced intervals (typically every two weeks), which made it difficult to correlate to specific mining events.

Figure 37 shows the quarterly cumulative methane production from each bleeder fan as well as from the producing gob gas ventholes. Methane flow from Bleeder Fan 2 for the 1st quarter of 1996 was approximately 243 MMcf and declined slightly to about 220 MMcf during the second quarter of 1996. At the same time as Bleeder Fan 2 declined in production, there was an increase in gob gas venthole methane production, suggesting a link between the two methane control systems. In August of 1996 (middle of the 3rd quarter), Bleeder Fan 3 began venting gas, and mining on G Panel began. As Bleeder Fan 3 came on production, there was a decrease in methane flow from Bleeder Fan 2. The combined total methane production for the two bleeder fans was 247 MMcf, a slight increase from the previous quarter when only Bleeder Fan 2 was producing. As methane production from the two bleeder fans increased during the 3rd quarter of 1996, there was a decrease in gob gas venthole methane production, again suggesting that methane production from one methane control system has an influence on the other.

During the 4th quarter of 1996, methane production from Bleeder Fan 3 increased significantly while production from Bleeder Fan 2 continued to decline. Total bleeder fan production increased about 117 MMcf to 364 MMcf. Gas production from the gob gas ventholes also increased during this quarter. It is important to note that mining had begun on G panel midway through the 3rd quarter of 1996, and that this panel was larger than the previous panels, extending approximately 3,500 ft further to the east than F panel. The basic change in geometry of the panels (figure 1) and associated changes in the ventilation system, including the start-up of Bleeder Fan 3, may have contributed to the increase in methane production from the bleeder fans and gob gas ventholes during the 4th quarter of 1996. The increase in methane production may also be related to an actual increase in methane emissions associated with the mining of G panel, which had just reached gob gas venthole G2 at the end of 1996. The 49 MMcf of methane production from the previously intercepted hole G1 was the highest quarterly gas production from any hole in the study area, and accounted for 28% of the total gob gas production during this quarter.

The bleeder fan methane production results fluctuated significantly during the first 3 quarters of 1997, as shown on figure 37. The magnitude of these fluctuations and apparent low methane production from Bleeder Fan 2 may be related to instrumentation problems and/or extended time intervals between measurements.

STUDY FINDINGS

Tracer gas studies can be a valuable tool to study ventilation airflows associated with longwall gobs, bleeders, and gob gas ventholes. The primary findings resulting from the

analysis of the data obtained from the 1997 tracer gas releases (7 underground and 1 gob gas venthole injection) and ancillary investigations at the Emerald Mine are as follows:

UNDERGROUND TRACER GAS RELEASES

1. Tracer gas released into the ventilation airflow generally stayed in the bleeder system. Exceptions were the 2 releases in the F panel #2 entry, inby the face, and the release in A+ #1 panel and A panel IEP's. A maximum of 0.7% of the tracer gas released from an underground location reached a gob gas venthole.
2. Flow paths for tracer gas released at the underground IEP's and from the gob gas venthole on G panel were inby, i.e. towards the back (start-up) end of the panel.
3. A wide range of velocities was observed in the underground tracer gas tests. The velocities of the SF₆ arrivals, peaks, and tails to bleeder fans from release points ranged from 259 ft/min, 72 ft/min, and 13 ft/min on A+ Panel, to 17 ft/min, 9 ft/min, and 0.67 ft/min on F Panel.
4. Ventilation variations and gob consolidation may be responsible for the different tracer gas migration characteristics observed on the two tracer gas releases on F Panel.

BOREHOLE TRACER GAS INJECTION

1. Tracer gas released into the gob generally stayed in the gob, as long as the associated gob gas ventholes were operating. The flow of tracer gas (4.5% recovery) to BF2 may be associated with gob gas venthole G2 going off production 4 days prior to the arrival at BF2.
2. The arrival of tracer gas at both G2 and G1 from the injection into G3 indicates that all three gob gas ventholes on G panel are in communication.
3. The relatively quick arrival of tracer gas at G2 (1.1 days, 2.4 ft/min velocity) indicates a relatively high permeability flow path between these two points in the gob, even 5 and 6 months after G3 and G2, respectively, were mined through.
4. Production variations at gob gas ventholes G2 and G1 influenced the borehole pressure at the shut-in injection hole G3, further confirming that all three boreholes on G panel were in communication during the borehole injection experiment.

GOB GAS VENTHOLE AND BLEEDER FAN EVALUATION

1. Gob gas ventholes located at the start-up end of the panels produced methane at higher rates for a longer time than holes located in the central or completion end of the panels.
2. The bleeder fans generally produced more gas than the active gob gas ventholes during the same time intervals.

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- 26 Graph of the amount of SF₆ recovered over time at the BF2 monitoring sites during Test 2-6 shown as a percentage of the released tracer gas.
- 27 Detailed map of F, G, and H longwall panels, Emerald Mine.
- 28 Schematic of G3 wellhead configuration for tracer gas injection and shut-in pressure monitoring.
- 29 Schematic of G3 borehole configuration for gob gas production.
- 30 Graph of tracer gas concentration at G2 during borehole injection experiment.
- 31 Graph of tracer gas cumulative recoveries for borehole injection experiment.
- 32 Graph of tracer gas concentration at G1 during borehole injection experiment.
- 33 Graph of tracer gas concentration at BF2 during borehole injection experiment.
- 34 Graph of tracer gas concentration at G3 during borehole injection experiment.
- 35 Graph of influence of gob gas venthole production on G3 shut-in pressure.
- 36 Graph of average cumulative gob gas venthole methane production by location on longwall panel.
- 37 Graph of bleeder fan and gob gas venthole quarterly methane production.

Table 1. - Tracer gas release specifications and cumulative recovery percentages.

Emerald Mine Tracer Gas Study																	
Description of SF ₆ Release																	
Study - Test	Date-Time yy/mm/dd+hh:mm:ss	Vol ft ³ STP	Release Method					Location									
2-0	97/03/14 Fri 08:00:00	4.34	2 bottles, slow (24 min), 08:00-08:24					#29 X-cut in the #2 entry of F Panel entries, inby G face									
2-1	97/04/03 Thu 09:00:00	4.38	1 bottle, fast, 2.07 ft ³ , 09:00					Release 1: IEP 1North #1									
2-1			1 bottle, fast, 2.33 ft ³ , 10:45					Release 2: IEP 1North #2									
2-2	97/04/08 Tue 09:17:00	4.40	2 bottles, fast					IEP B-Panel									
2-3	97/04/11 Fri 09:05:00	4.10	2 bottles, fast, 2.25 ft ³ , 09:05-09:08					Release 1: IEP A Panel									
2-3			1 bottle, fast, 1.86 ft ³ , 10:35					Release 2: IEP A+ Panel #1									
2-4	97/04/23 Wed 09:13:00	5.23	2 bottles, fast, 2.61 ft ³ , 09:13-09:16					Release 1: IEP C Panel #1									
2-4			2 bottles, fast, 2.62 ft ³ , 09:17-09:20					Release 2: IEP C Panel #2									
2-5	97/05/07 Wed 08:15:00	5.14	4 bottles, fast					#26 X-cut in the #2 entry of F Panel entries, inby G face									
2-6	97/05/15 Thu 07:50:00	5.22	4 bottles, fast					IEP E Panel									
3-1	97/07/21 Mon 08:15:00	9.62	Slow (25 min), 08:15-08:40					GVB-G3									
Recovered Percentage of SF ₆ at Monitoring Locations																	
Study - Test	Underground							Bleeder Fan		Gob Ventilation Borehole							Total
	CBR	E1	E2	F1	F5	FR	GR	BF2	BF3	A+1	D1	E1	F1	G1	G2	G3	
2-0								Detected	Detected					Not Det	Detected	Detected	
2-1								65.99%	0.00%	0.00%							65.99%
2-2								89.09%	0.00%	0.00%							89.09%
2-3								57.40%	0.00%	Trace							57.40%
2-4	0.72%							85.16%	0.00%		0.00%	0.00%	0.00%				85.88%
2-5				0.00%	1.11%			56.17%	1.14%				0.00%	0.00%	0.74%	0.00%	59.15%
2-6		0.00%	0.00%					68.75%	0.00%		0.00%	0.00%	0.00%				68.75%
3-1						0.00%	0.00%	4.48%	0.00%				0.00%	3.19%	75.34%	Injected	83.01%

Note 1: Light green indicates SF₆ detected.Note 2: No SF₆ from Study 2 Test 6 can reach GVB-G2. All SF₆ detected during this period is reported as Test 5.

Note 3: All Study 2 Test 0 data from 97/03/15.

Table 2. - Calculated velocities for underground tracer gas releases

Tracer Gas Velocities (first arrival), ft/min					
<u>Test No.</u>	<u>Location</u>	<u>BF2</u>	<u>BF3</u>	<u>A+1</u>	<u>G2</u>
2-0	F Panel entries	Unknown.....			
2-1	1 North IEP's	259			
2-2	B Panel IEP	31			
2-3	A&A+ Panel IEP's	147-153		15-16	
2-4	C Panel IEP's	29-30			
2-5	F Panel entries	17	18		5
2-6	E Panel IEP	31			

Table 3. - Tracer gas durations for underground releases

Tracer Gas Duration						
<u>Test</u>	<u>Location</u>	<u>BF2</u>	<u>BF3</u>	<u>A+1</u>	<u>G2</u>	<u>Underground</u>
2-0	F Panel entries	Unknown.....				
2-1	1 North IEP's	13.8 hours				
2-2	B Panel IEP	2.8 days				
2-3	A&A+ Panel IEP's	4.1 days		15.4 min.		
2-4	C Panel IEP's	7.8 days				40 min.
2-5	F Panel entries	5.5 days	18.4 hours		22.4 days	1 hour
2-6	E Panel IEP	6.5 days				

Table 4. - Velocity calculations for G3 borehole injection experiment

Distance, ft	Time, min	G3-G2 Velocity, ft/min	G3-G1 Velocity, ft/min
Total = 3, 888 (518 vert. down G3, 2,500 horiz., 870 vert. up G2)	1,621	2.40	
Partial = 3,018 (518 vert. down G3, 2,500 horiz., 0 vert. up G1, (i.e., instantaneous))	1,621	1.86	
Total = 8,036 (518 vert. down G3, 6,800 horiz., 718 vert. up G2)	22,399		0.36
Total = 8,036	Partial = 10,436 (subtracting time G1 off production)		0.77

Table 5. - Relative performance scale of gob gas venthole production

POOR	- Low production rate and/or short production time
FAIR	- Moderate production rate ($\approx$ 100 Mcfd methane) and extended production time ($\approx$ 6 months)
GOOD	- High production rate ($>$ 200 Mcfd methane) and long production ($>$ 6 months)
VERY GOOD	- High production rate ($>$ 400 Mcfd methane) and long production ($>$ 12 months)

Table 6. - Individual gob gas venthole relative performance ratings (through 6/3/98)**A+ Panel**

Hole 1-N	GOOD
----------	------

A Panel

Hole 1	FAIR - GOOD (several intervals of high production significantly above 100 Mcfd trend)
--------	---

Hole 2	POOR
--------	------

B Panel

Hole 1	POOR - FAIR (several months of >200 Mcfd production at start of approximately one year of production life)
--------	--

Hole 2	POOR
--------	------

Hole 3	POOR
--------	------

C Panel

Hole 3	POOR
--------	------

Hole 4	POOR - FAIR (2 months of >400 Mcfd production at end of short production life)
--------	--

D Panel

Hole 1	GOOD
--------	------

Hole 3	POOR
--------	------

E Panel

Hole 1	VERY GOOD
--------	-----------

Hole 2	GOOD
--------	------

Hole 3	FAIR - GOOD (high production rate, short production time)
--------	---

F Panel

Hole 1	GOOD - VERY GOOD (generally high production with some variability over about 14 months)
--------	---

Hole 2	POOR (high production, short production time)
--------	---

Hole 3	POOR (high production, short production time)
--------	---

G Panel

Hole 1	VERY GOOD
--------	-----------

Hole 2	GOOD (high production for about 6 months)
--------	---

Hole 3	POOR (high production, very short production time)
--------	--

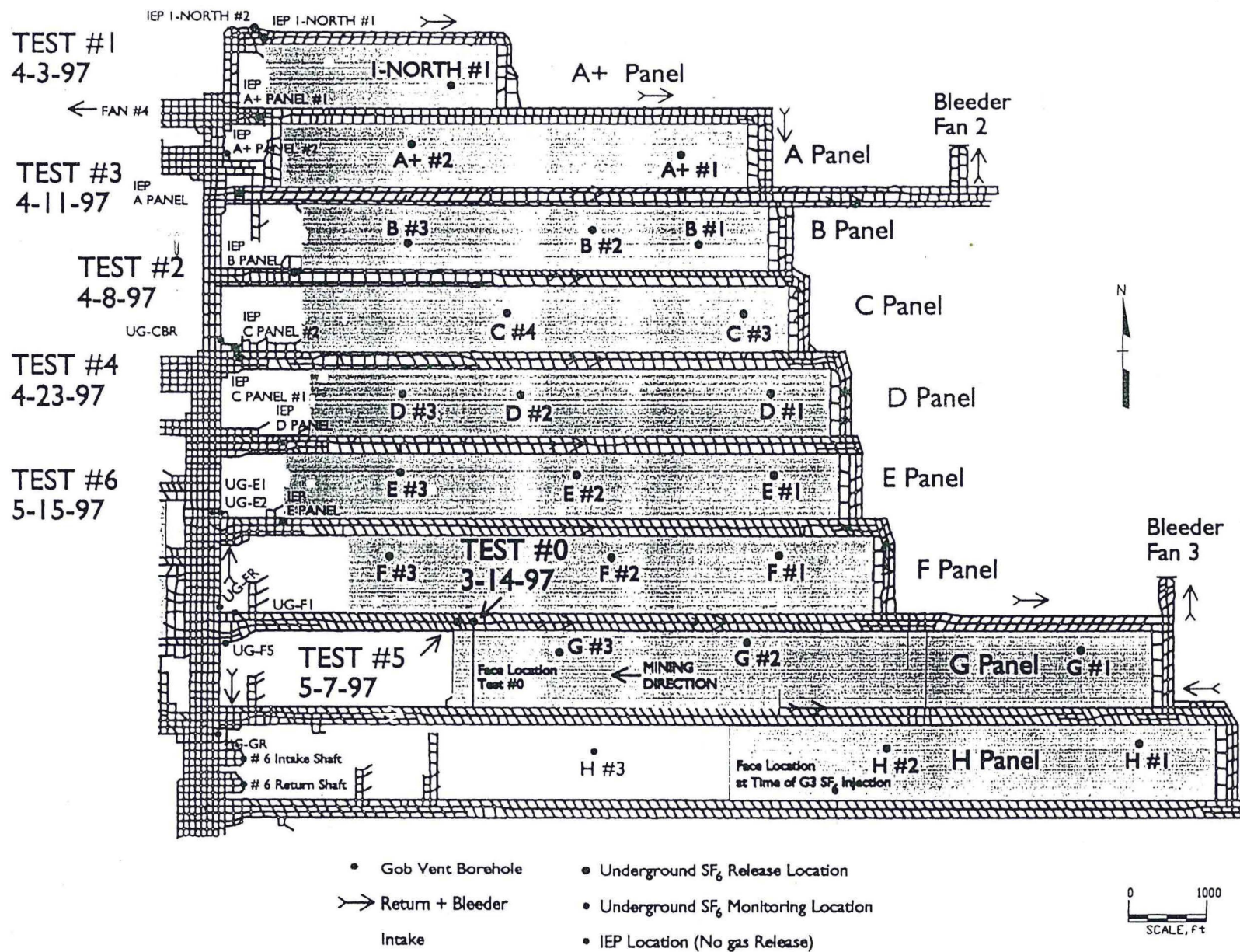


Figure 1.-Map of Emerald Mine study area.

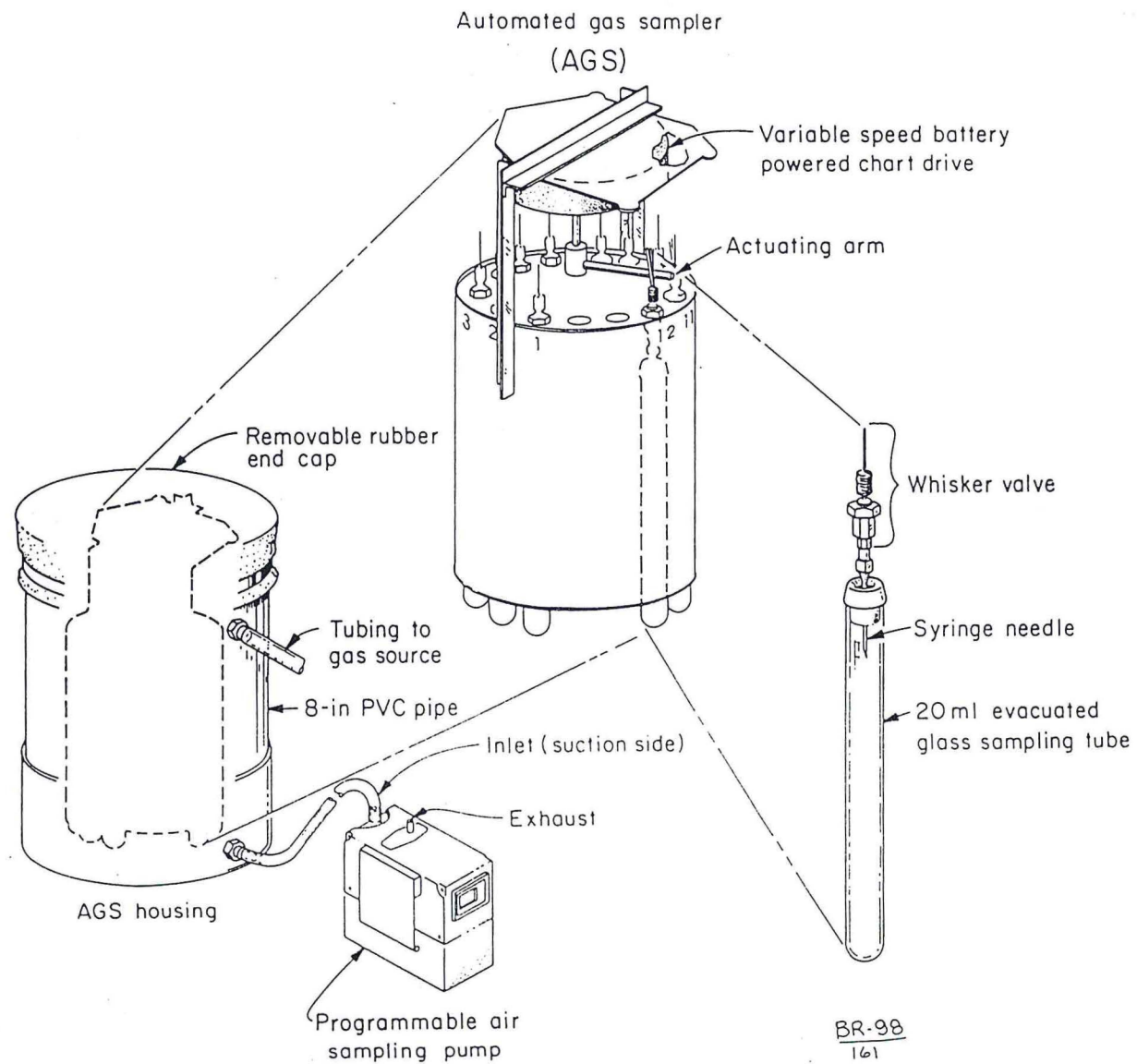


Figure 2.-Schematic drawing of AGS system.



Figure 3.-Photo of AGS system.

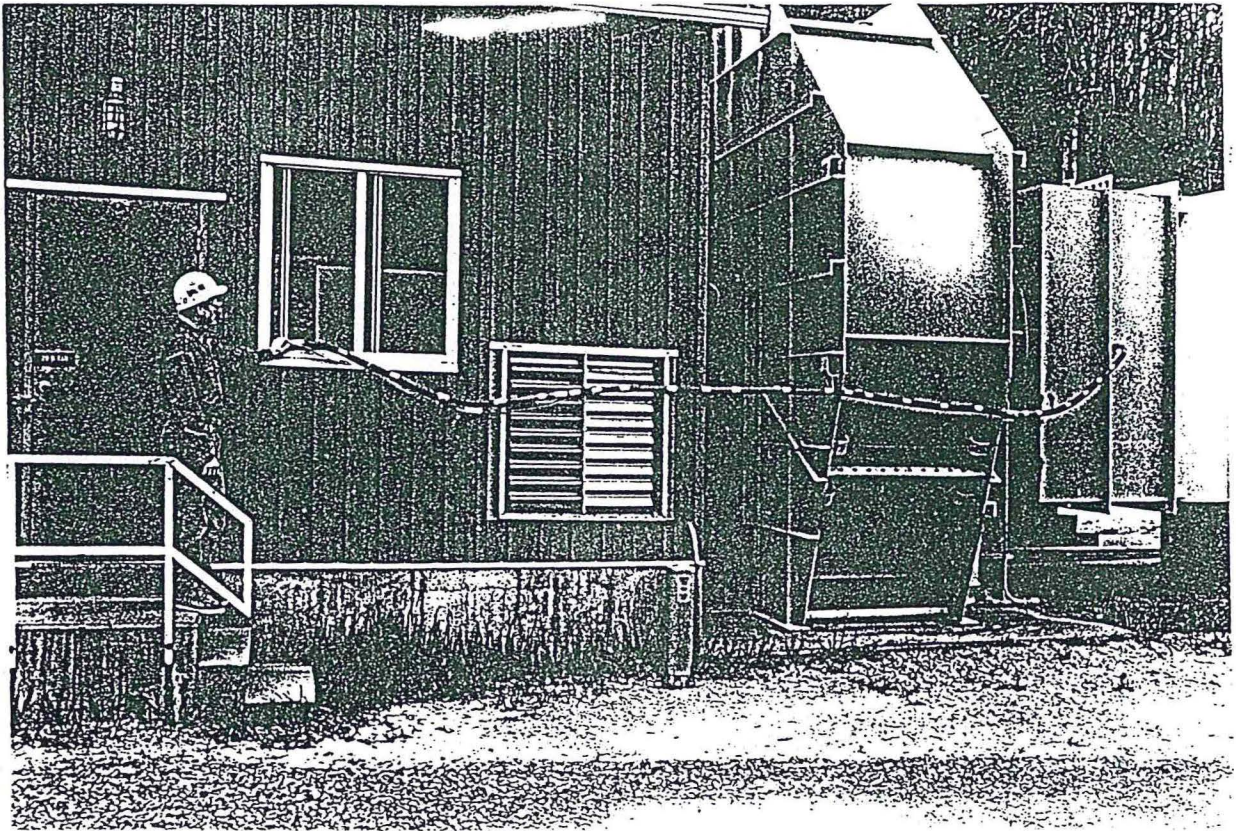


Figure 4A.-Photo of insulated copper sampling tubing extending from bleeder fan housing to equipment room.



Figure 4B.-Photo of copper tubing from bleeder fan housing connected to AGS system in equipment room.

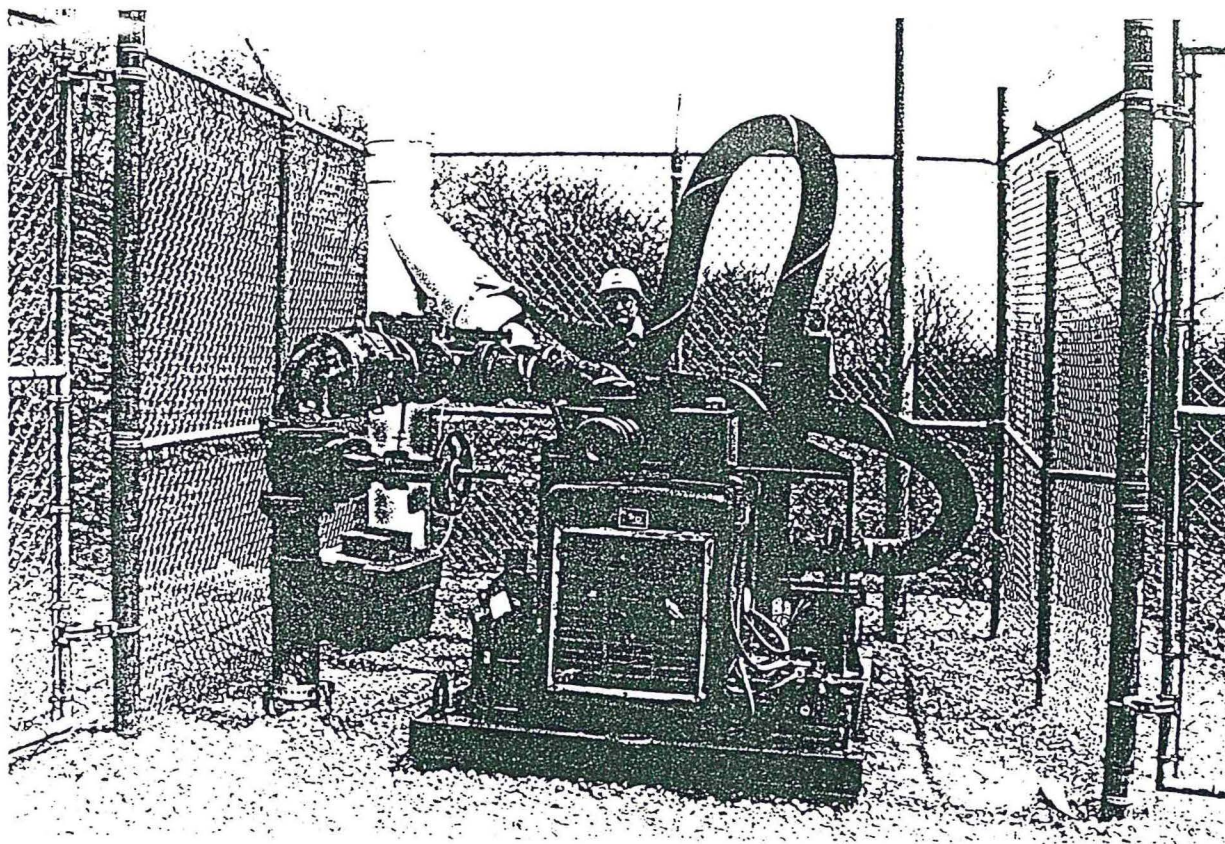


Figure 5A.--Photo of AGS system connected to gob gas venthole exhaust stack.

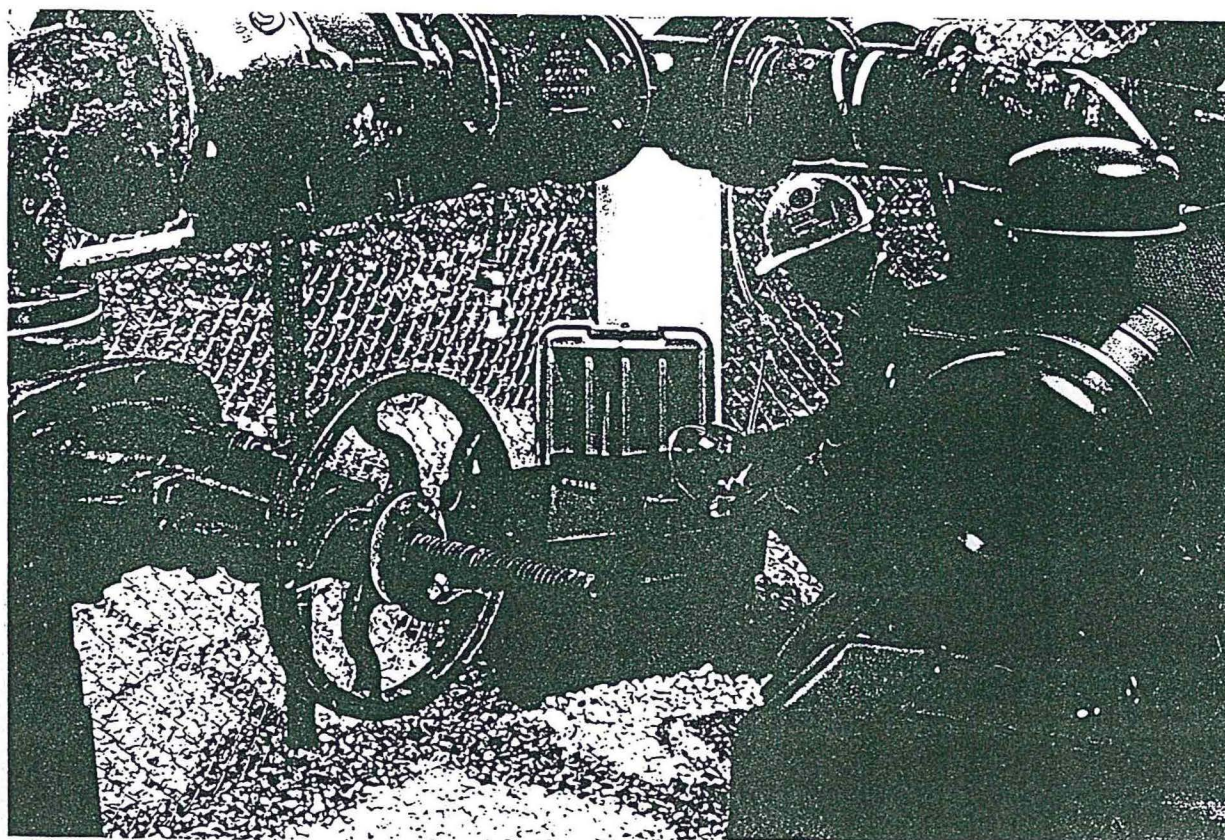


Figure 5B.--Photo of AGS system housed in weatherproof box at gob gas venthole monitoring site.

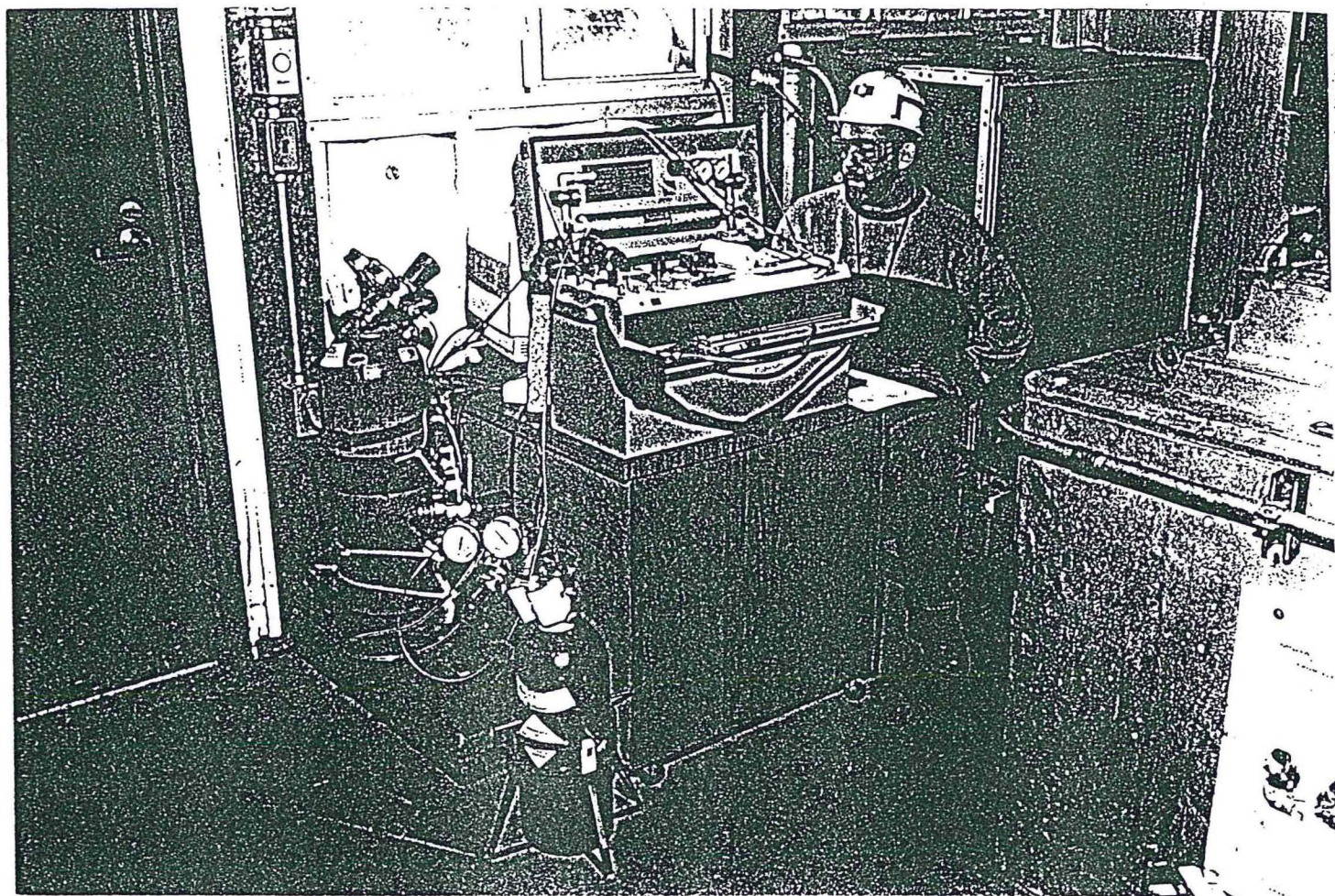


Figure 6.-Photo of portable GC unit in the field.

TEST #4
4-23-97

TEST #6
5-15-97

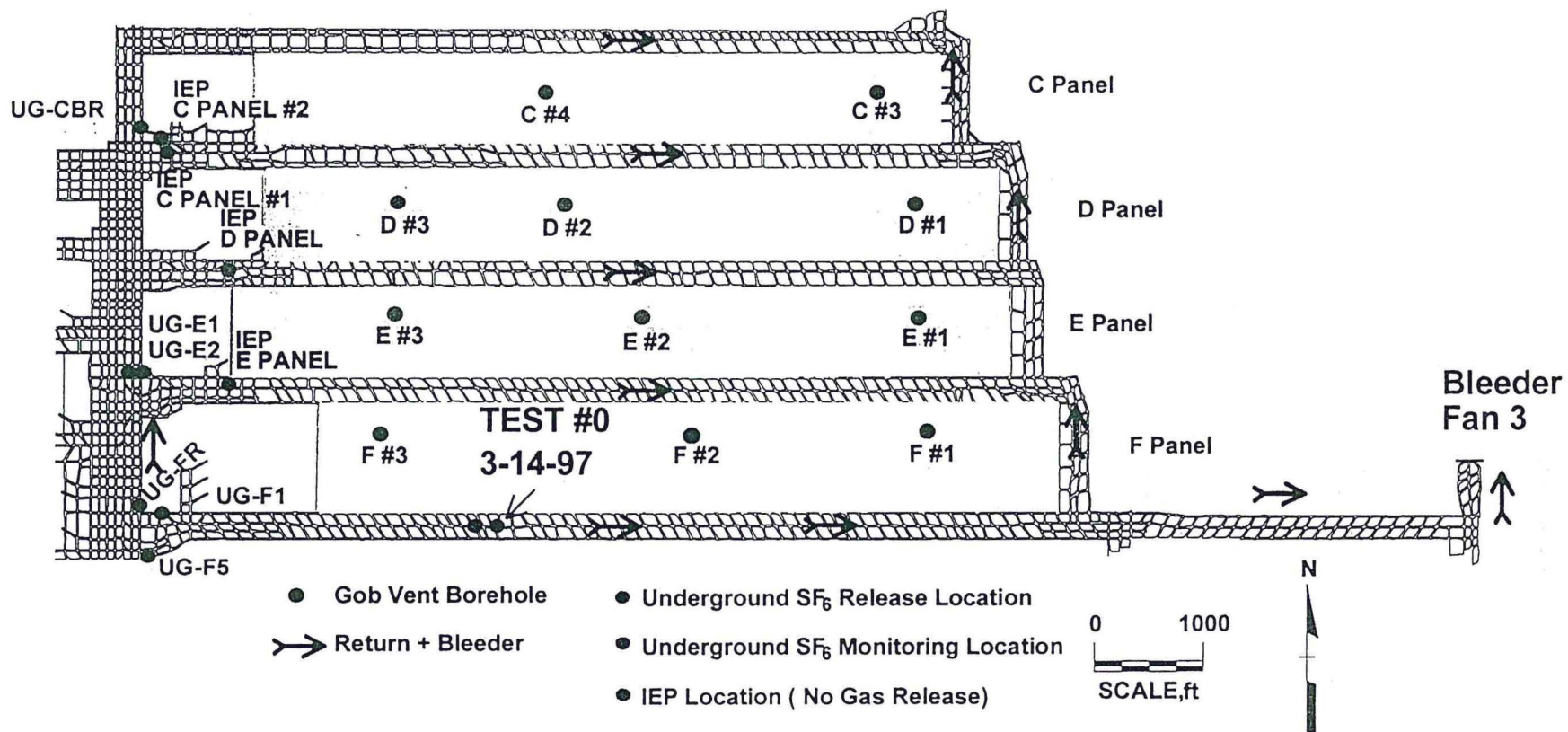


Figure 7.-Location of Tests 2-0, 2-4 and 2-6.

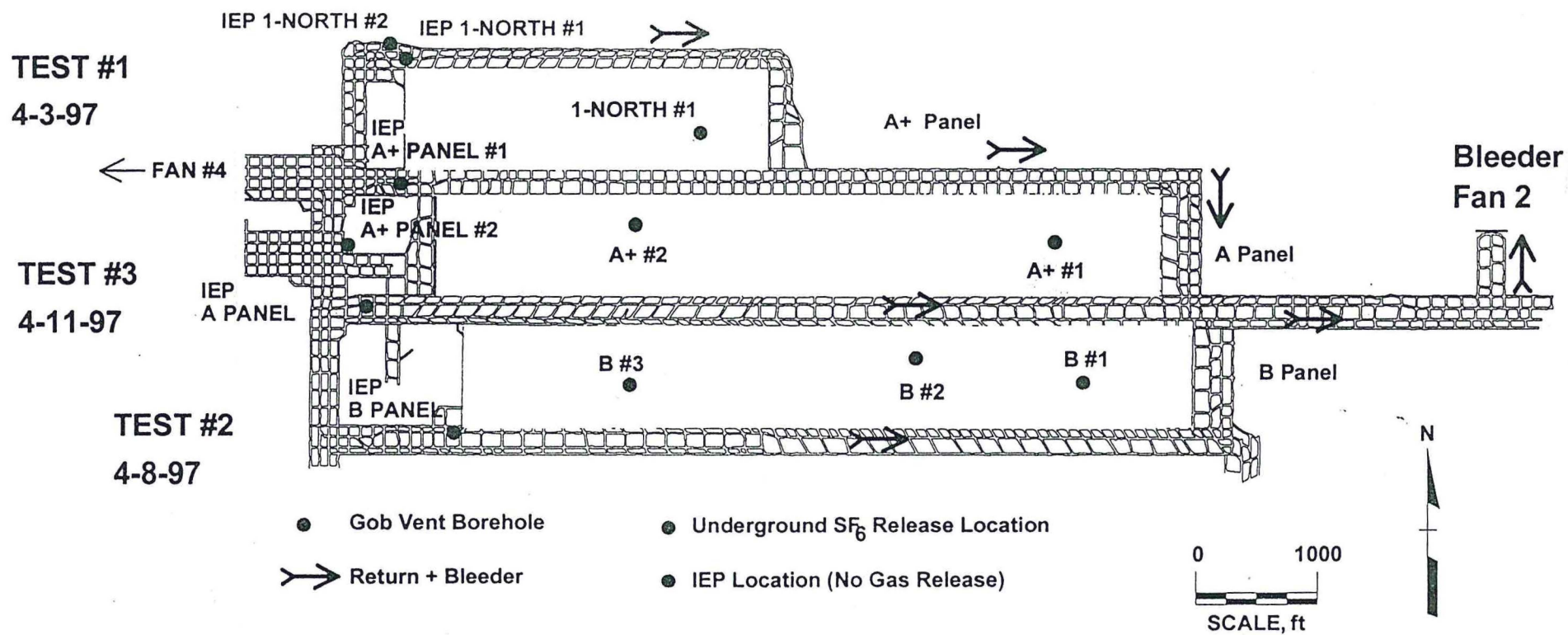


Figure 8.-Location of Tests 2-1, 2-2 and 2-3.

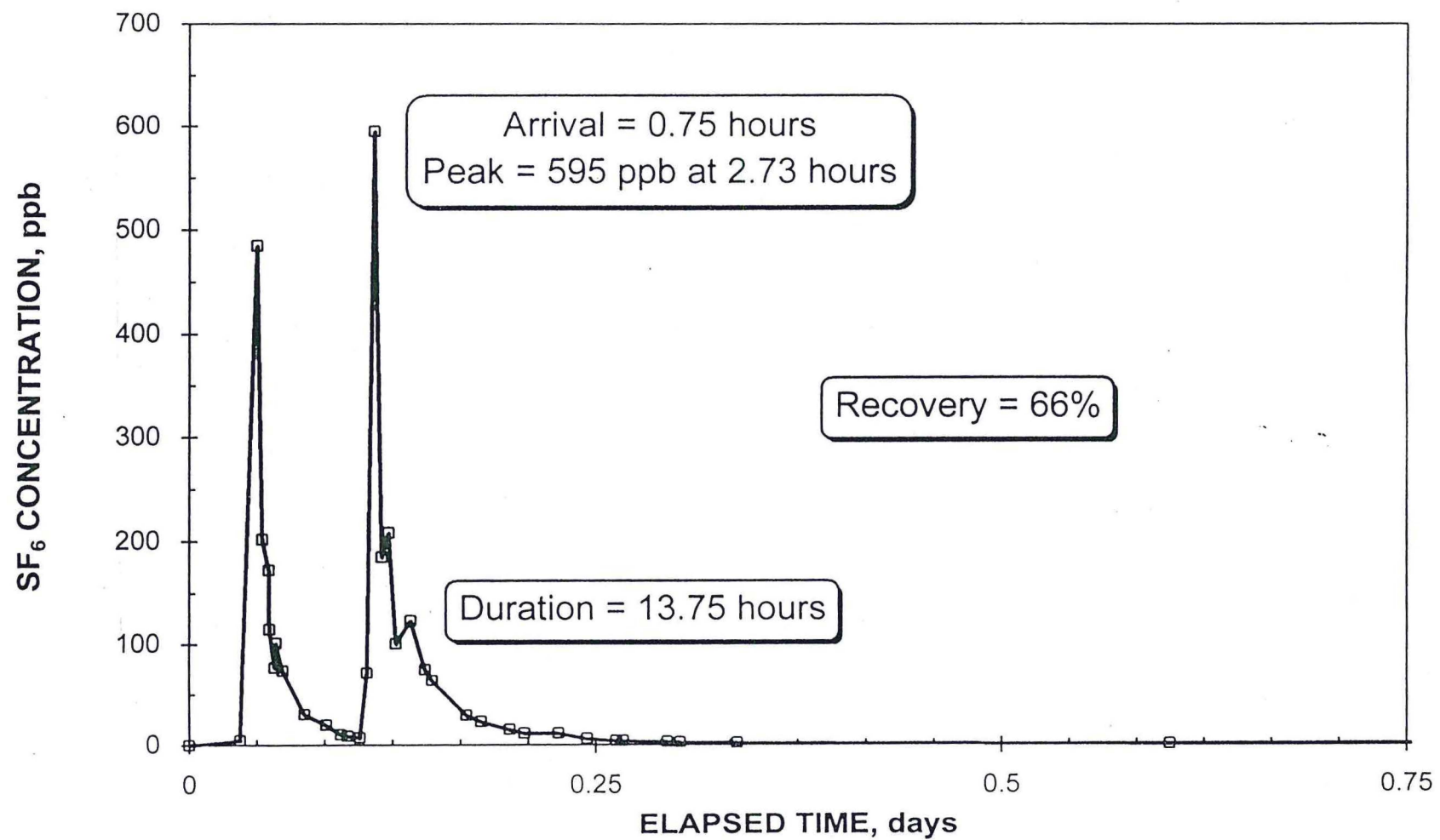


Figure 9.-Graph of changing SF₆ concentrations over time at the BF2 monitoring site during Test 2-1.

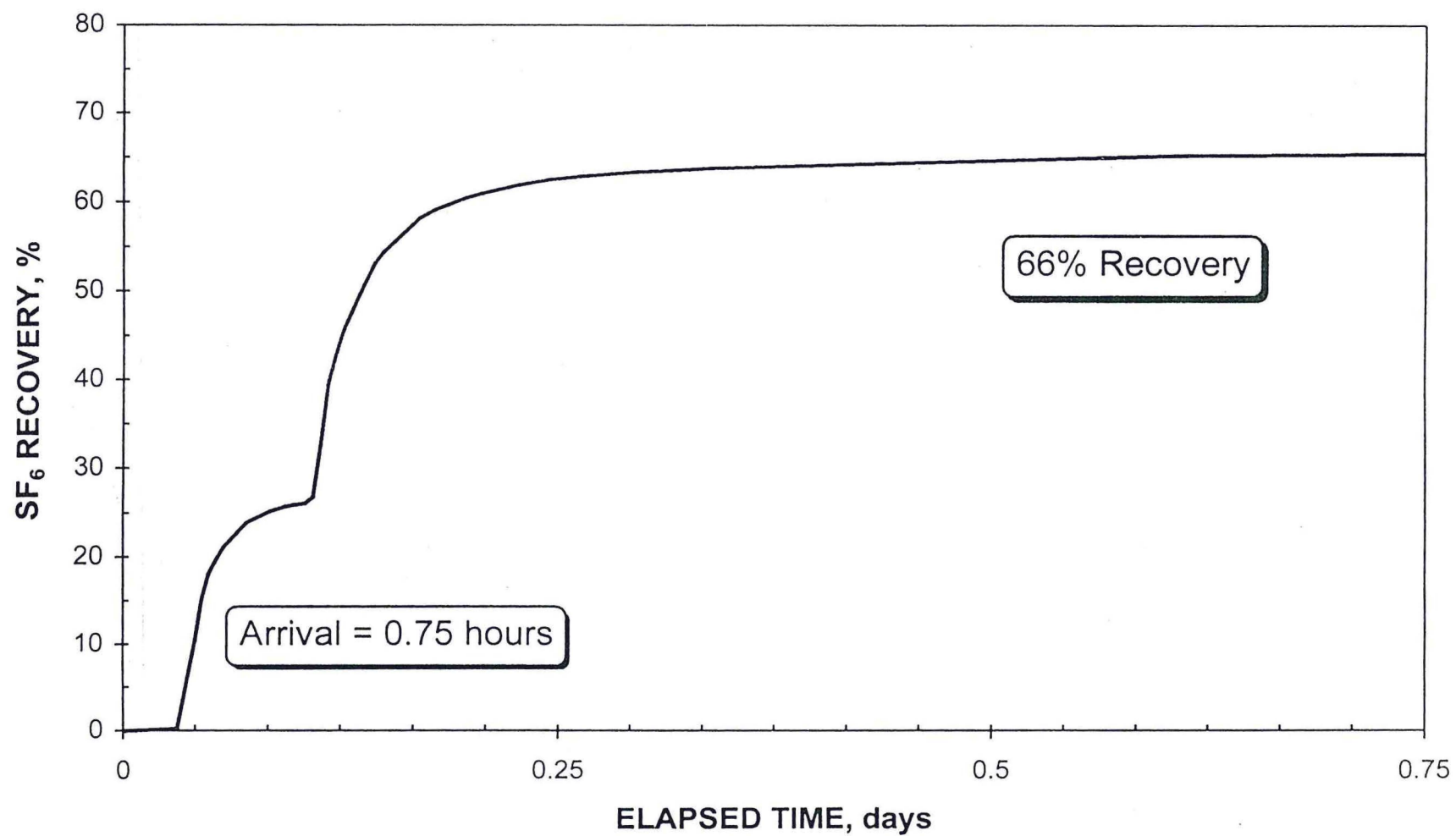


Figure 10.-Graph of the amount of SF₆ recovered over time at the BF2 monitoring site during Test 2-1 shown as a percentage of the released tracer gas.

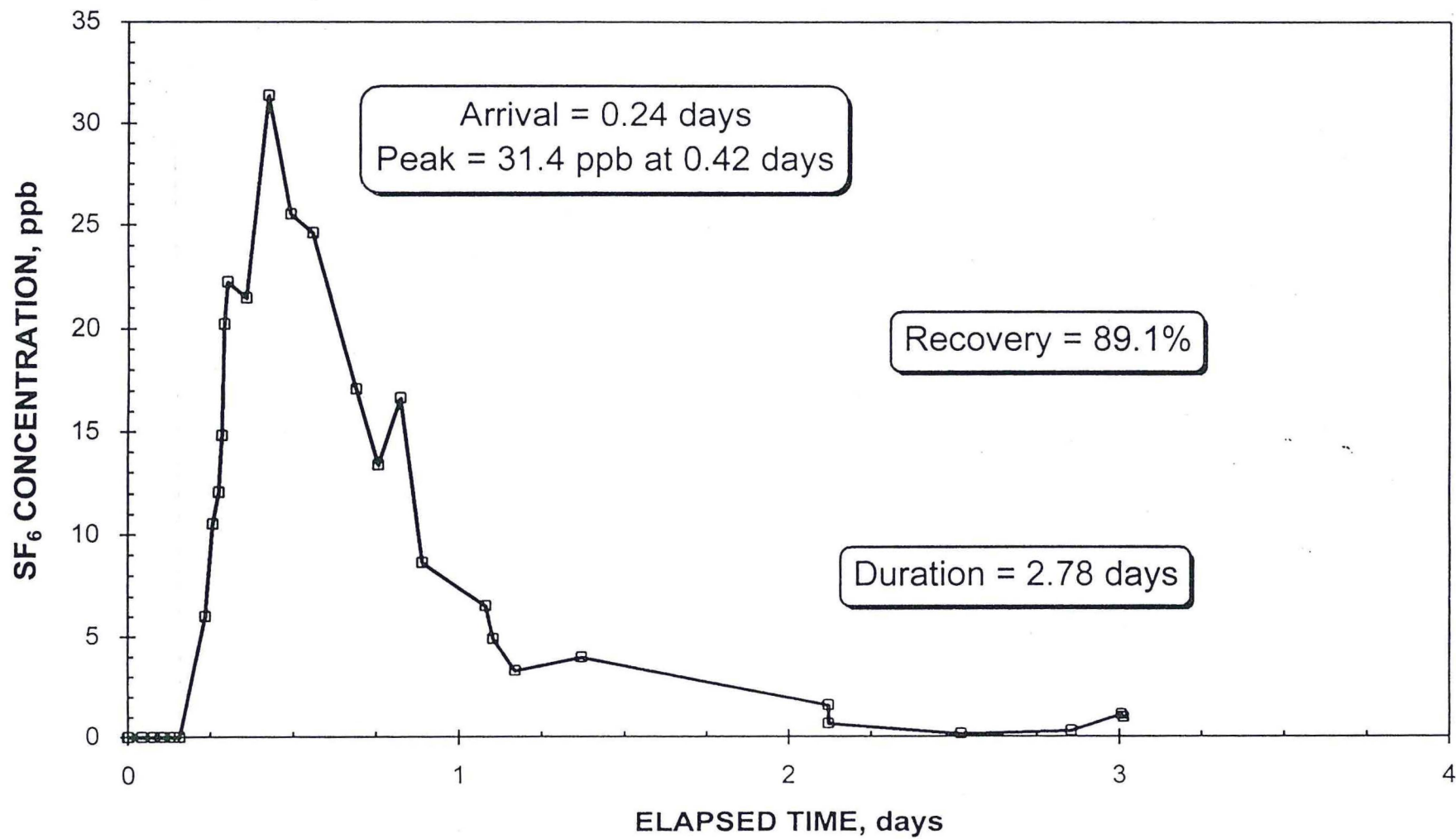


Figure 11.-Graph of changing SF₆ concentrations over time at the BF2 monitoring site during Test 2-2.

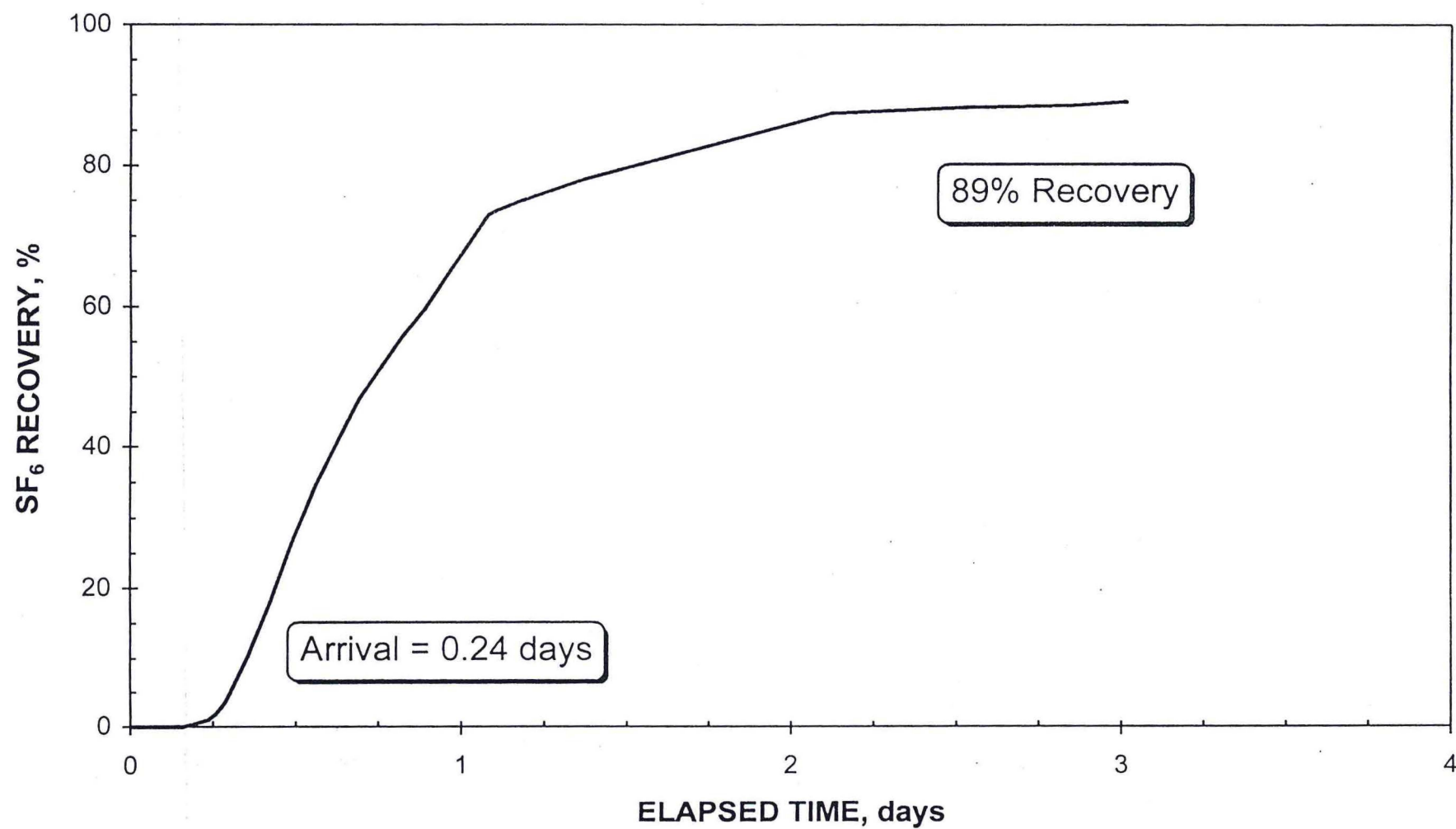


Figure 12.-Graph of the amount of SF₆ recovered over time at the BF2 monitoring site during Test 2-2 shown as a percentage of the released tracer gas.

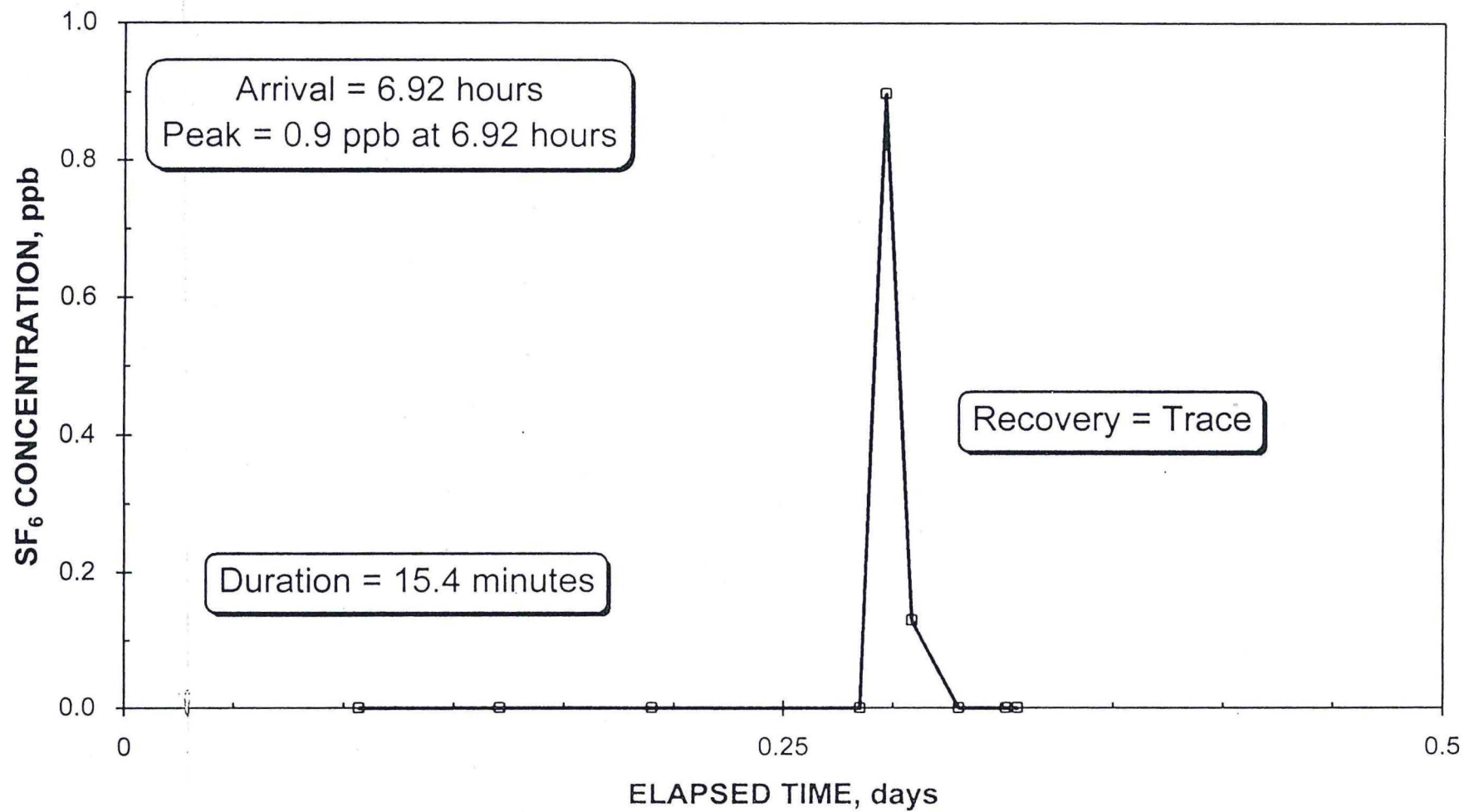


Figure 13.-Graph of changing SF_6 concentrations over time at the A+1 monitoring site during Test 2-3.

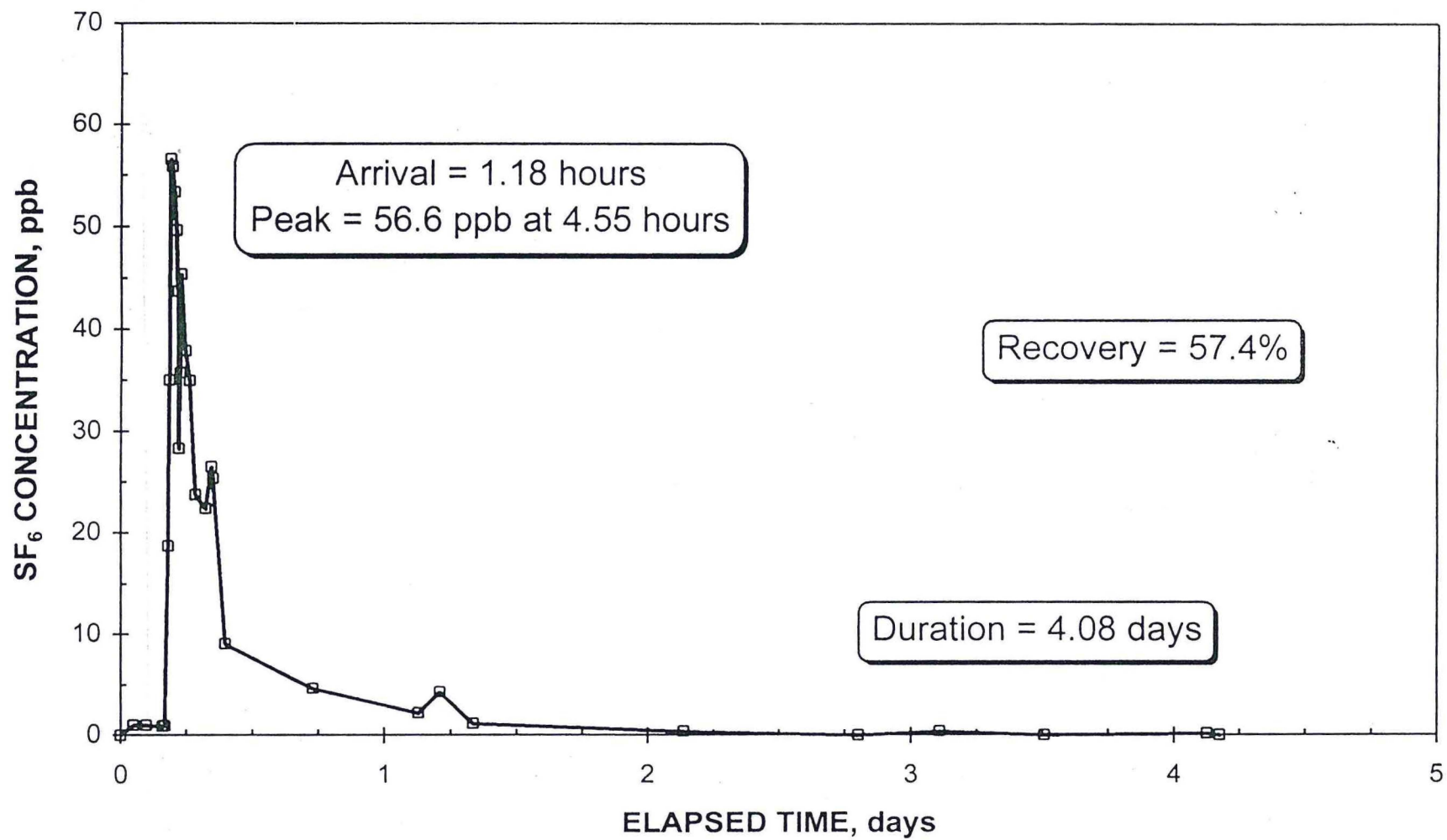


Figure 14.-Graph of changing SF₆ concentrations over time at the BF2 monitoring site during Test 2-3.

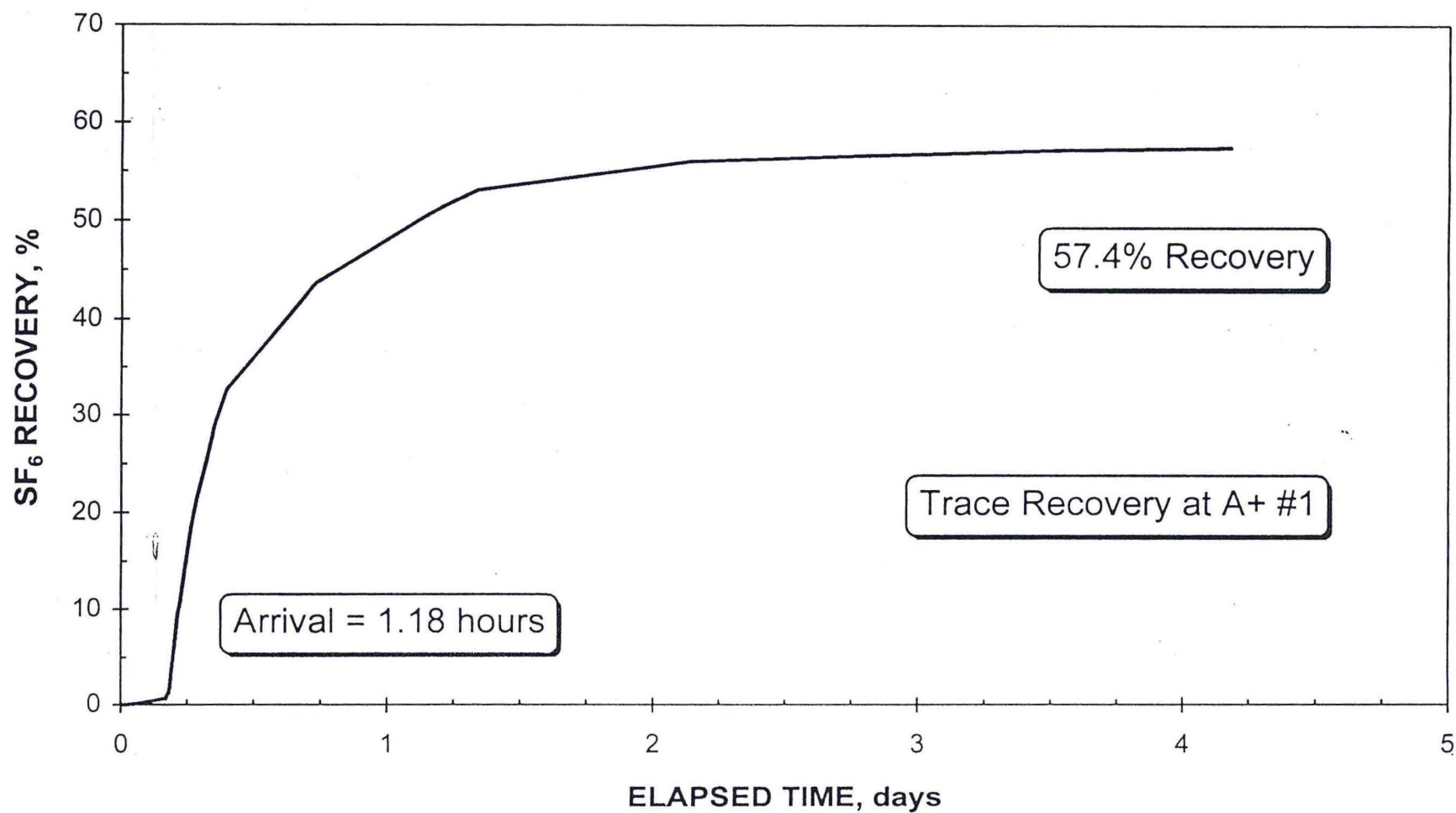


Figure 15.-Graph of the amount of SF₆ recovered over time at the A+1 and BF2 monitoring sites during Test 2-3 shown as a percentage of the released tracer gas.

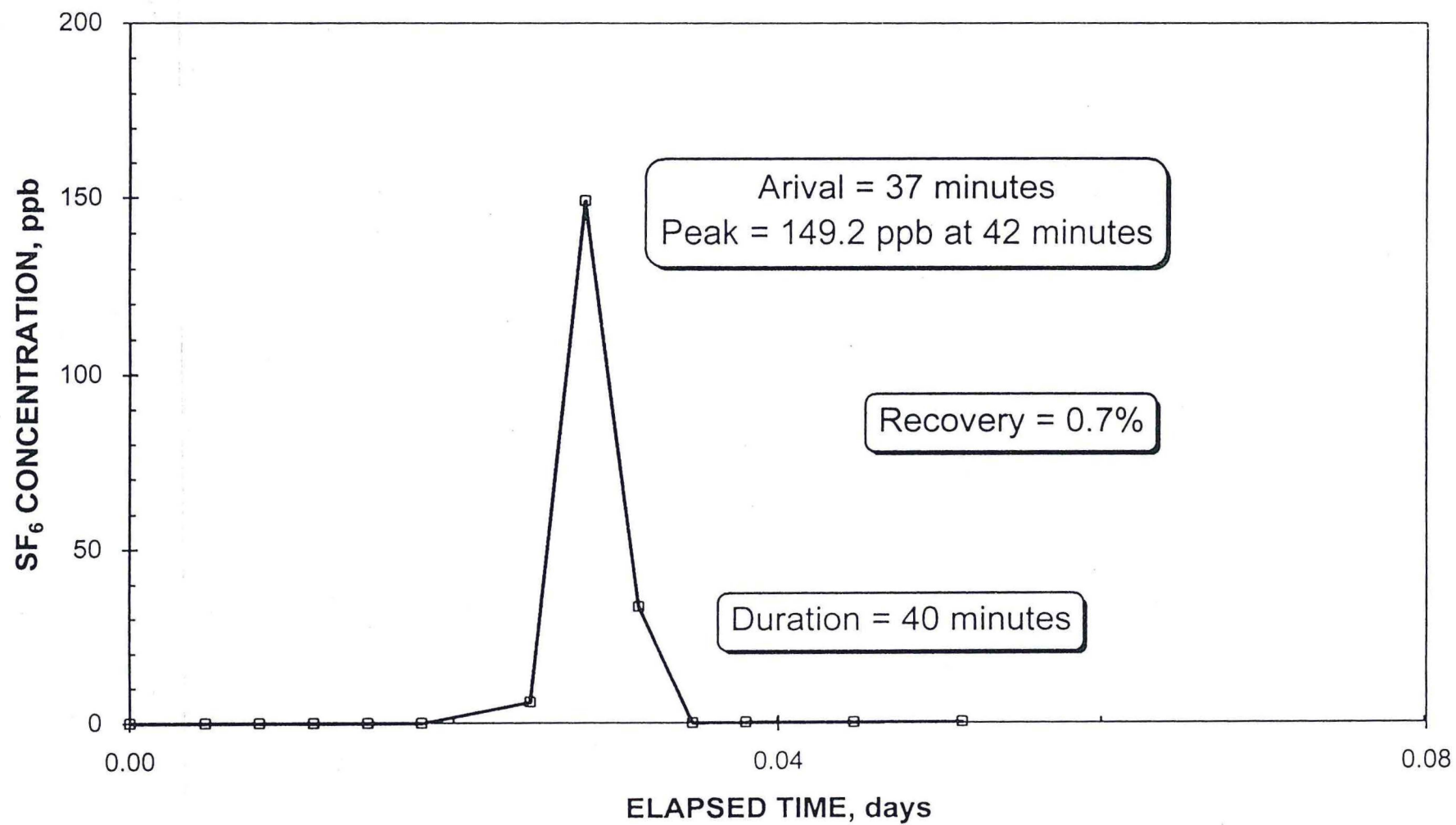


Figure 16.-Graph of changing SF_6 concentrations over time at the underground UG-CBR monitoring site during Test 2-4.

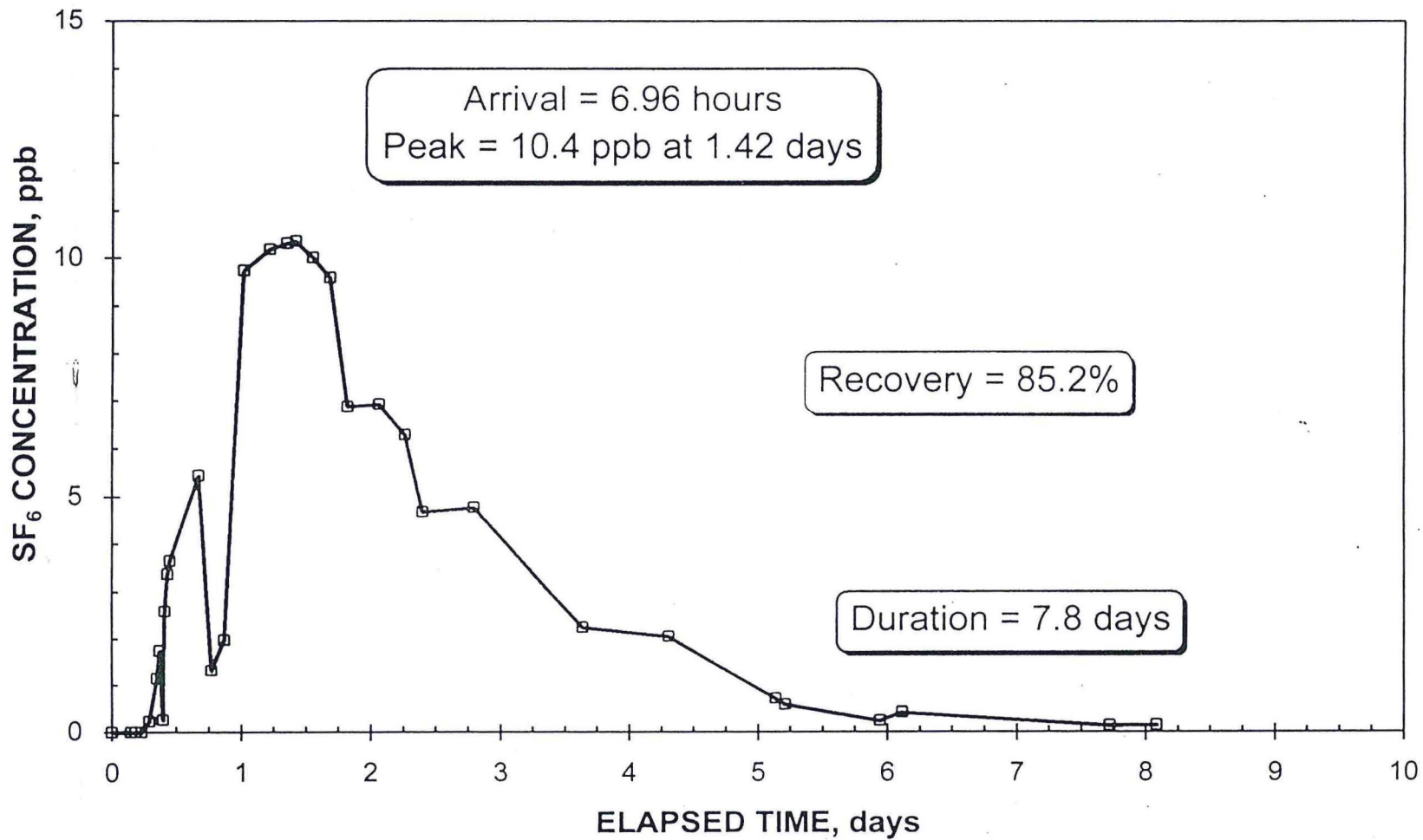


Figure 17.-Graph of changing SF₆ concentrations over time at the BF2 monitoring site during Test 2-4.

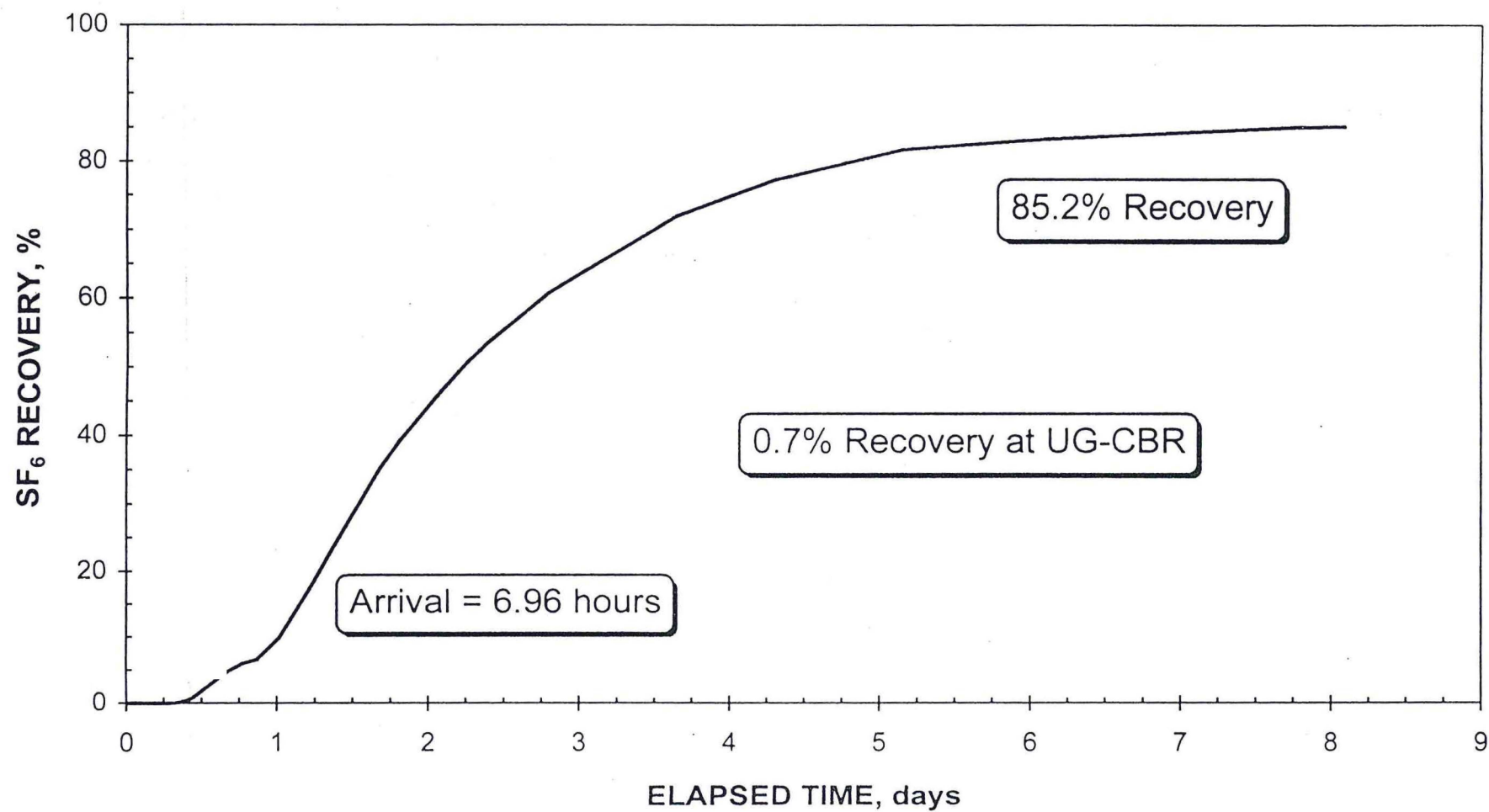


Figure 18.-Graph of the amount of SF₆ recovered over time at the underground UG-CBR and BF2 monitoring sites during Test 2-4 shown as a percentage of the released tracer gas.

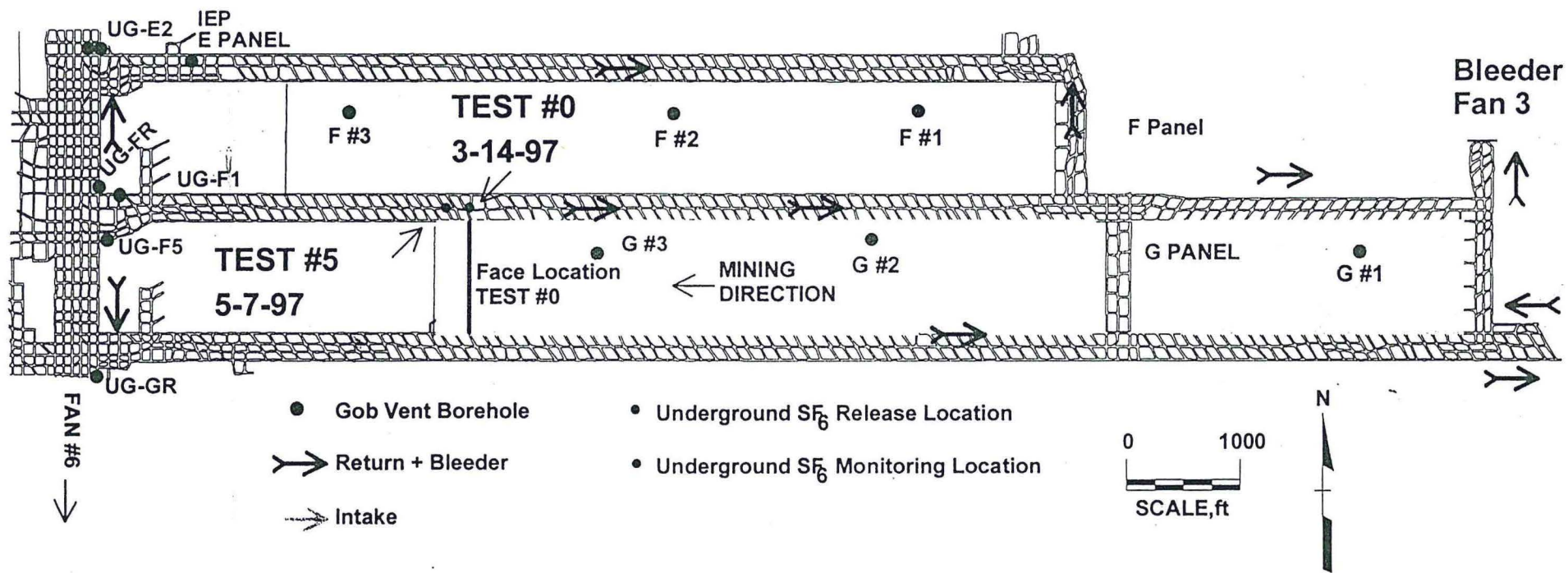


Figure 19.-Location of Test 2-0 and 2-5.

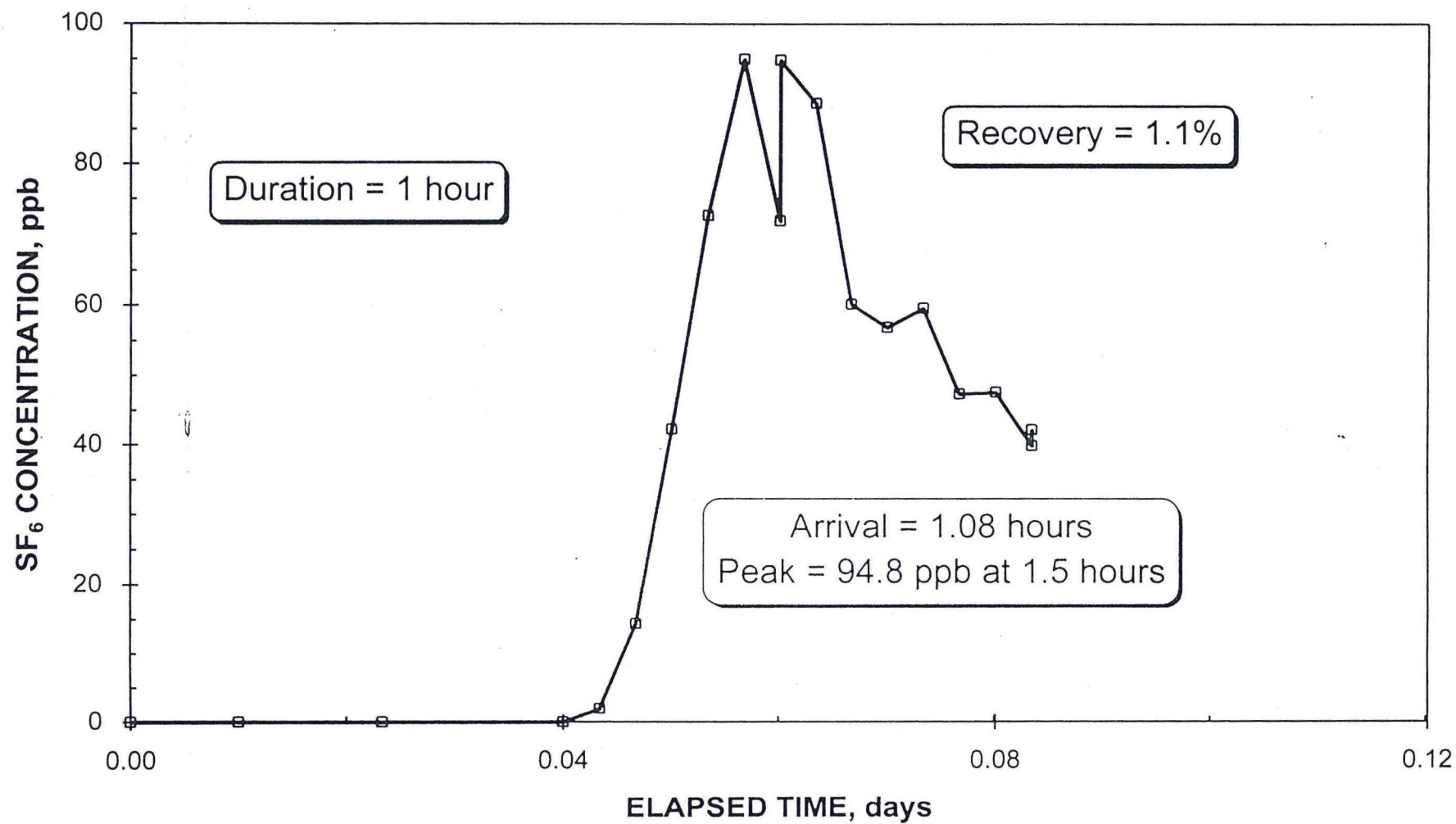


Figure 20.-Graph of changing SF₆ concentrations over time at the underground UG-F5 monitoring site during Test 2-5.

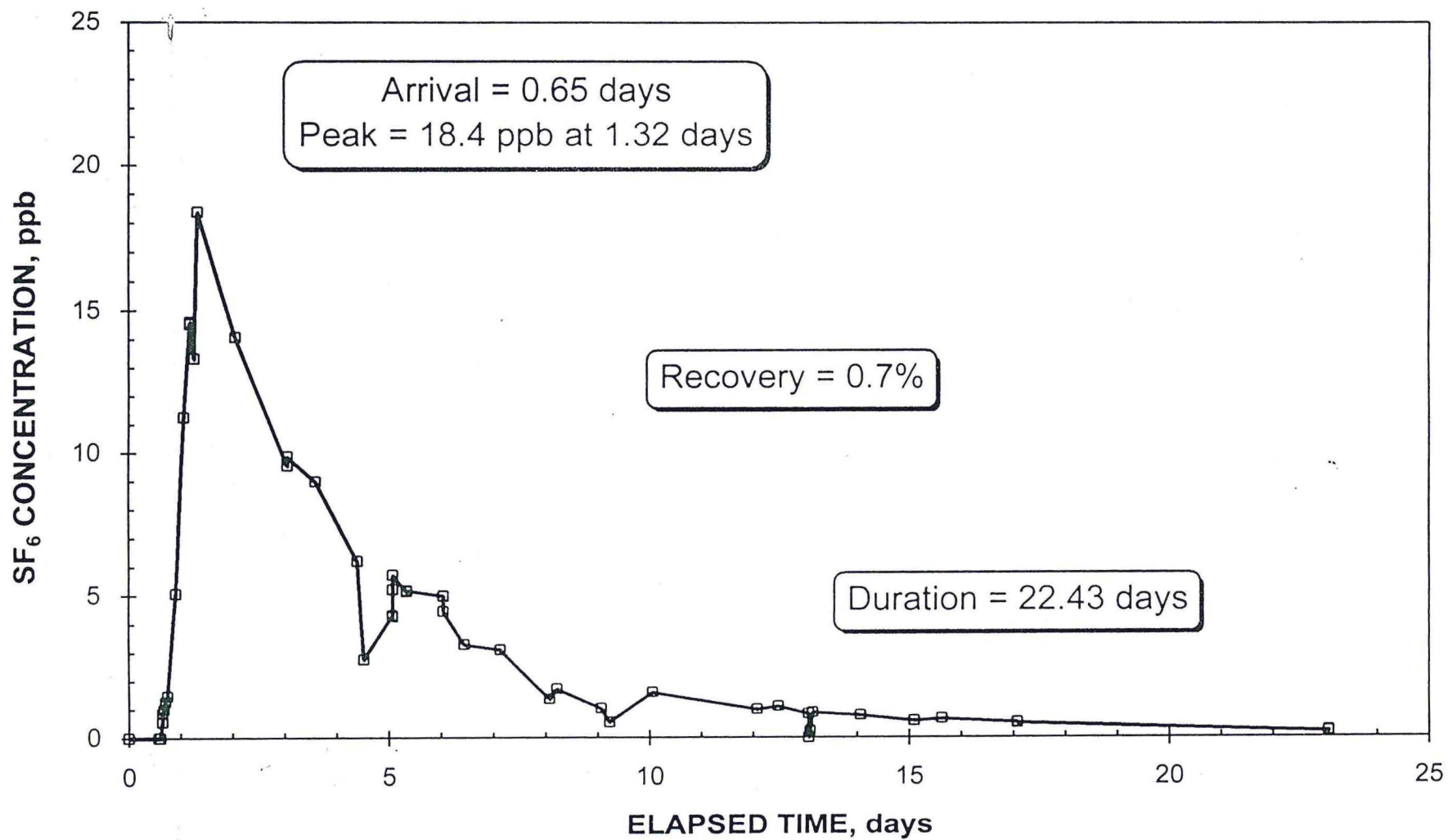


Figure 21.-Graph of changing SF₆ concentrations over time at the G2 monitoring site during Test 2-5.

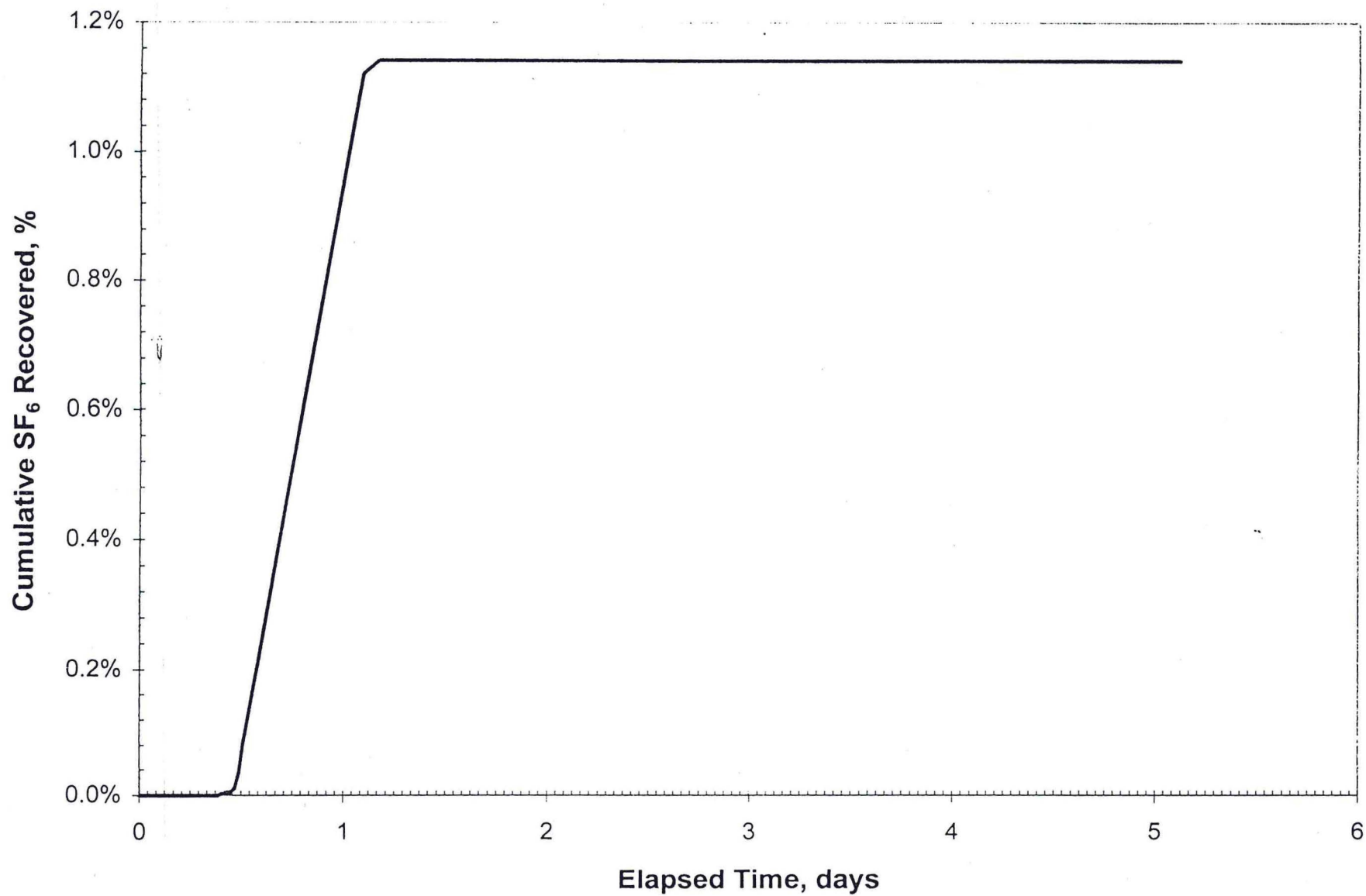


Figure 22.-Graph of changing SF₆ concentrations over time at the BF3 monitoring site during Test 2-5.

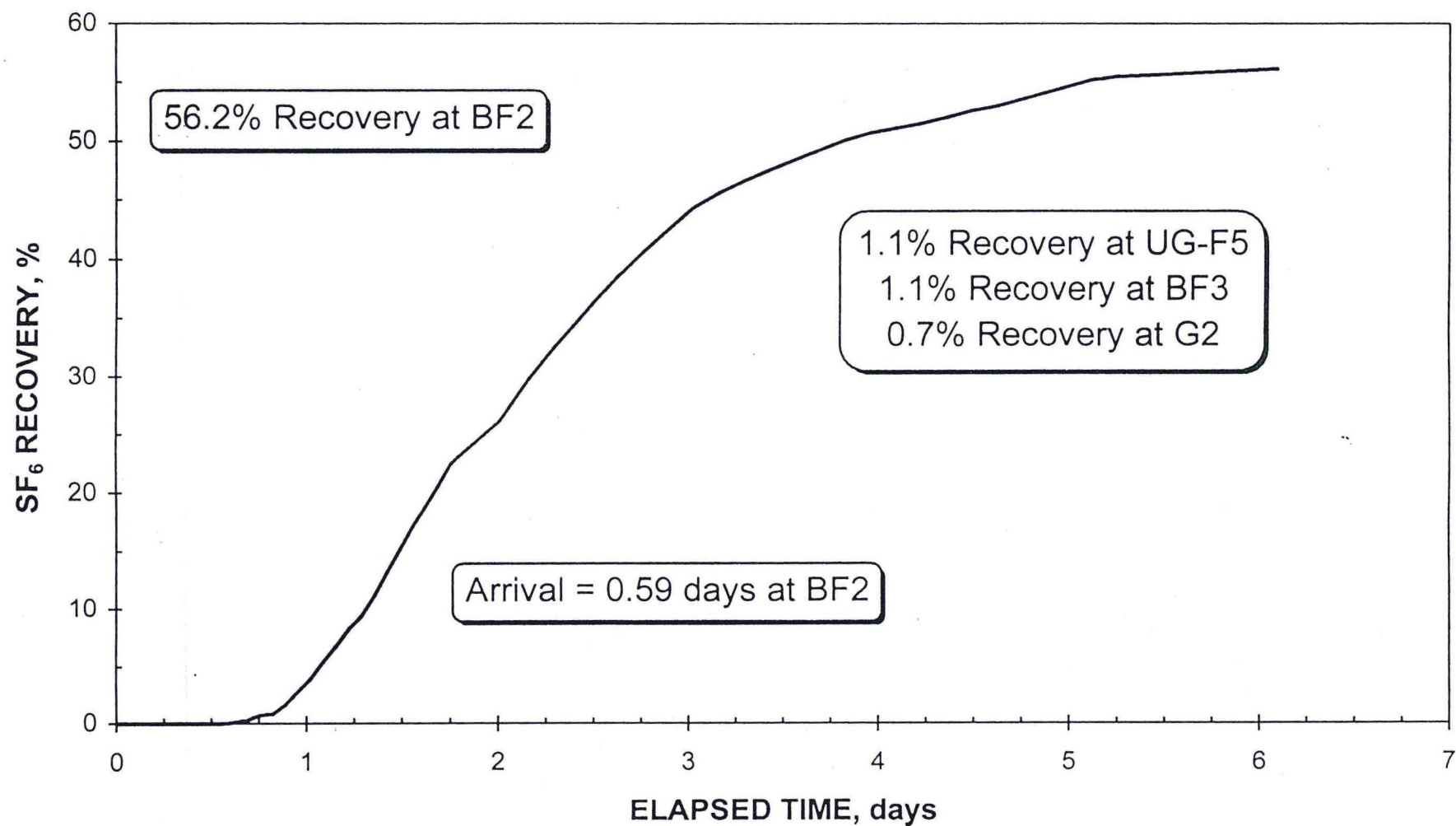


Figure 23.-Graph of the amount of SF₆ recovered over time at the underground UG-F5, G2, BF2, and BF3 monitoring sites during Test 2-5 shown as a percentage of the released tracer gas.

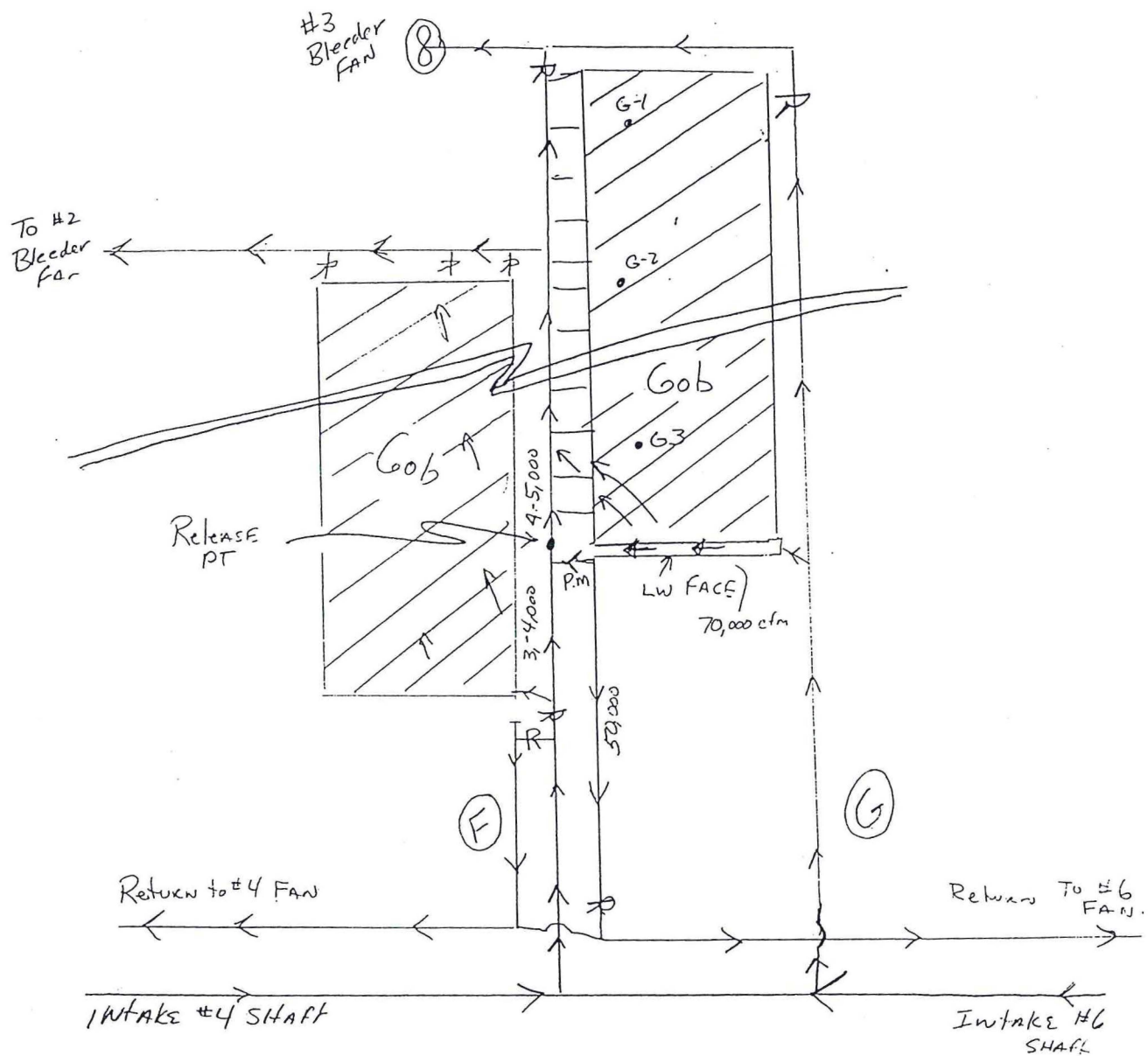


Figure 24.-Ventilation air movement on G Panel during Test 2-0.

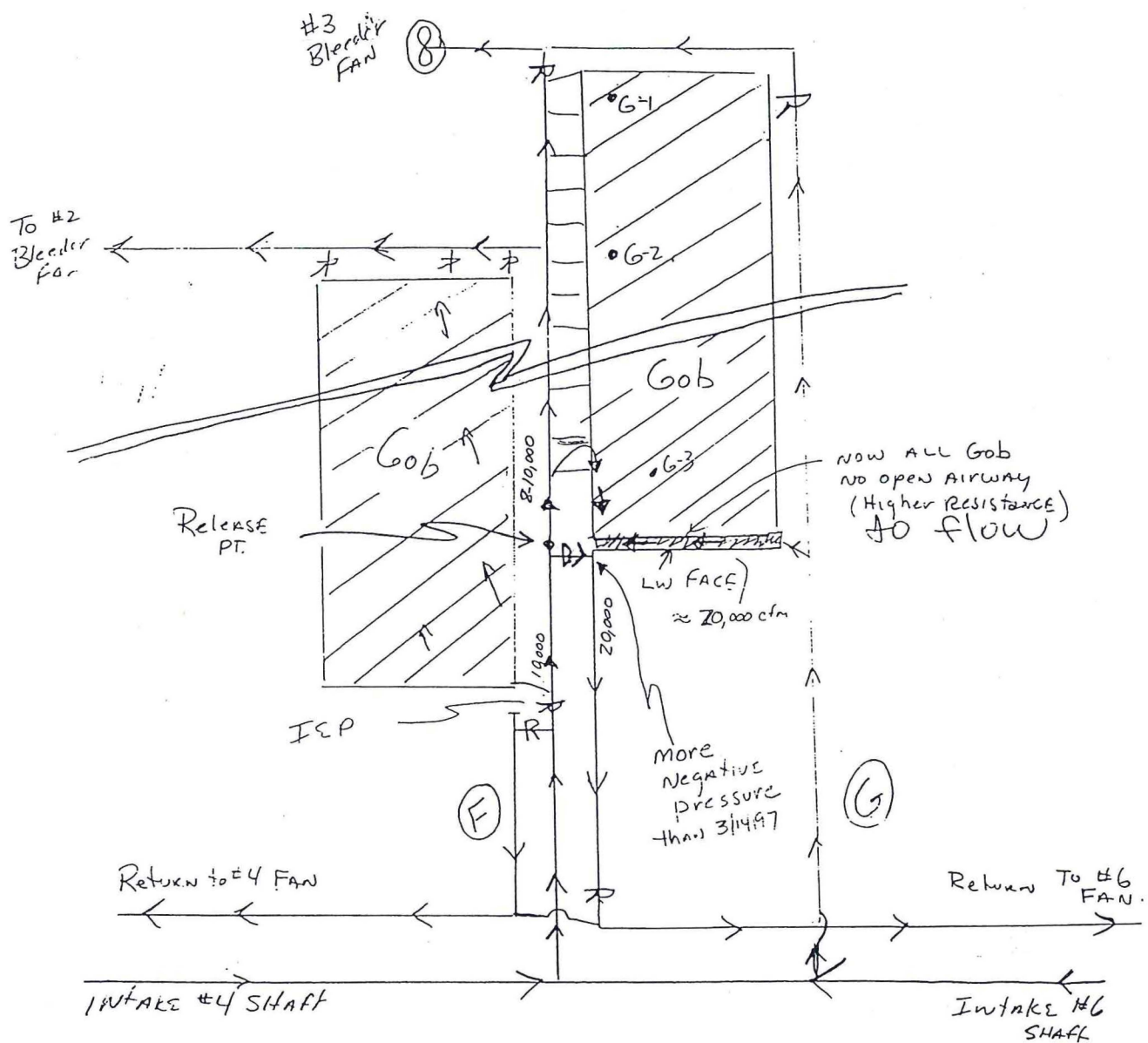


Figure 25.-Ventilation air movement on G Panel during Test 2-5.

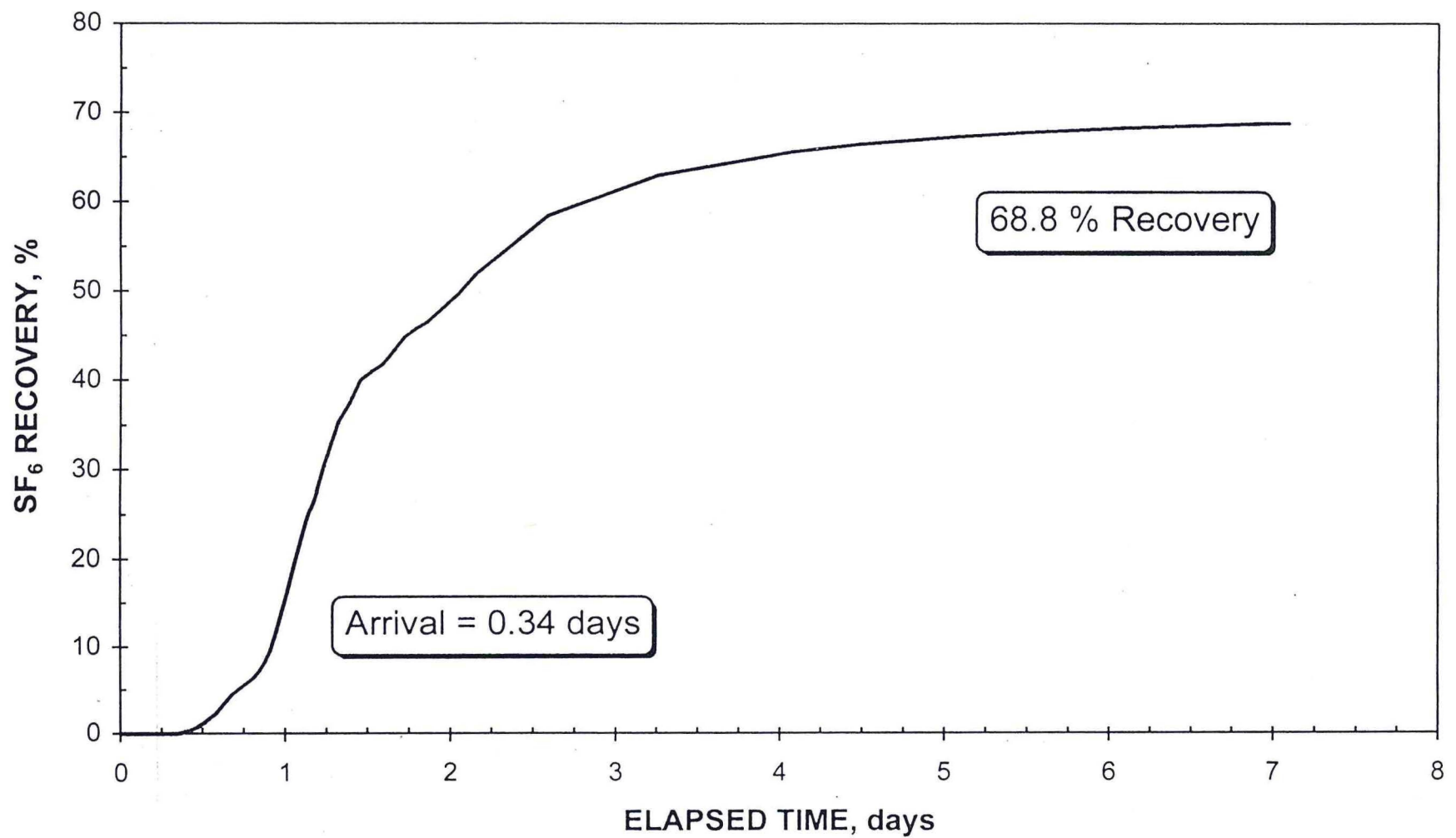


Figure 26.-Graph of the amount of SF₆ recovered over time at the BF2 monitoring sites during Test 2-6 shown as a percentage of the released tracer gas.

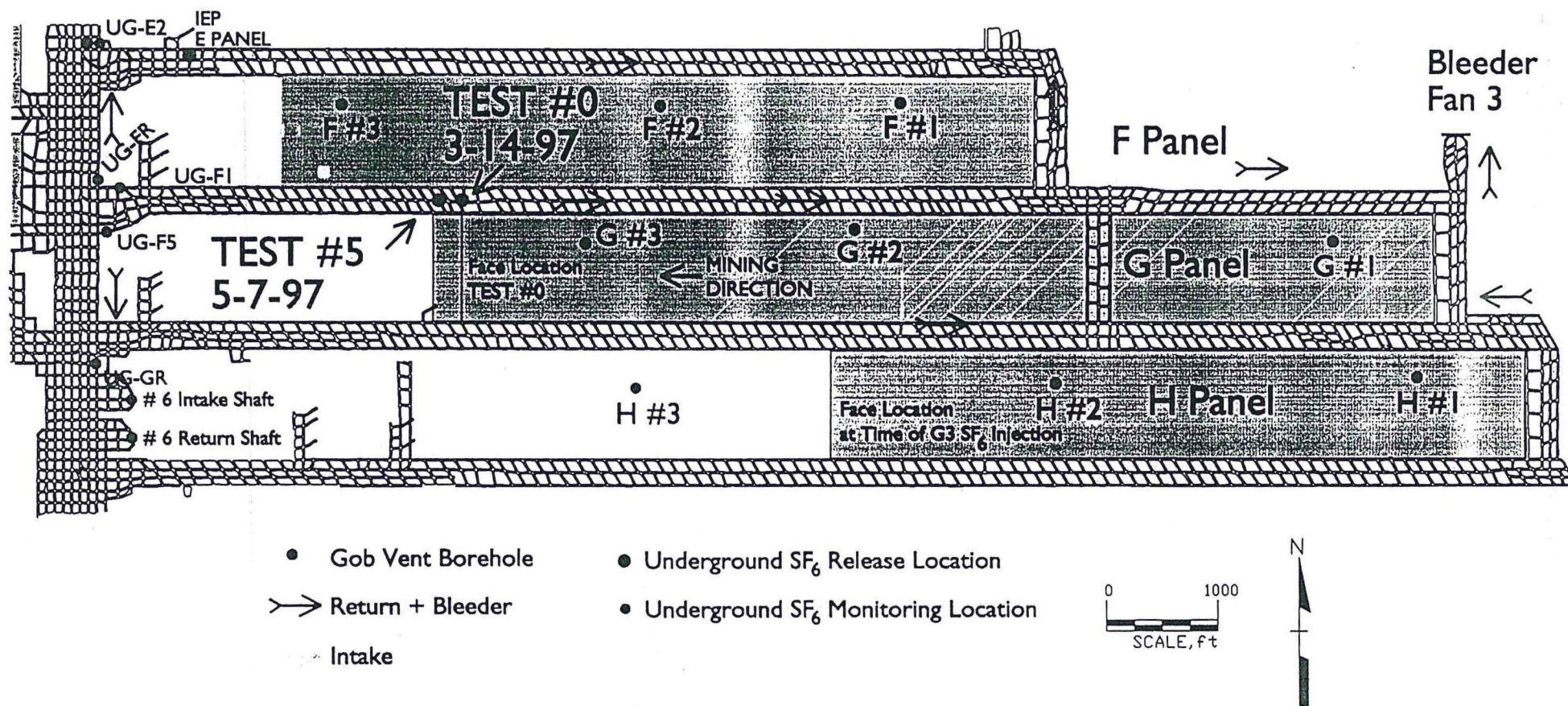


Figure 27.-Detailed map of F, G, and H longwall panels, Emerald Mine.

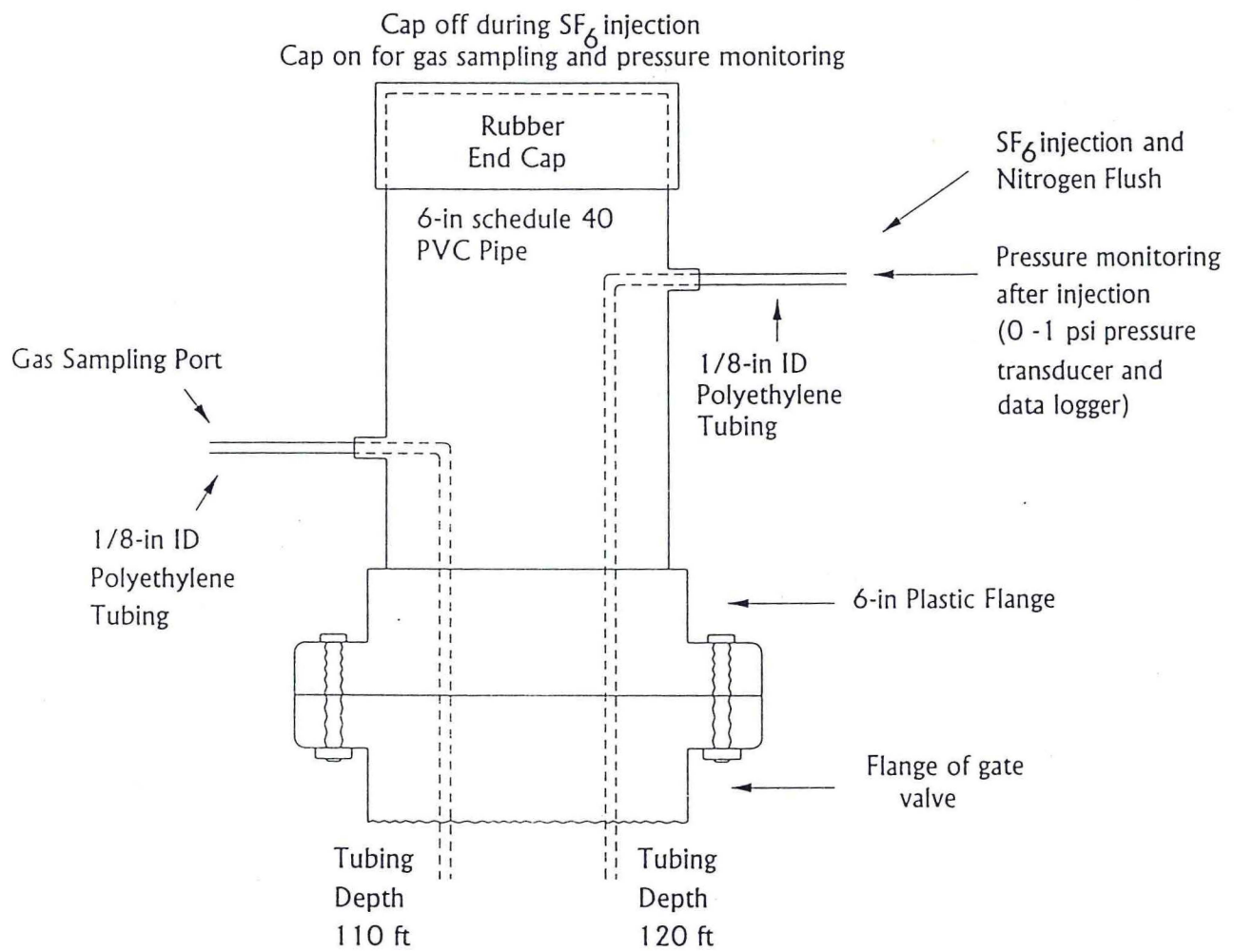


Figure 28.-Schematic of G3 wellhead configuration for tracer gas injection and shut-in pressure monitoring.

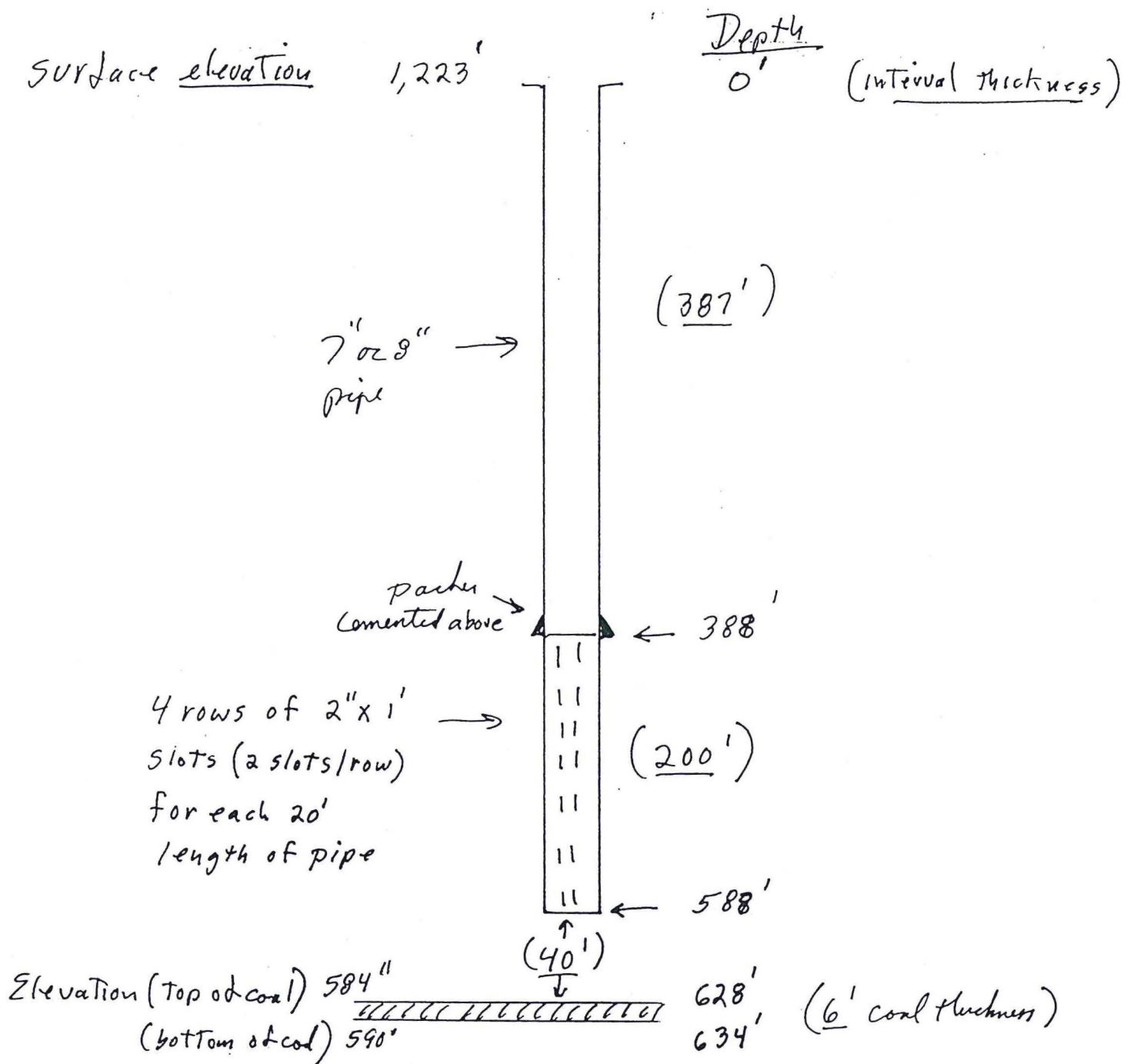


Figure 29.-Schematic of G3 borehole configuration for gob gas production.

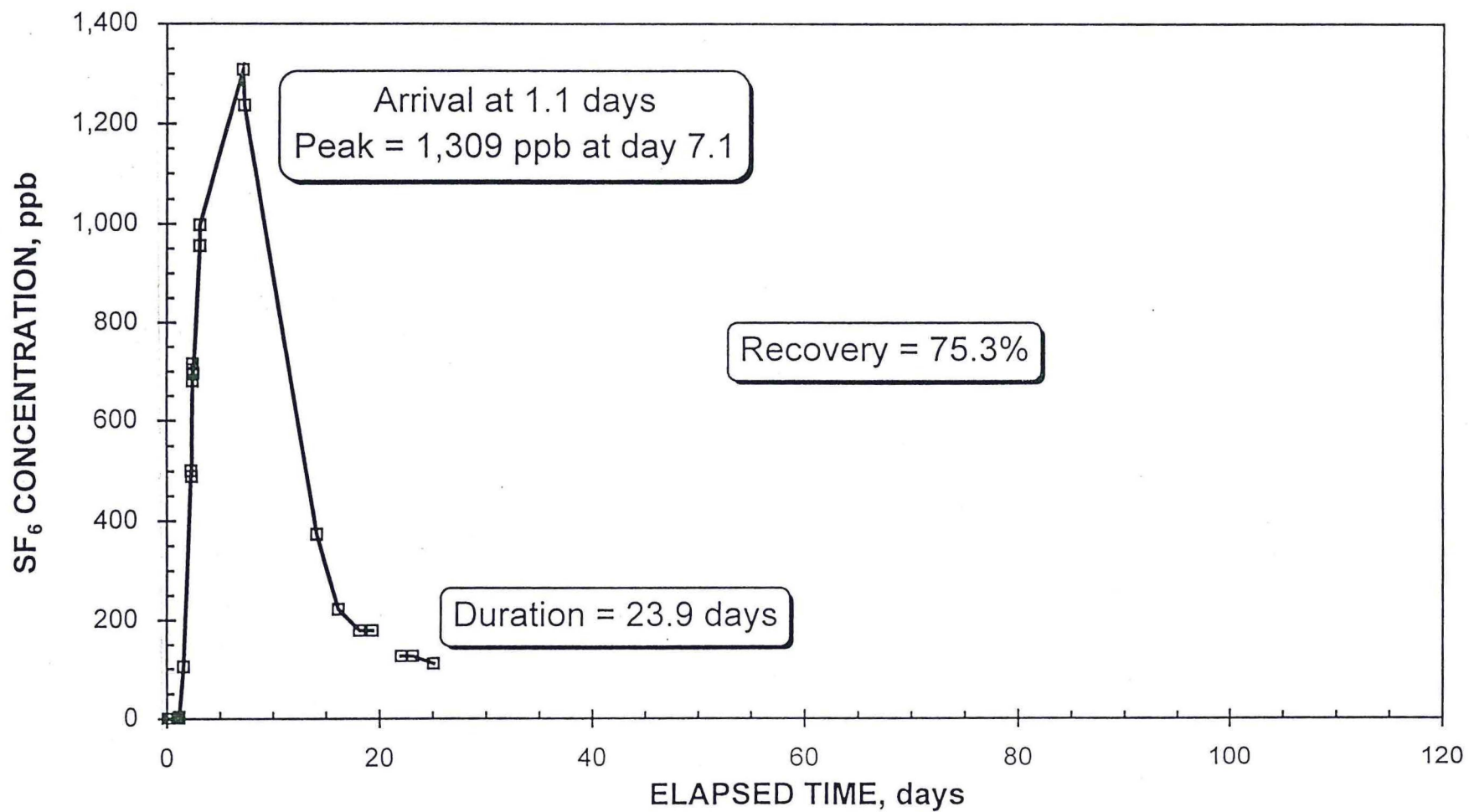


Figure 30.-Graph of tracer gas concentration at G2 during borehole injection experiment.

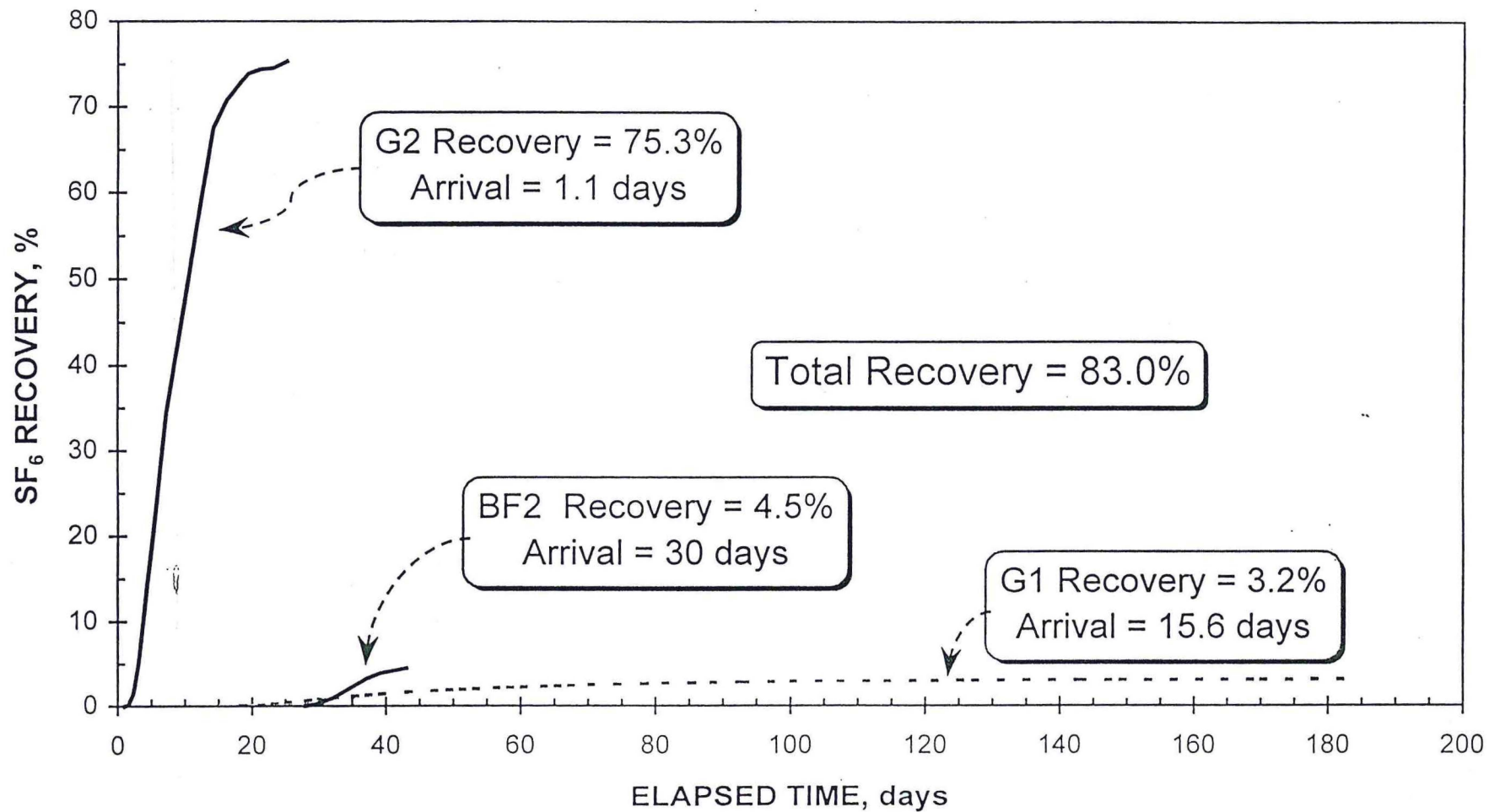


Figure 31.-Graph of tracer gas cumulative recoveries for borehole injection experiment.

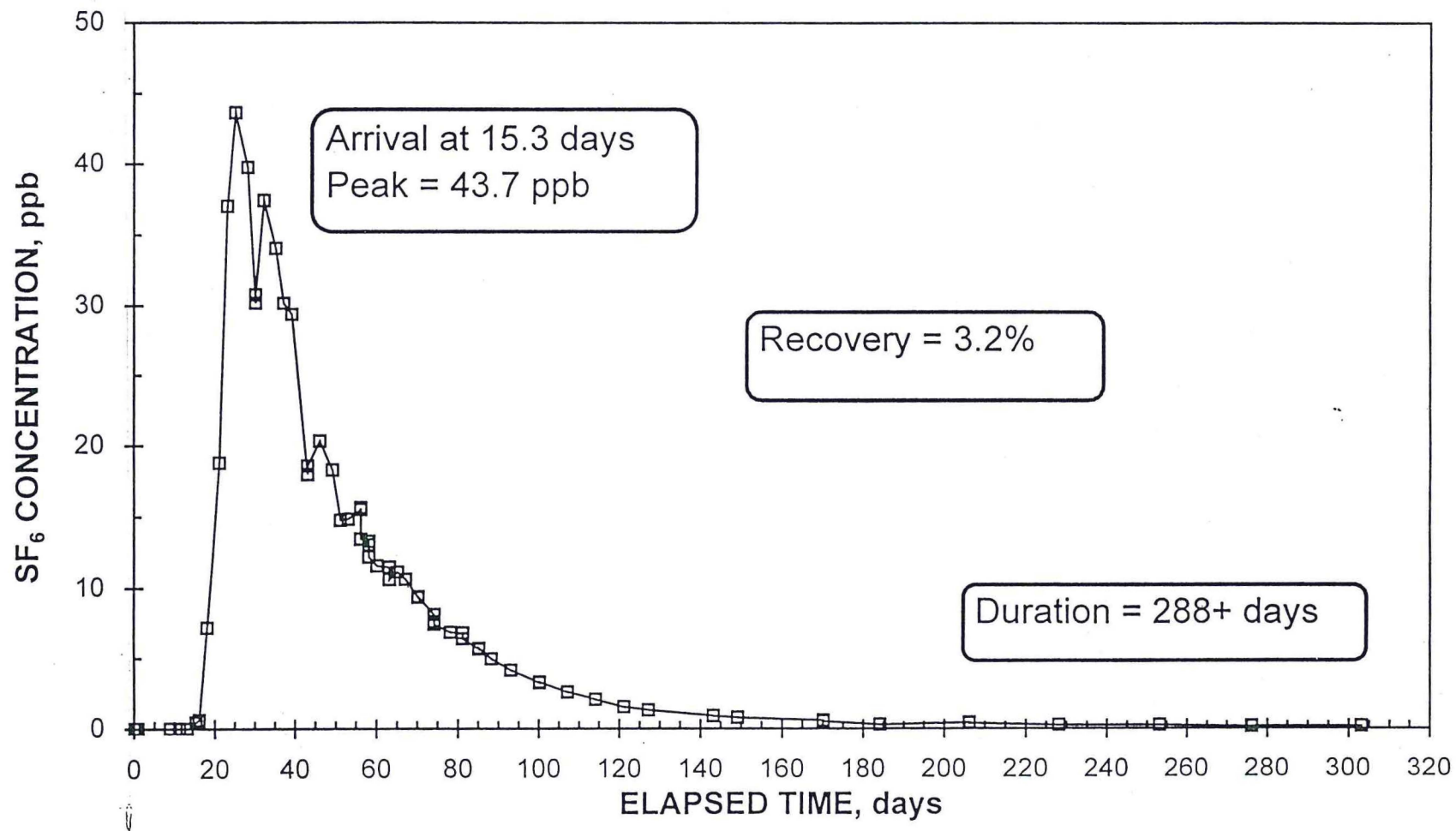


Figure 32.-Graph of tracer gas concentration at G1 during borehole injection experiment.

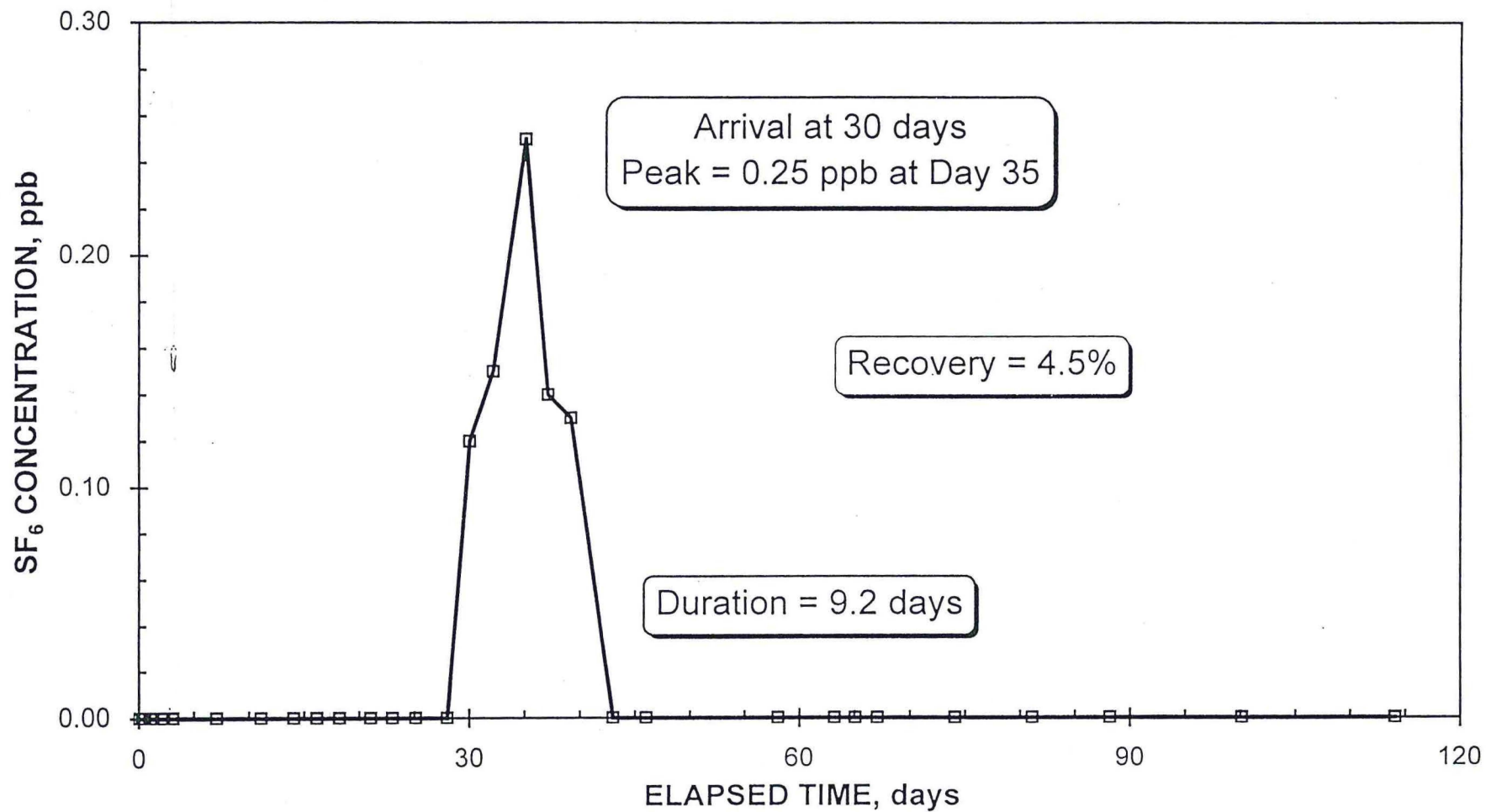


Figure 33.-Graph of tracer gas concentration at BF2 during borehole injection experiment.

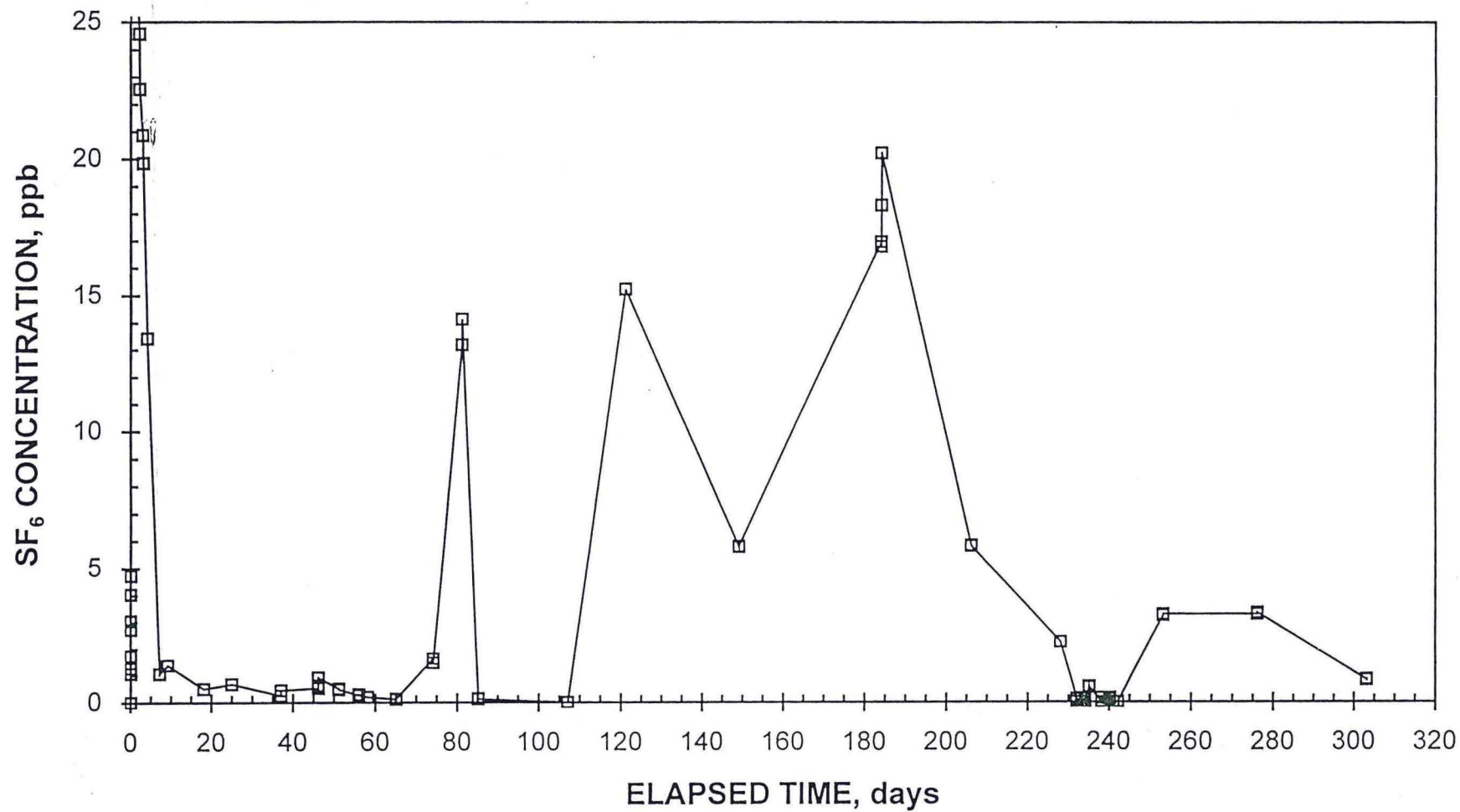


Figure 34.-Graph of tracer gas concentration at G3 during borehole injection experiment.

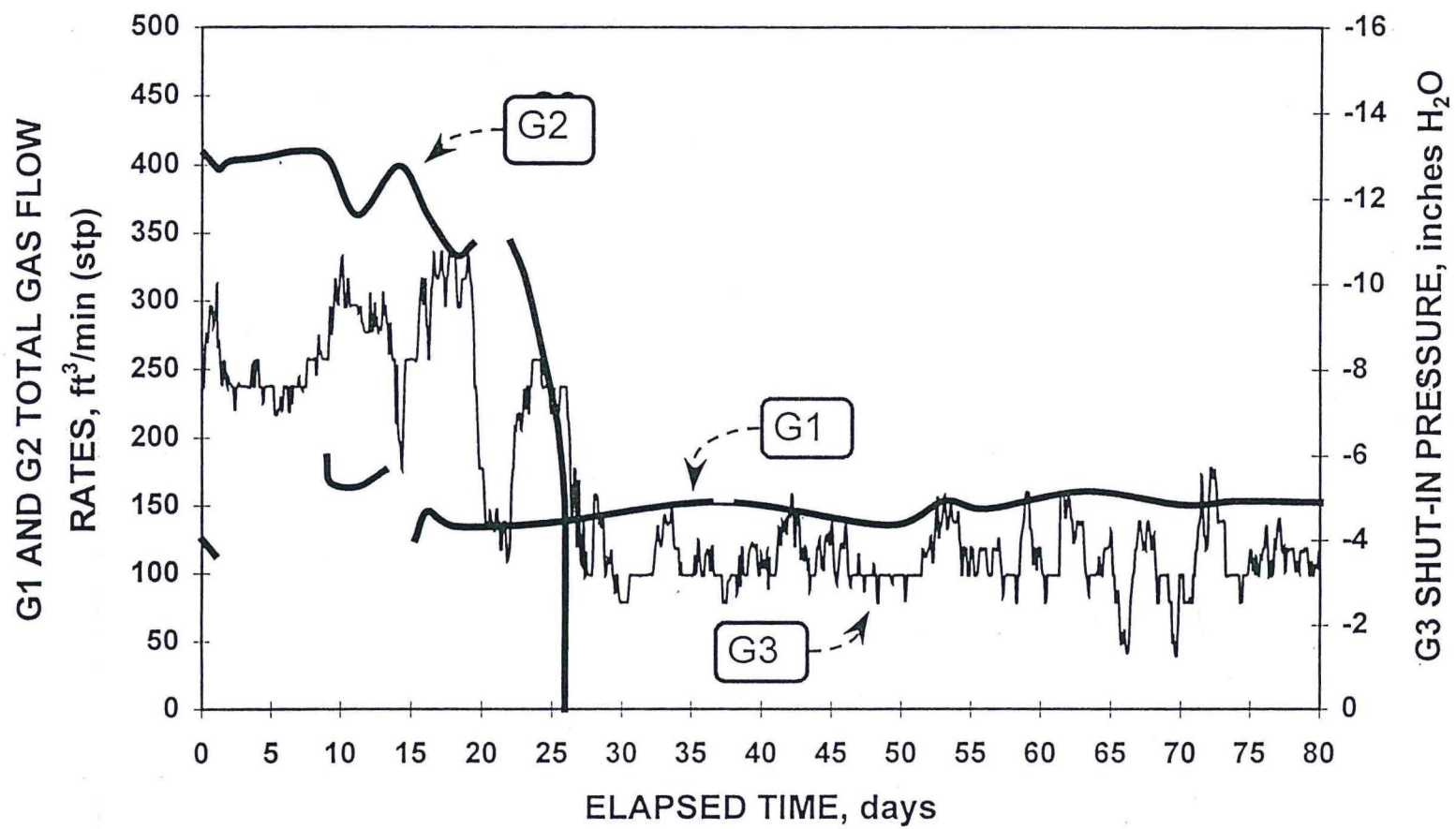


Figure 35.-Graph of influence of gob gas venthole production on G3 shut-in pressure.

**AVERAGE METHANE PRODUCTION
VS. HOLE LOCATION ON PANEL (through G panel)
EMERALD MINE**

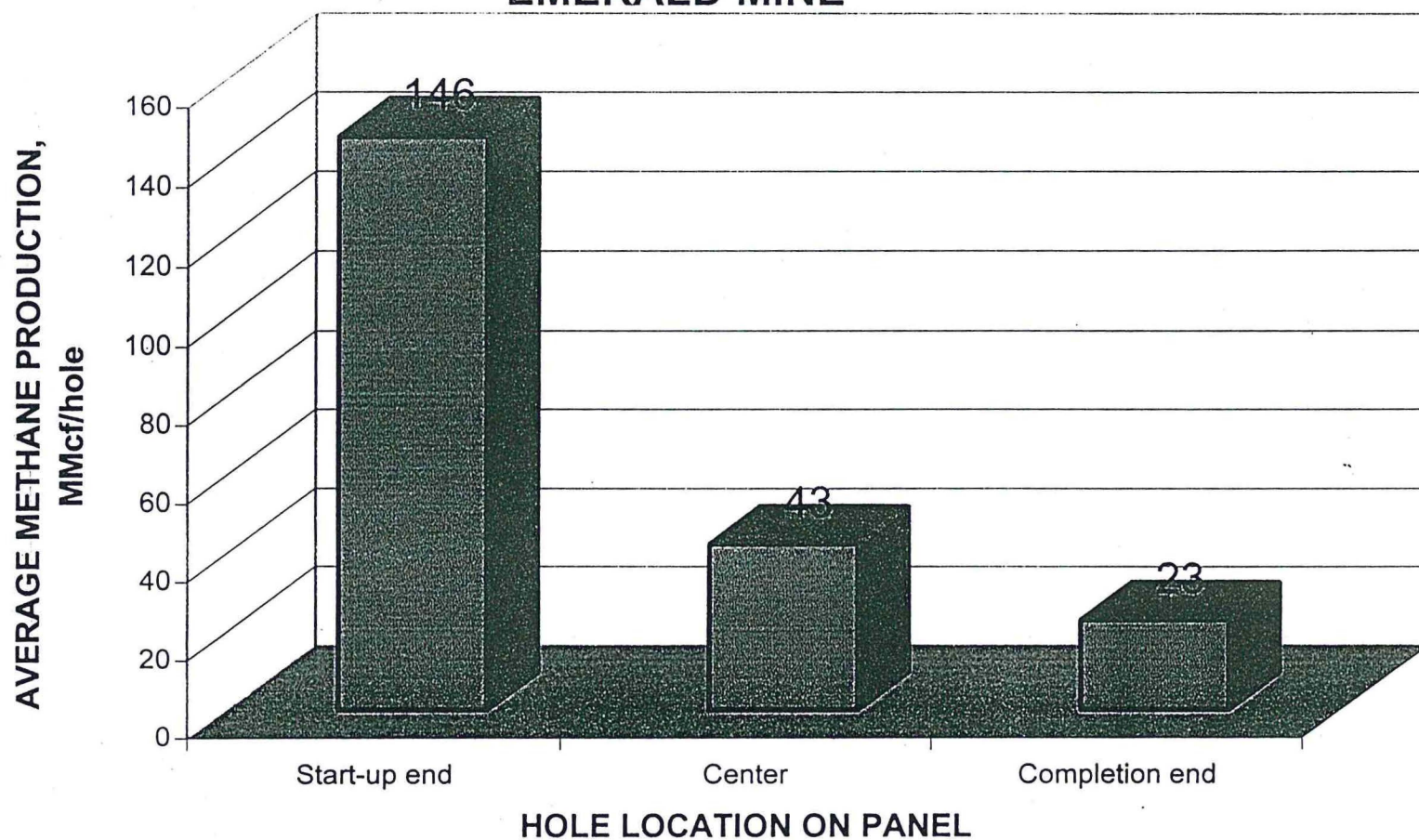


Figure 36.-Graph of average cumulative gob gas venthole methane production by location on longwall panel.

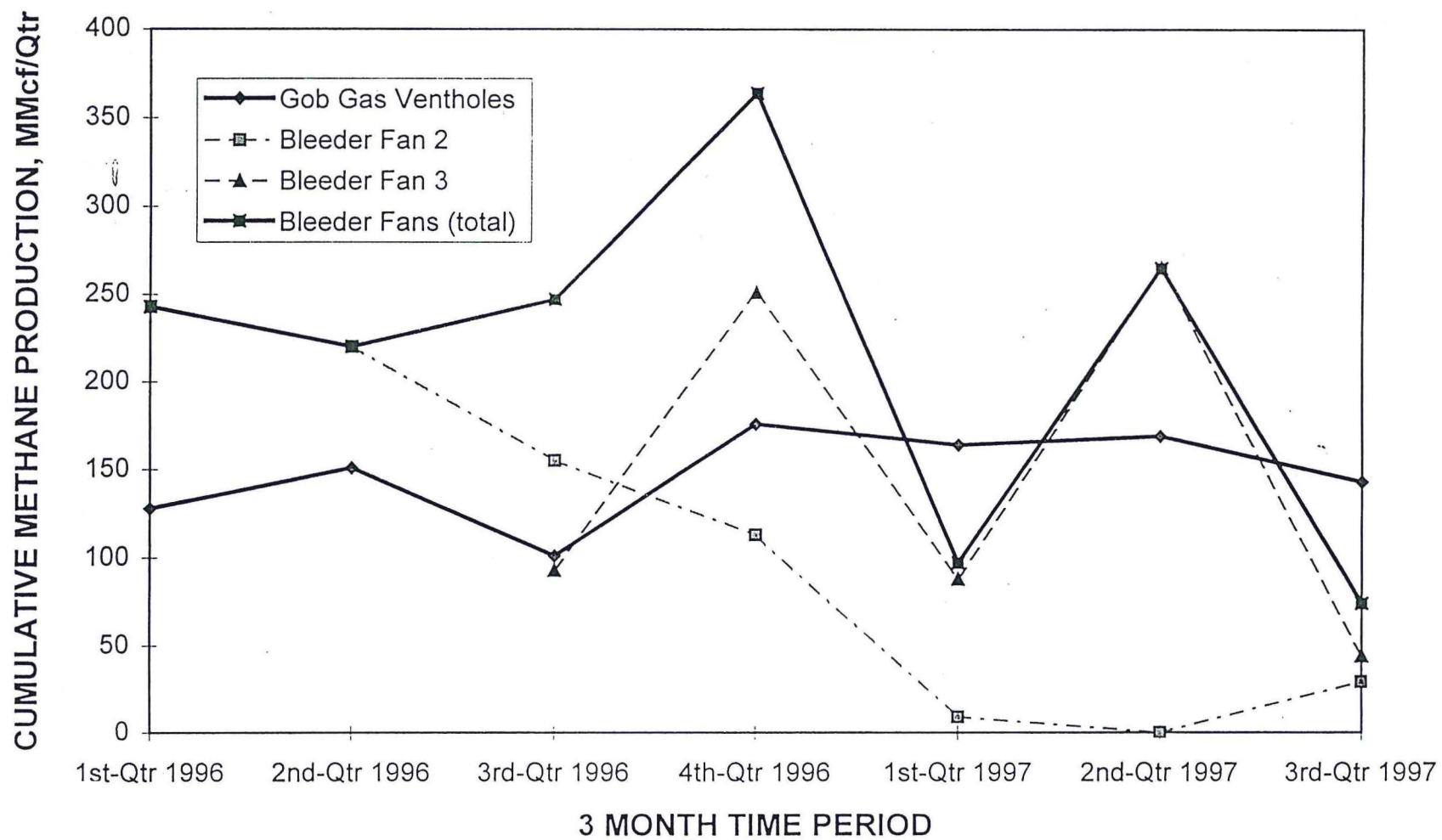


Figure 37.-Graph of bleeder fan and gob gas venthole quarterly methane production.