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Methane emissions and airflow patterns along longwall faces and through bleeder ventilation systems

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) conducted an investigation of longwall face and bleeder ventilation systems using tracer gas experiments and computer network ventilation. The condition of gateroad entries, along with the caved material's permeability and porosity changes as the longwall face advances, determine the resistance of the airflow pathways within the longwall's worked-out area of the bleeder system. A series of field evaluations were conducted on a four-panel longwall district. Tracer gas was released at the mouth of the longwall section or on the longwall face and sampled at various locations in the gateroads inby the shield line. Measurements of arrival times and concentrations defined airflow/gas movements for the active/completed panels and the bleeder system, providing real field data to delineate these pathways. Results showed a sustained ability of the bleeder system to ventilate the longwall tailgate corner as the panels retreated.

Keywords

longwall coal mining; ventilation; bleeder systems; bleederless systems; methane; explosions; tracer gas; SF_6; ventilation modelling; NIOSH; National Institute for Occupational Safety and Health

1 Introduction

The primary purpose of a mine ventilation system is to remove and render harmless methane gas and other contaminants from the mine. In a longwall mining operation, the design and implementation of an effective ventilation system to dilute and remove contaminants from the longwall face, at the tailgate intersection, and in the mined-out areas of a large longwall district require a thorough knowledge of the airflow paths and quantities within and around a longwall gob (caved material). However, the airflow paths and quantities in the inaccessible, mined-out areas of a longwall panel and district are not easily measured. Further complicating the issue are the changing potential methane flow paths as the longwall panel retreats and as subsequent panels are extracted. In addition, airflow patterns in the gob at the

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start of a longwall panel differ greatly from those at the midpoint or at the end of the panel due to compaction of the gob.

During longwall panel extraction, the caved zone and some inby gateroad entries become inaccessible to direct ventilation measurements. Mine operators use ventilation controls (regulators) to create pressure differentials at the outside boundaries of the longwall panels and supplemental ground support in maintained entries to create desired airflow patterns and deliver air quantities required to control methane levels. The effects of size and age of the bleeder system on airflow patterns at the longwall tailgate corner were evaluated.

Larger longwall panels, with both increased length and width, have the ability to produce greater volumes of contaminants that have to be controlled by other methods than just the basic ventilation system. As longwall panels increase in width and length, it becomes harder to supply the same volume of airflow at the same working fan pressures as with smaller panels (Hartman et al., 1997). In these larger panels, the airflow will be lower at the same applied ventilation pressure and the contaminant quantities may increase. Most gases produced in a longwall district are produced by the gob and surrounding strata, and may require other ventilation strategies (pre/post degasification) to be effectively ventilated (Schatzel et al., 2008). Increasing designed capacity for the bleeder system alone likely will not be sufficient for these larger panels.

One method employed to better understand ventilation behaviour in a longwall mining system is the use of tracer gas to delineate pathways and air quantities in these inaccessible areas. By measuring the arrival times and quantities of a released tracer gas at various locations in the ventilation system, airflow pathways and possible gas movement in the active and inactive panels and gobs can be inferred.

In this investigation, a series of tracer gas experiments were conducted at a mine in a four-panel longwall district using a bleeder ventilation system. The tracer gas was released in the intake air stream at the mouth of the longwall section (Figure 1) and sampled at various gateroad locations inby the shield line. Measurements of arrival times and concentrations defined airflow/gas movements for active and inactive bleeders/gobs and provided field data delineating these pathways. Previous work with tracer gas has shown it to be an effective tool to help characterise underground mine ventilation systems (Thimons and Kissell, 1974; Timko and Thimons, 1982) and to calibrate network ventilation models (Vinson and Kissell, 1986). The results from the current investigation were used to evaluate the effects of size and life cycle of the bleeder system on airflow patterns at the longwall tailgate corner. The results showed a sustained ability of the bleeder system to ventilate the longwall tailgate corner as the panel retreated away from the setup rooms. The results along with recorded ventilation data were also used to calibrate a ventilation network model which was used to provide preliminary determinations of airflow patterns in the worked-out areas including the caved material (gob) and inaccessible entries. This manuscript presents suggestions to achieve and maintain the desired airflow split at the longwall tailgate corner, supplies information on the ventilation changes that occur over the life of the gateroads and bleeders, and provides measured data on gas transport in the inaccessible regions of the bleeder system.

2 Experimental description

The tracer gas used in this study was sulphur hexafluoride (SF_6), a colourless, odourless, non-reactive, inorganic compound with a detection limit at less than 1 part per billion (ppb). Samples from the underground sampling were analysed using the NIOSH 6602 (NIOSH, 1994) method and a gas chromatograph with an electron capture detector. Some samples collected at the surface locations (bleeder fan and gob vent boreholes) were measured using a portable gas chromatograph to confirm the presence of the tracer gas in the ventilation system and its interaction with the gob vent borehole drainage system. Testing of the active gob vent boreholes showed that no tracer gas reported to those locations during the test; however, tracer gas was still detectable at the bleeder fan 8 hours after the release. The gob vent boreholes' high methane concentration and lack of oxygen (below 1%) indicate that mine air was not being pulled towards the gob vent boreholes and therefore no tracer gas was detected. This was consistent for all three tests.

2.1 Test 1

Three experiments were conducted at a Pittsburgh seam operation mining a four-panel longwall district. In Test 1, the active panel was #3, while the panel #4 headgate was being developed (Figure 1). Panel 3 was developed as a 2650-m-long (8700-ft-long) and 410-m-wide (1350-ft-wide) block of coal and had retreated 850 m (2800 ft) from the setup room, just passing the stair-step offset feature between LW #2 and LW #3 where the back bleeders do not align. The longwall district employed a bleeder-type ventilation system with a bleeder shaft at the back end of LW #1. Each gateroad was developed with three entries and the entries were numbered 1 to 3, left to right, looking inby.

During the startup of mining panel #3, sampling tubes were installed in the #2 entry of the headgate and the #3 entry of the tailgate to measure the arrival times and quantities of SF_6 during the tests. As the longwall retreated, the tubing lines became situated within the inaccessible regions of the gob area. The #3 entries of the gateroads had double rows of standing supports (pumpable cribs) that maintained the entries about 50% open after the longwall panel was extracted. The standing supports in the #2 entries were assumed to maintain the entries open and limit deterioration, while allowing these airways to be the primary transportation pathway for airflow on the tailgate and on the headgate.

The mine utilised a bleeder design with parallel entries but separated airflow paths that the authors have labelled the travelable outer bleeder (lowest pressure) and a parallel inner bleeder (Figures 1 and 2). The inner bleeder entries brought airflow from the headgate gateroads across the back of LW #3 (via the inner bleeder entry and the longwall setup room access entry) up to Bleeder 2 location and then into the outer bleeder entry at BEP #2 (Figure 1). Both bleeder sample locations were situated approximately 365 m (1200 ft) from the start of LW #3. Figure 1 shows a schematic of the longwall district, ventilation system, release SF_6 location, sample pumps, sampling tube locations, Mixing Point #1 (MP #1), Intake Evaluation Point (IEP), and Bleeder Evaluation Points (BEP #). The Mixing Point #1 regulator was located in entry 1 of the tailgate for LW #1, which was partially open and delivered main return airflow into the outer entry of the bleeder system.

The installed bleeder system design created multiple layers of parallel bleeder airflow across the back side of the longwall panels. The system is all considered to be part of the same bleeder split of air but each entry has a different function from a ventilation engineering perspective. Because of the use of parallel but separated entries across the back side of the longwall panels, the system can be defined as an inner bleeder system design (Figure 2). The stair-step offset feature of the back bleeders is shown in both Figures 1 and 2.

Four polyethylene sampling tubes were installed ahead of a retreating longwall face in the #3 entry of the tailgate labelled TG1 through TG4. The #3 entry was supported by a double row of pumpable cribs to maintain tailgate access during panel extraction and that resulted in portions of the #3 entry remaining open for some distance inby the longwall face. The sample tubes were hung between the two supports with the support closest to the removed block of coal almost fully collapsing after extraction. Four additional sampling tubes were installed in the #2 entry of the headgate, labelled HG1 through HG4, with all ended at the mouth of the section. Tube locations HG 1 and TG 1 were the longest at 2290 m and 2100 m (7500 ft and 6000 ft), respectively. HG 2, HG 3, and HG 4 and TG 2, TG 3, and TG 4 were located outby the face at the time of the release, with HG 4 and TG 4 being the shortest at 460 m (1500 ft). The sample tubes were 1.3-cm (0.5-in) OD polyethylene tubing, 1.0-cm (0.375-in) ID, each attached to a permissible SKC, Inc. Aircheck[1] vacuum pump. All samples were collected in 15-ml glass vacutainers which had been previously evacuated at NIOSH's Office of Mine Safety and Health Research (OMSHR) in Pittsburgh, Pennsylvania. A description of the sample tube locations, sample volumes, and transit times of samples in each of the tubes is shown in Table 1 as well as in previous papers by Schatzel et al. (2011) and Krog et al. (2011). Pump flow rates and tubing volumes were calibrated in the lab together before the tests by measuring the transit time of methane slugs in known length of tubing at different flow rates. The calculated transit times shown were rounded to the nearest minute based on the significant figures of the pump flow rate and to match the SF_6 sampling frequency. All other sample locations were collected at in-mine locations and therefore have no transit time.

For the first test, 149 L (5.27 ft^3) of SF_6 at standard temperature and pressure conditions (STP) of 1 atm and 16°C (14.7 psia, 60°F) was released over a three-minute time period. This relatively high concentration of SF_6 was released into the main ventilation air stream (~9000 ppb on a volume basis) to achieve a measurable concentration over the large longwall bleeder area. All of the fresh air supplied to the longwall headgate section entered through a single entry at the mouth of the section (shown as 'release location' in Figure 1). The 90 m^3/s (191,000 cfm) of intake air travelled down a single entry for over 120 m (400 ft) before splitting between the #2 and #3 intake entries within the next two open crosscuts. Next, the #2 and #3 intakes were separated by a stopping line up until the longwall headgate corner. The #3 headgate entry (normally a return entry on development) was used as a secondary intake for panel extraction. The tracer gas was released in this single intake, and mixing was assumed to be complete before the intake air split into the #2 and #3 entries.

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2.2 Test 2

At the start of Test 2, the longwall had progressed about 1250 m (4100 ft) from Test #1 as indicated in Figure 3. The release location was not changed. The volume of SF_6 released was 68.8 L STP (2.43 ft^3). Mixing Point #1 shown near the LW #1 tailgate introduced SF_6 from the main return into the bleeder system. Belt air from the LW #3 headgate and the LW #3 return air passing sample location TG 4 were both transported by the main return out to Mixing Point #1 (Figure 3), where a portion of the return air entered the bleeder system in LW #1 tailgate. This fast moving airstream reached the bleeder fan before airflow reached the Bleeder 1 or 2 sampling locations. The headgate gateroad development for LW #4 had not yet been connected to the back bleeder system during Test 2. During extraction of the LW #3 panel between Test 1 and Test 2, the headgate and tailgate sample tube lines were damaged. The two longer sample tube lines in the headgate (HG 2A and HG 1A) were cut to a length of 1280 m (4200 ft), while the previous longest sample tube line in the tailgate was cut to 920 m (3000 ft). A description of the sample tube locations, sample volumes, and transit times to the collection point are shown in Table 2. Arrival times of the tracer gas, corrected for sample tube transportation times at all the sampling locations, are shown in Figure 3.

2.3 Test 3

At the start of Test 3, longwall panel 3 was completed and the longwall system had moved to longwall panel 4 and mined approximately 2040 m (6700 ft) from the setup room. The longwall #4 face was located just behind the location of the adjacent longwall #3 face during Test 2 (Figure 4). SF_6 was released with a total volume of 69.4 L STP (2.45 ft^3). The release location was changed for Test 3 to shield 19 (38 m from headgate corner) on the longwall #4 face and the lengths, volumes, and transit times for the sample tubes are shown in Table 3. The sample line labelled TG 3B was cut at or near the sample pumps and recorded no tracer gas. This release differs from the previous two tests as all of the intake airflow to the district did not pass the release location. After completion of LW #3, the original sample tube lines in the tailgate entry were pinched closed and no airflow was able to be pulled by the sample pumps. Repairs to the lines were not successful due to limited access so direct measurement of airflow travel between two completed gobs by tracer gas was not performed. Note that the locations for Bleeder 1 and Bleeder 2 were moved closer to the bleeder fan to measure the different tracer gas pathways during this test and a third sample location was installed (Figure 4).

Changes made to the ventilation system altered the third and final tracer gas test at this mining district as the mine operator removed the last continuous miner unit from this district and redistributed airflow on a mine-wide basis. An internal bleeder design was utilised during the extraction of LW #4, where the majority of the longwall tailgate airflow was directed towards the main return and then diverted towards the bleeder system using the recovery rooms and access entries of the previous panels, also referred to as an internal ladder design (Barletta, 2007). A previous paper on internal bleeders indicates the advantages and disadvantages of this system design (Brune et al., 1999) and should not be confused with the use of an ‘inner bleeder’ system running parallel to the single-entry outer bleeder system at the back of the panels for the first two tests. The inner bleeder system was still being used for Test 3, but now the mine operator was also using an internal bleeder system to direct return airflow – approximately 21 m^3/s (45,000 cfm) – from the longwall tailgate corner towards the mains, around the previous recovery rooms, and back towards the bleeder fan by using the tailgate of the first panel.

The internal bleeder system created a dramatic alteration to the airflow pattern at the longwall tailgate corner and throughout the longwall district. In the previous two tests, the majority of the airflow at the longwall tailgate corner travelled inby towards back entries of the bleeder system and pulled the airflow behind the shields away from the face. During Test 3, about 70% of the airflow on the longwall face was sent outby the longwall tailgate corner via the two remaining tailgate entries with most then dumped into the bleeder system at the previous panel’s recovery room. Most of the 70% was transferred through the #2 entry (bleeder airflow) which is separated from the #3 entry (section airflow) by a row of stoppings. This indicated that only 30% of the longwall face ventilation travelled inby back towards the entries at the back of the panel.

The Mixing Point #1 regulator located in entry 1 of the tailgate for LW #1, which was partially open for the first two tests, was fully closed, but now an even greater airflow quantity was being directed back towards the bleeders through the recovery room access entries (internal bleeder). Most of the airflow moved by the internal bleeder passed through the Intake Evaluation Point (IEP) located on LW #1 tailgate.

The originally planned tracer test was to measure the airflow travelling between two completed gobs, LW #2 and LW #3, but the loss of the sampling tube lines eliminated that option. The third test was modified to determine the longwall tailgate corner airflow distribution and the capacity of the internal bleeder by releasing the tracer gas on the longwall face. Under these conditions, the airflow travelling behind the longwall at shield 19 would not be mixed with the released tracer gas and carried no tracer gas, which enabled the determination of the origin of the air reaching sampling locations inby the longwall face (TG 2B and TG 1A of Figure 4).

3 Results and discussion

The release point for Tests 1 and 2 was important because all intake airflow for every sample point except the bleeder fan passed through the release point. This allowed for calculation of recovery percentages at all locations including the bleeder fan based on the following assumptions: perfect mixing at the release location, a closed system with no other intakes except at the IEP at LW #1 TG, and minor stopping leakage. These assumptions are reasonable with airflow velocities of over 6.1 m/s (1200 ft/min) at the release point, and with no other intake path besides minor stopping leakage and the airflow passing through Mixing Point #1, which was dumped directly into the low-pressure outer bleeder entry with no possibility to interact with other sampling points. Every sampling location, regardless of airflow quantity and given enough time, should have the same integrated area under the SF_6 concentration vs. time curve (Figures 5 and 6). These integrated areas multiplied by the measured airflow quantity determine the standard recovered volumes of SF_6 at each location. These are compared to the expected recoveries that are based on the integrated area of the release location. Direct airflow quantity measurements were not possible at all locations but could be estimated based on arrival times and assumed cross-sectional areas.

3.1 Test 1

Arrival times of the tracer gas, corrected for sample tube transportation times at all the sampling locations, are shown in Figure 5. The high-speed airflow travelling down the headgate carries the tracer gas to the sample locations. The SF_6 concentrations over time are shown in Figure 6. The HG 1 sample location was inby the longwall headgate corner and shows little exchange of ventilation airflow between the gob and the intake airflow (HG 2), as represented by the same decline rate as HG 2. A curtain in the #2 entry close to the longwall headgate cause very little air interaction with the longwall gob corner as airflow passed through this corner to reach HG 1 located in the #2 entry.

A ventilation study at the start-up of the third panel extraction showed that the longwall tailgate corner was ventilated primarily by the bleeder fan, with the majority of the longwall face airflow pulled back towards the bleeder fan (Krog et al., 2011; Schatzel et al., 2011). The arrival times and concentrations of the SF_6 in the tailgate entry in Test 1 are shown in Figure 7. The results showed that the inby TG 1 location had half the peak concentration compared to those sampling locations outby the tailgate (TG 2). This indicates that half of the airflow at TG 1 came directly from the longwall face, travelling down the supported #3 entry that is open to the gob, with initial dilution from slower moving air without SF_6 behind the shields. The secondary rise in SF_6 concentration at time 0:28 indicates that the other half of the airflow came from the broken rock mass behind the shields. Test 1showed the ability of the sampling system to record fast-moving SF_6 slugs in the main ventilation airflow, as shown in the headgate tracer gas samples where airflow velocities of over 3.6 m/s (700 ft/min) were measured and differentiate between slower-moving air behind the shields.

3.2 Test 2

In test 2, all three inby sample locations in the headgate entry showed similar gas concentrations indicating very little air exchange from the gob to the sample locations as well as any migration from the #3 entry to the #2 entry (sample locations) because the headgate #3 entry is at a lower pressure than the #2 entry. In Figure 8, the sharp initial tracer gas release slug is indicated by HG 4, with similar decline curves for the three inby sample locations (note that the previous zero value for HG 4 does not plot on the log scale). For lines that have been cut, the labelling is altered by adding a suffix to the location name, e.g., HG 1A.

In Figure 9, SF_6 concentrations for TG 1A and TG 3 match closely for the first two hours but then diverge afterwards due to airflow that travelled slowly behind the shields and within the gob arriving at the more distant TG 3 sample location. This longer interaction period with airflow from the gob caused the flatter tail of TG 3 when compared to the closer TG 1A. TG 4 shows the highest tracer gas concentration, which is expected from a sample location that had little interaction with the gob. The three inby locations (TG 1A, TG 3, TG 2) had much lower peak concentrations and increasing tail lengths showing a greater mixing interactions with airflow paths within the gob.

The travel pathways of the tracer gas give an internal view as to the design of the inner bleeder entries and the transportation of gob gas to the measuring locations (BEPs). Airflow velocity down the #2 entry of the headgate was calculated to be 1.22 m/s (240 ft/min) and was maintained until reaching the back end bleeders (Figure 10). At the tailgate, the airflow velocity in the #3 entry started at 0.95 m/s (190 ft/min) from the longwall face to TG 3, and slowed to 0.51 m/s (100 ft/min) between TG 3 and TG 2. The airflow velocity from TG 2 to Bleeder 2 was calculated to be 0.34 m/s (67 ft/min). Airflow velocity decreased between TG 3 and TG 2 as compared to between LW face and TG 3 due to air leaving the #3 entry airflow path and entering the #2 entry airflow path because of the lower resistance. This would be expected as flow resistance was lower in entry #2 due to the likelihood that entry #3 was obstructed, being adjacent to the gob. The inferred airflow velocity in entry #2 increased as it flowed inby the longwall tailgate corner due to potential blockages in entry #3, as corroborated by the SF_6 arrival time at the bleeder fan. The airflow travelling down tailgate entry #2 of LW #3 was predicted by network models to be pulled across the setup room of LW #2. This airflow did not arrive at Bleeder 2 but bypassed this location and arrived at BEP 2 (Figure 10). The inner bleeder system is designed to bring four different airflow streams (Panel #1 inner bleeder entry, Panel #1 setup room access, Panel #2 inner bleeder entry, Panel #2 setup room access) together just before BEP 2, then pass this airflow to the outer bleeder entry. BEP 2 is responsible for over one-third of the total airflow of the surface bleeder fan, and all interior airflow entries flow toward this location.

The cumulative SF_6 totals in bleeders 1 and 2 and at the bleeder fan and the expected cumulative amounts are shown in Figure 11. The expected cumulative amounts were calculated based on known airflow measurements in the accessible locations of the mine and assumed full recovery. Predicted SF_6 amounts were calculated using ventilation network models for the inaccessible locations and then compared to the recorded SF_6 amounts. Bleeder 1 reached its peak total while both Bleeder 2 and the bleeder fan were still increasing when sampling stopped. The sampling times for Test 2 were extended underground based on the results from Test 1, but it was determined after data analysis that equilibrium had still not been achieved at some locations, indicating that low-velocity high-retention airflow paths existed in some portions of the bleeder system. During Test 3, the underground sample times were extended even further to try to capture all SF_6 released, but longer gob retention times and the long pathways between gobs made completing the test in one extended shift impossible.

The concentration of SF_6 reporting to Bleeder 2 was still increasing after 5 hours and had not reached its expected cumulative tracer gas amount, while Bleeder 1 had levelled off after 4 hours. Actual tracer gas recovery at Bleeder 2 was only 31% of that expected (Table 4) at that time but was still rising. Some of this tracer gas was captured at the bleeder fan which was observed for a longer period. The high expected recovery in the outer bleeder (Bleeder 1) shows that this airflow path had very little interaction with the gob, while the inner bleeder (Bleeder 2) had airflow paths with longer retentions times with the gob. This was not unexpected because the airflow from the longwall tailgate corner passed through the inaccessible tailgate towards Bleeder 2 and the low-velocity zone along the caved material of the gob.

The recovery percentage at any location is related to the interaction with the gob and the amount of air travelling in the predominant and faster flowing paths of the main ventilation system (entries). Tailgate #2 (TG 2) had only 33% of the expected recovery of SF_6, indicating that 2/3 of the expected tracer gas did not pass this location within the sampling time frame but instead remained in the gob (Table 4). The long retention time of tracer gas passing TG 2 is reproduced by network models and reveals a slow outgassing from the gob along the entire length between TG 3 to TG 2 and up to the offset step feature of the bleeder system between longwall panels 2 and 3.

Bleeder 2 had a low expected recovery of tracer gas (31%), which is consistent because it was located downstream of TG #2, which also had a similar low expected recovery of tracer gas. The airflow travelled from TG 2 to Bleeder 2 (730 m) in 36 minutes at 0.34 m/s (2400 ft/36 min = 67 ft/min). Four hours after the tracer gas release, Bleeder 2 experiences a second arrival of tracer gas (Figure 12) that did not show up at TG 2, indicating a different pathway. The longer pathway was determined to be from the LW 3 setup room which then travelled back towards the stair-step bleeder feature and then to Bleeder 2 using the inner bleeder entries (Figures 2 and 3). The airflow total in Table 4 is for the combined entries listed in the ‘Comments’ column.

The open exposure to the gob and the possibility that a short section of the supported #3 entry in the tailgate (Figure 2) could be completely blocked and enveloped by the gob would have the following consequences. Airflow quantities down the #3 entry would be much lower than at the longwall tailgate corner. Airflow travelling down the #3 entry after reaching the blockage would transfer preferentially to the #2 entry, which was assumed to remain open. Assuming a well-compacted gob, after the blockage was passed, the airflow in the #3 entry would predominantly flow from the periphery of the gob, as the general airflow pattern was towards the bleeder fan. Therefore, airflow travelling down the #3 entry would likely come from the surrounding gob. Tracer gas travelling along the periphery of the gob in #3 entry would have a much longer retention time than tracer gas travelling down the #2 entry.

The peak concentrations and flatter tails in Figure 9 show that the longwall tailgate corner is ventilated with 40% of the air at TG 1A coming directly from the longwall face. The remainder takes the slower path through the corner of the gob and from behind the shields. The airflow leaving the tailgate side of the longwall face splits and travels to both TG 4 and TG 1A. The SF_6 concentration at TG 4 (Figure 9) has a non-diluted (pure) peak concentration of 1000 ppb, while TG 1A has a diluted (mixed) peak of 400 ppb. The peak ratios indication of 40% of the airflow at TG 1A came directly from the longwall face and travelled inby down entry #3. Table 4 shows that both TG 4 and TG 1A had the same high recovery of expected SF_6, indicating that all SF_6 had passed these sample locations. The results of Test 2 show that the bleeder system was still able to ventilate the longwall tailgate corner of the longwall panel #3 after retreating the majority of the longwall panel, 2100 m (6900 ft) from the setup room.

3.3 Test 3

Test 3 results in Table 5 can be used to determine the airflow distribution at the longwall tailgate corner and throughout the longwall district. The tracer gas was released at shield 19 of the active longwall panel 4 and the transit times are shown in Table 3. The recovered tracer gas at the tailgate shows that while longwall face airflow flowed inby through the bleeder system at the longwall tailgate corner, about one-half of the air at the inby locations TG 2B and TG 1A did not pass the longwall face at shield 19 but travelled behind the shield line and through the gob (Figure 13). This indicates that the airflow entered the gob between the longwall headgate corner and shield 19, before passing behind the shields and then towards the back bleeders.

The SF_6 concentration chart from Figure 14 shows the depressed peaks and slow decline curves for the two sampling locations inby the longwall tailgate corner. The TG 4 sample line shows the high peak SF_6 concentration experienced on the longwall face followed by a decline curve, indicating some interaction with a longer retention airflow travelling in the longwall tailgate corner gob. The expected result for TG 4 based on the decline curves from the first two tests is shown to represent the difference when an internal bleeder system is operated.

The majority of the tracer gas released on the longwall face passed through the IEP sample location, towards Bleeder 2 and Bleeder 1, and then to the bleeder fan (Figure 4). Figure 15 shows the SF_6 concentrations for airflow travelling this path. The majority of the SF_6 that passed through the IEP reached Bleeder 1 via Bleeder 2 and the parallel air path of the setup room of LW #1 (Figure 16). The expected amounts of SF_6 for the IEP and Bleeder 1 are the same at 41.6 L (1.47 ft^3) but do not represent the same SF_6 at both locations.

In Test 3, the recovered concentration vs. time curves at the two inby locations, TG 2B and TG 1A, were only 45–51% of those expected (Table 5). The two sample locations were located in entry 2 of the tailgate and the data indicate that one-half of the airflow being pulled from the longwall tailgate corner came from the longwall face, and one-half came from airflow travelling behind the shields that entered the gob before shield 19. The implications are that while the total amount of airflow being pulled inby from the longwall tailgate corner was reduced by the use of the internal bleeder system, the longwall tailgate corner and longwall face were still being ventilated and contaminants behind the shields were being pulled away from the face towards the back bleeder system. Half of the airflow travelled through the gob and diluted methane there.

The data in Figure 14 differed from data in the two previous tests. For instance, the levels at TG 4 in Test 3 took over one hour to drop to 1% of peak concentration while it took less than 30 minutes in Test 2 (Figure 9), indicating that some of the tracer gas remained behind the shields or there was an interaction with the adjacent worked-out area of the previous longwall panel. In both previous tests, the concentration of tracer gas had fallen off rapidly, indicating little exchange with the gob and with the airflow at or near the longwall tailgate corner. In Test 3, the inby sample locations (TG 1A and TG 2B) both have flatter peaks and slower decline curves, indicating a greater retention of tracer gas at the longwall tailgate corner.

This interpretation of tracer gas concentrations in the inby locations in conjunction with the cumulative recovery data indicated that while the bleeder system does pull a majority of the airflow from behind the shields, there is a greater retention of tracer gas at the longwall tailgate corner when an internal bleeder system is paired with an inner bleeder design. The flatter tail of the concentration plot at TG 4 indicates that there is a greater retention of tracer along the longwall face that continues for hours after the initial tracer gas release (Figure 14). This flat tail was not observed in the previous two releases, and indicated that while an internal bleeder system can increase longwall face ventilation, it also increases the exchange between face airflow, any airflow movement behind the shields, and longwall tailgate corner airflow moving towards the mains. This is a known feature of the internal bleeder system and this study confirms previous work (Brune et al., 1999).

4 Discussion

During the three tracer gas tests, longwall face quantities were able to dilute tracer gas from the shearer and coal face and remove it from the longwall tailgate corner. During the first two tests, when the original bleeder design was used, most airflow at the longwall tailgate corner was pulled inby through the bleeder entries. The original bleeder system was able to effectively ventilate the tailgate during the early and late stages of panel extraction. During the third test, most of the longwall face airflow was pulled towards the mouth of the section and then transferred by the previous recovery rooms back towards the first panel's tailgate entries (internal bleeder system). A smaller amount of longwall face airflow was removed via the inby bleeder entries, allowing determination of the airflow behind the shields. Reduced SF_6 concentrations and expected recoveries at the tailgate inby locations suggest dilution by other air paths lacking SF_6 – i.e., the only possible air path came from behind the shields. The tracer gas release was at shield 19 so the air flowing behind the shields had to enter this pathway upwind of the release point. This is consistent with results from the two previous tests, with ventilation airflow readings at the longwall headgate corner showing more intake airflow entering than leaving the longwall face area at accessible locations. The determined airflow paths of the tracer gas indicate that any methane located behind the shields would be removed from the face and directed towards the back entries. The quantity of airflow leaving the longwall face and travelling inby the #2 middle tailgate entry was lower in Test 3 but airflow movement was away from the face.

A supported inner entry (#3 entry of the tailgate) next to the open gob is effective for removing the potentially higher methane concentrations located behind the tailgate shields. It is assumed that the entry will have at least one nearly complete collapse; this is due to the supported roof undergoing different weightings down its entire length, and given that the entry is not designed to stay open after panel extraction. The collapse will have the following implications to the ventilation system: the inner entry (#3 entry of the tailgate) should not be the only primary ventilation path in the bleeder system, but may be used as a secondary path; airflow travelling down the inner entry will migrate towards the open middle entry once an obstruction is encountered; this migrated airflow will come predominantly from within the gob (higher methane). The inby stoppings on the longwall tailgate corner, between the new gob and middle entry, need to be partially or completely removed to allow airflow movement from the inner entry to the middle entry.

Airflow travelling down the supported middle entry, assuming it remains unobstructed, will interact over time with higher methane airflow migrating out of the gob. As long as sufficient airflow is coursed through the middle entry between two gobs, the contaminants can be diluted to acceptable levels. As the number of panels in a district increases, it does become problematic to accurately engineer a system to course the desired airflow down each gateroad between two panels. An unobserved obstruction, such as a roof fall, that occurs anywhere down the length of a gateroad between two panels will change the airflow distribution pattern down each parallel gateroad in the district, making multiple panel districts difficult to ventilate.

Stair-stepped ventilation bleeders and the use of an inner bleeder system have to be balanced, because the use of both can seriously impact the performance of a typical bleeder system. Less contaminated air flowing around the gobs through the inner bleeder can be mixed with more contaminated airflow exiting the gobs to meet statutory limits. The use of a stair-stepped bleeder system increases the complexity of ventilating the back bleeders by placing a possible low-pressure point in front of the normal BEPs between longwall panel #2 and #3 (Figure 2). Until the longwall face passes the stair-step feature, the airflow in the #2 entry inby the tailgate corner of the active panel could reverse direction.

5 Conclusions

Tracer gas tests completed at a four-panel longwall district determined airflow paths and airflow quantities within the inaccessible portions of the gob and also determined the capacity of the bleeder system to remove contaminants from the longwall tailgate corner for varying positions of the longwall face. During the first test, the bleeder system was able to ventilate the active panel in the early stages of panel extraction. Results showed that half of the airflow moving inby from the longwall tailgate corner came from the longwall face while the remaining airflow came from behind the shields. During the second test, the longer longwall panel tailgate corner was effectively ventilated with about 60% of the airflow passing through the gob tailgate corner or flowing from behind the shields. These results matched the first test and showed that the bleeder system was ventilating the longwall tailgate corner of the longer panel.

The third test occurred during the mining of the fourth panel, which utilised an internal bleeder. The longwall tailgate corner was properly ventilated with contaminants being pulled inby towards the back bleeder system. However, the results showed that the interaction of the gob airflow/gas behind the longwall face and main return increased given the longer retention time of the tracer gas at the outby longwall tailgate corner sampling location. While gob gas did not enter the longwall main return during the test, the possibility of such an occurrence appears to increase with utilisation of an internal bleeder system. Tracer gas release on the longwall face during the third test showed that half the airflow moving away from the longwall tailgate corner and towards the back bleeders did not come from the longwall face but flowed from behind the shields. The determination that 7 m^3/s (15,000 cfm) of airflow entered the partially collapsed gob upwind of shield 19 and then moved towards the back bleeder matches the results measured during the first test under different ventilation conditions. The tightness of the caved material was assumed to remain constant across all three tests as no major geological features were noted. Initially it was surprising to find the same airflow split behind the longwall shields between the first and third tests with different mining conditions, more extensive panel extraction, and the use of an internal bleeder. The controlling factor appears to be the similar ventilation conditions (flow rates and pressure drops) on the longwall face generating the same pressure differentials between the longwall headgate corner and inby the longwall tailgate corner that creates airflow behind the shields.

A remnant entry adjacent to the longwall tailgate corner of the gob could be held partially open with standing supports, through which airflow could be directed towards the back bleeders, keeping the longwall tailgate corner clear of gob gasses. However, this supported entry should only be used as a secondary pathway because the probability of total collapse is high. All inby stoppings between the supported secondary and primary pathways (the middle #2 entry) should be partially or completely removed to permit airflow behind the shields and longwall tailgate corner to flow into both bleeder entries. If these stoppings remained intact and a total collapse occurred in the supported entry adjacent to the longwall tailgate corner, then no low-resistance path would remain from the caved material to the bleeder, which could then flow into the longwall tailgate corner to reach the middle entry of the bleeder. This condition must be minimised with the best approach being to remove all inby stoppings, which is standard practice at most but not all operations.

The choice to use an internal bleeder system is based on many design factors, and the possible longwall tailgate corner interaction is just one of many considerations. An internal bleeder system can increase the airflow quantity across the longwall face, but other ventilation conditions must be addressed regarding possible gob gas entering the return air at the longwall tailgate corner.

Biographies

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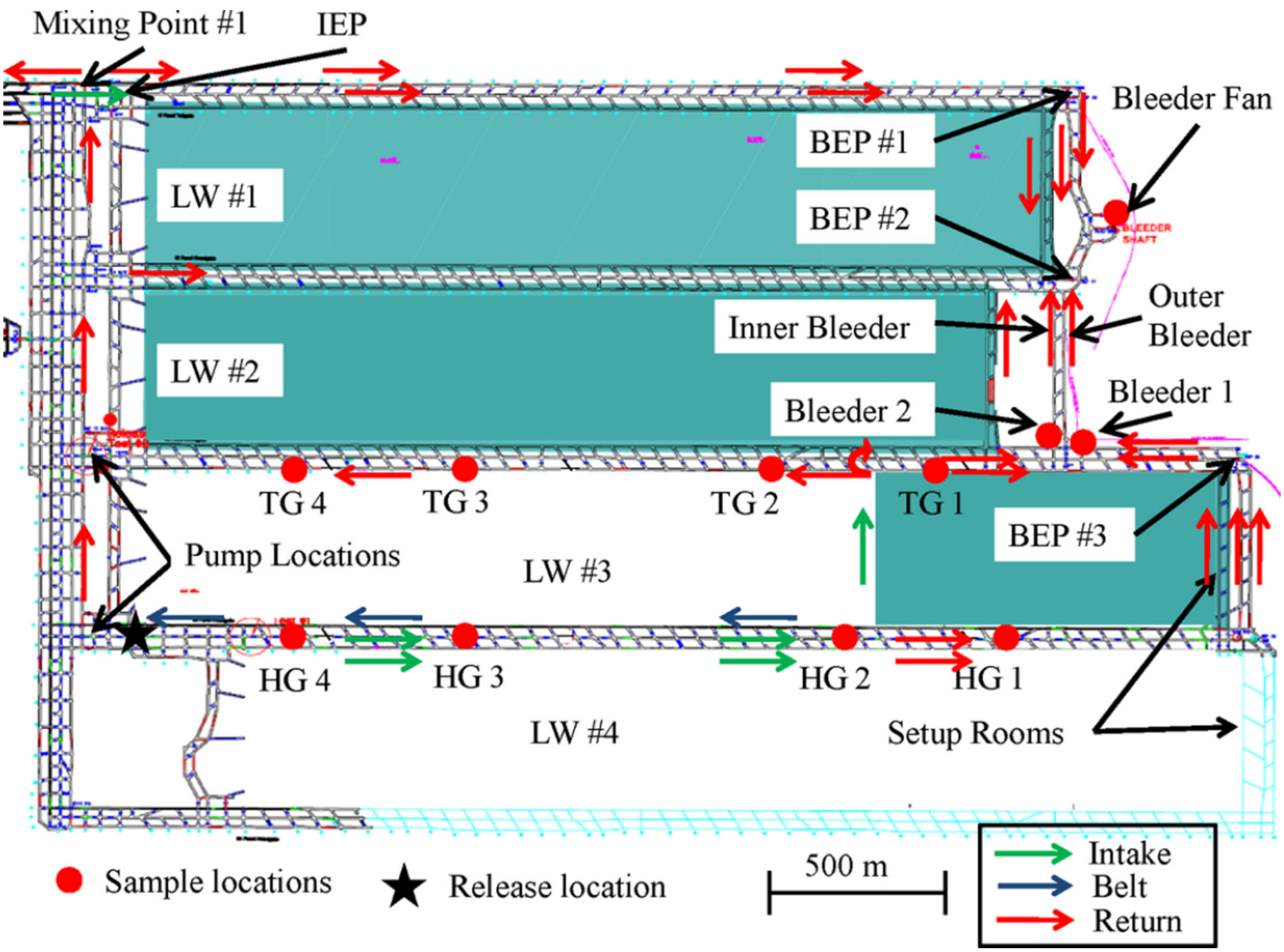

Figure 1.

Schematic of longwall district and ventilation system with sample tube placements in Test 1 (see online version for colours)

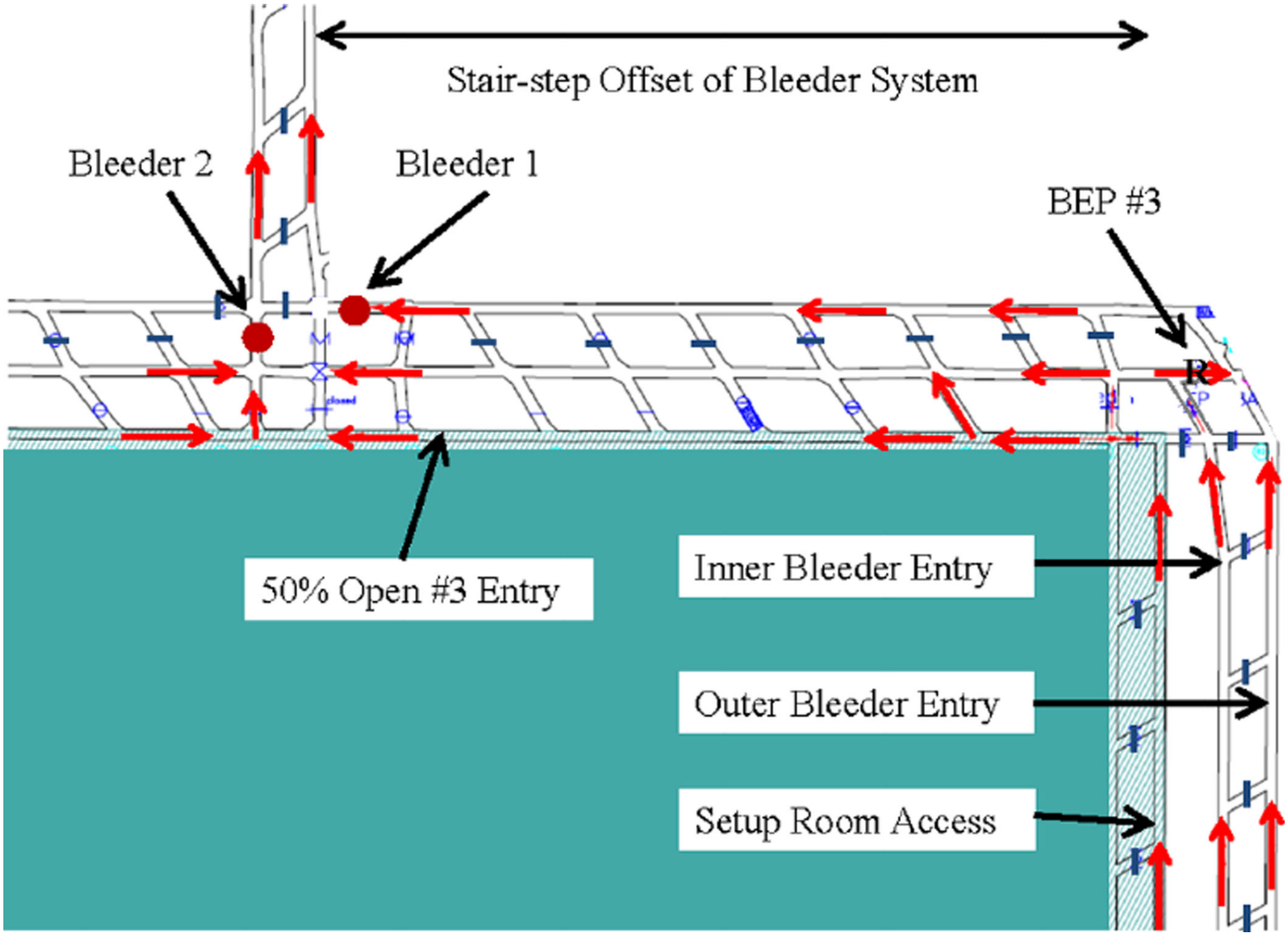

Figure 2.

Inner and outer bleeder entries and the stair-step bleeder offset between LW 2 and LW 3 (see online version for colours)

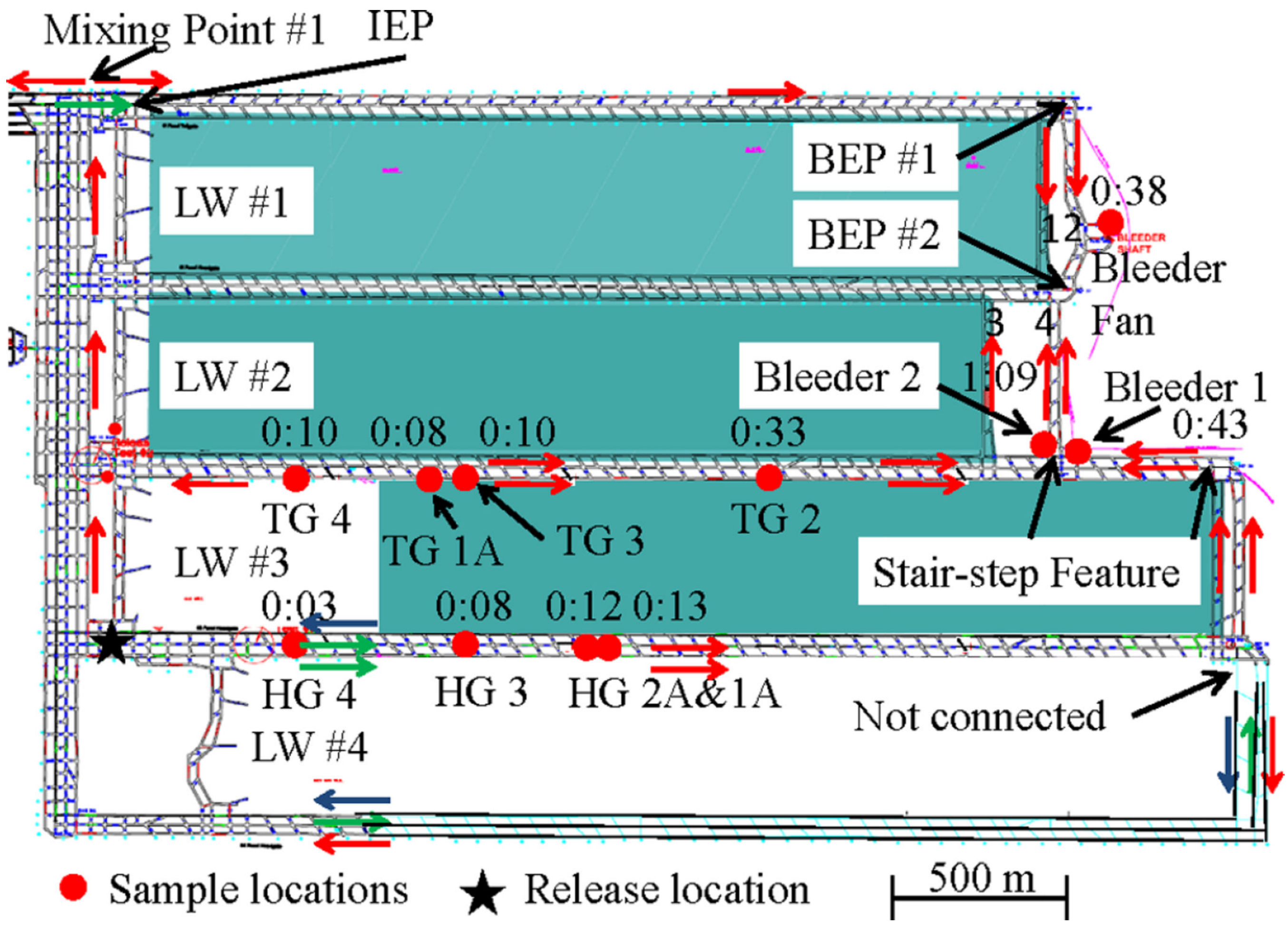

Figure 3.

Test 2 sample lines locations and corrected tracer arrival times (see online version for colours)

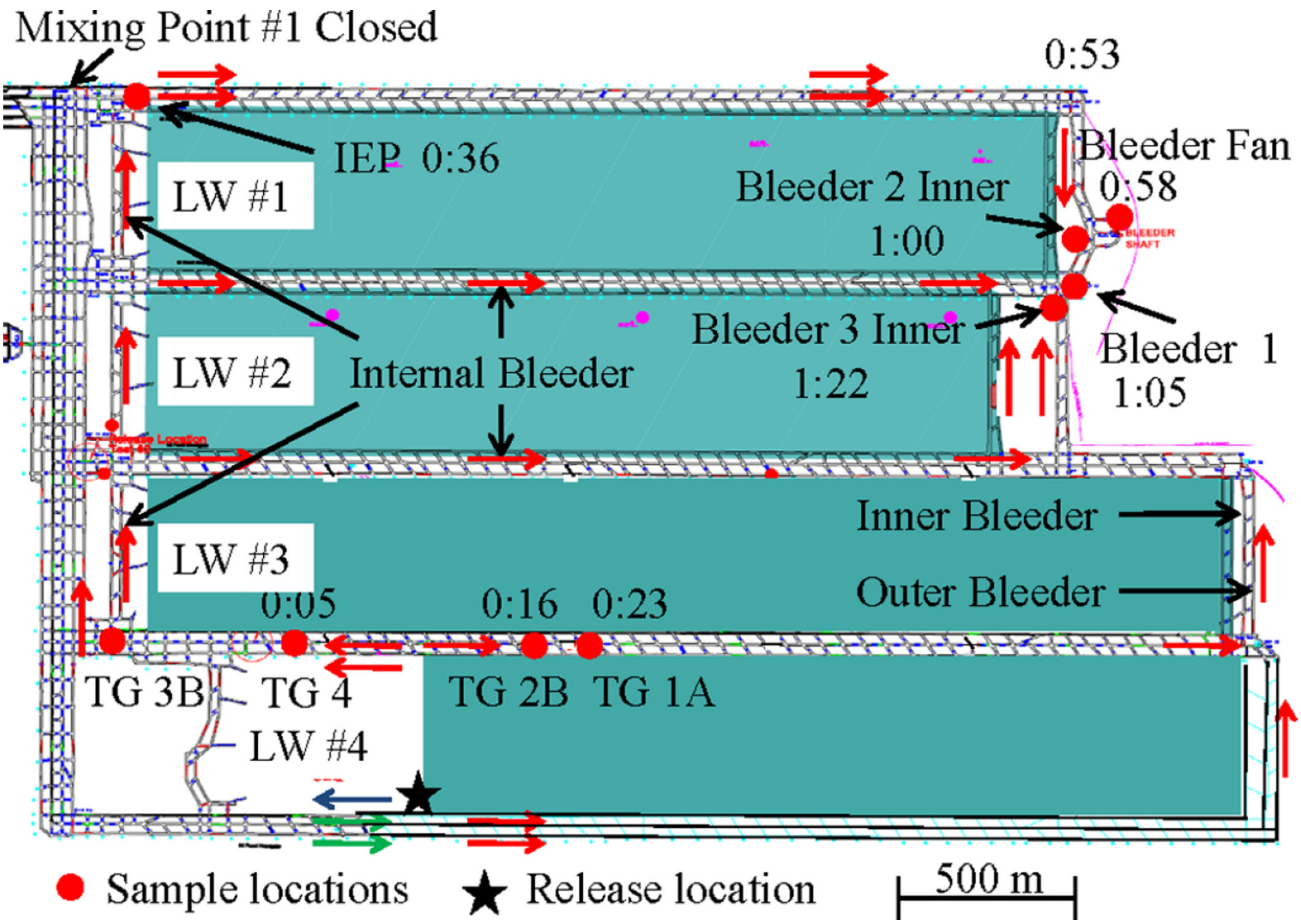

Figure 4.

Test 3, an internal bleeder ventilation system utilising the previous recovery rooms, along with arrival times listed for sampling locations. TG 3B was cut near the sample pumps and all four previous TG sample lines were pinched off (see online version for colours)

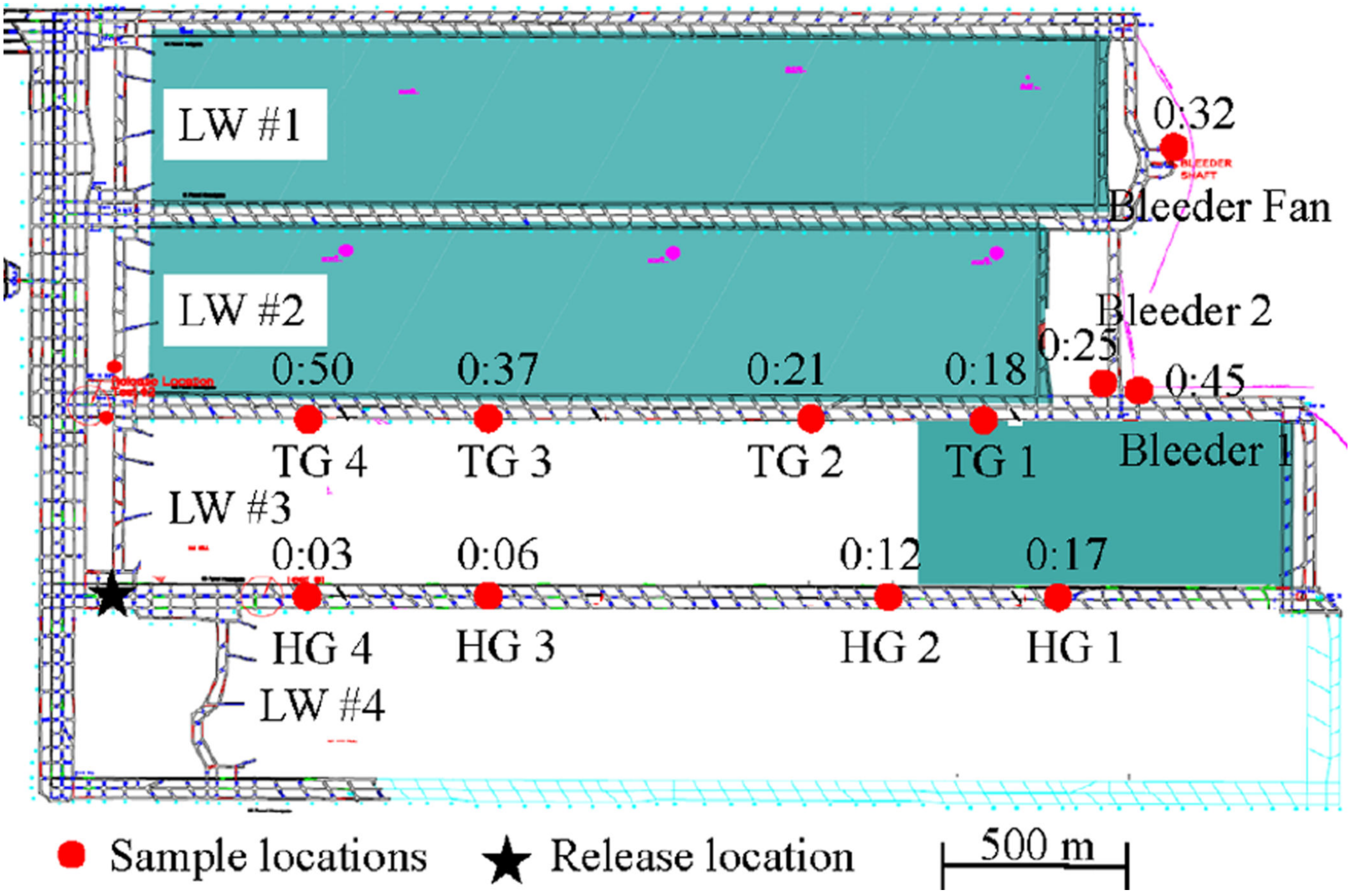

Figure 5.

Test 1 first arrival times for sample locations (see online version for colours)

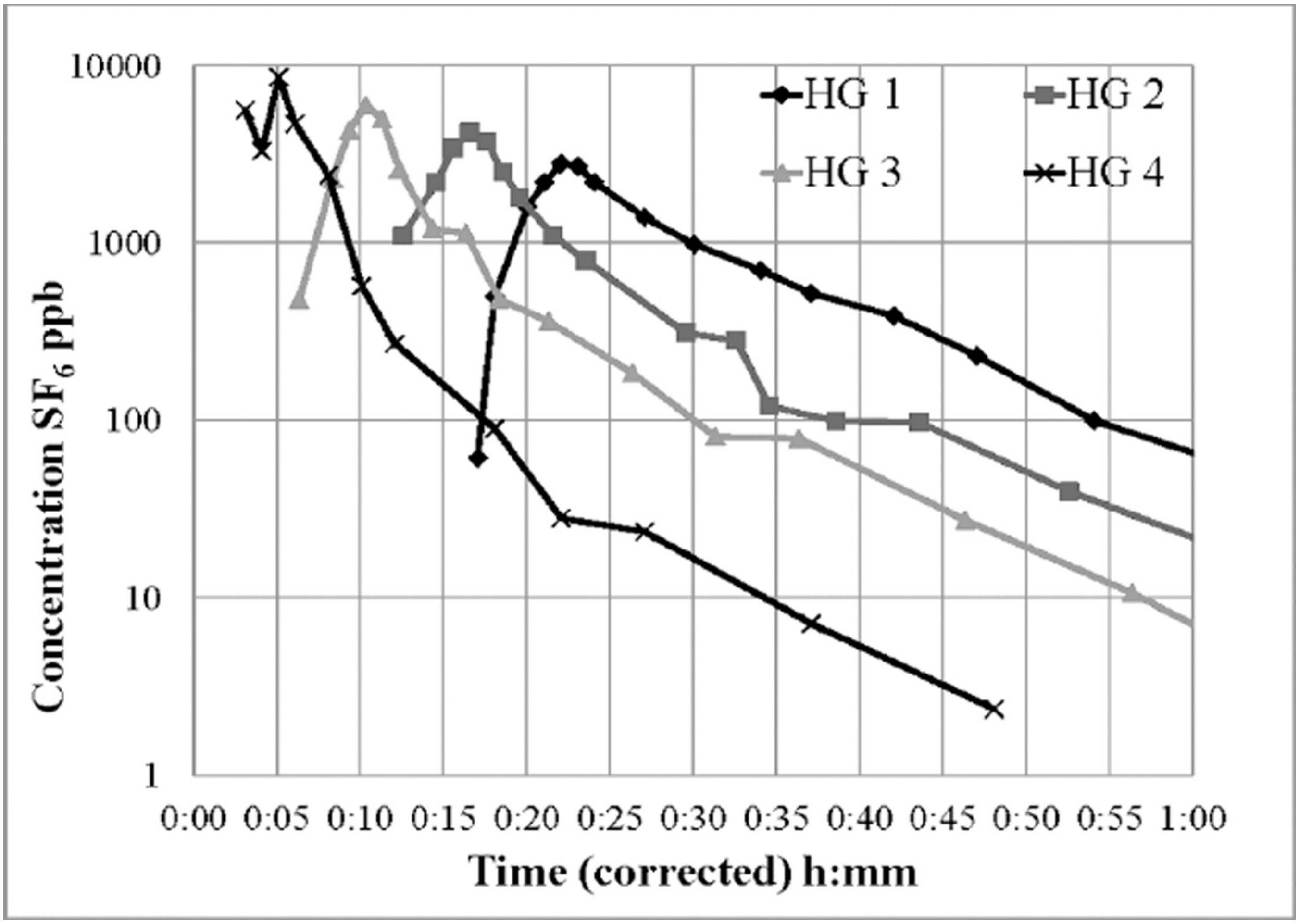

Figure 6.

Test 1 concentrations for the headgate samples corrected for tube sample transit times

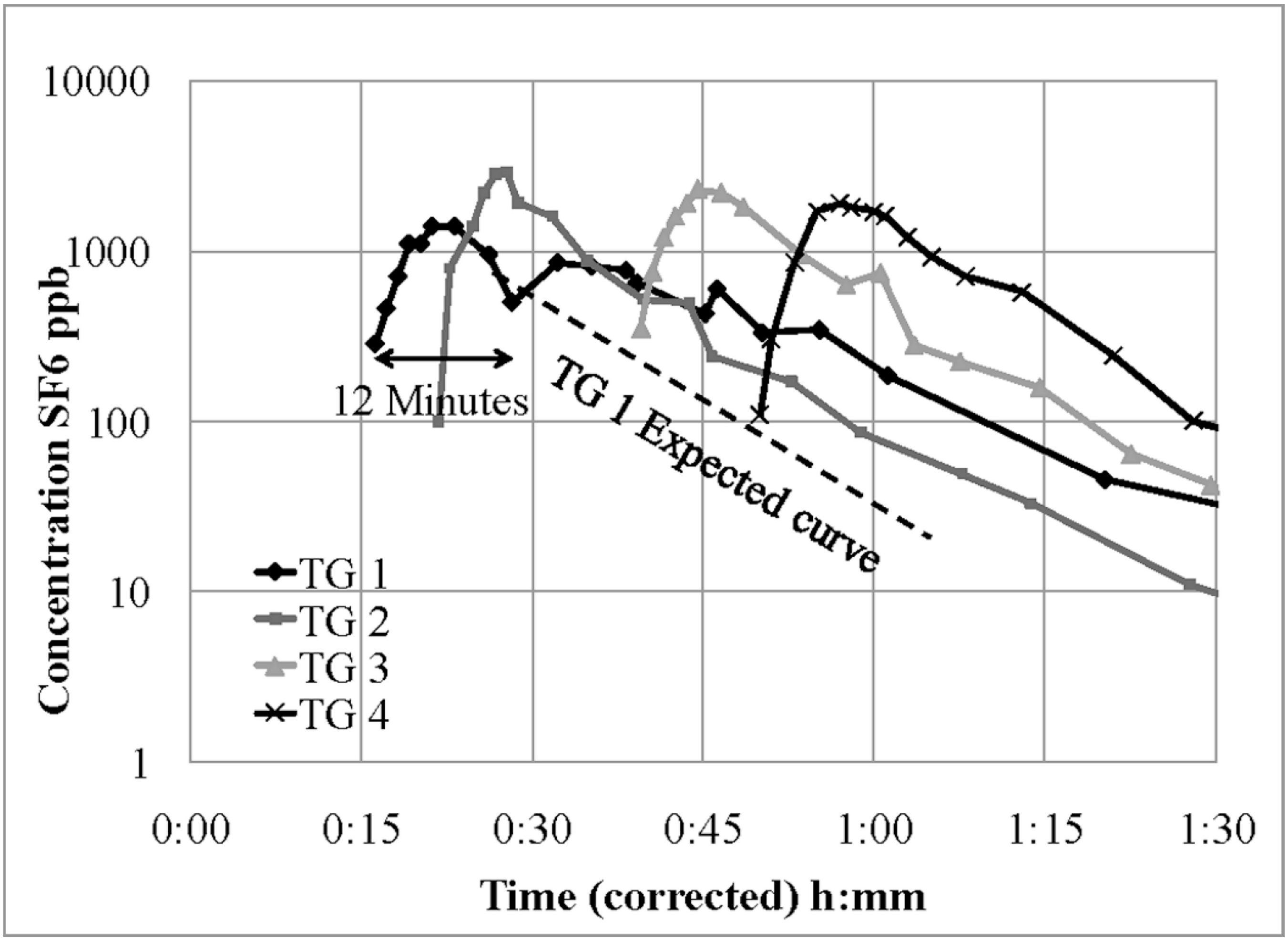

Figure 7.

Test 1, tracer gas concentrations for the tailgate samples corrected for tube sample transit times

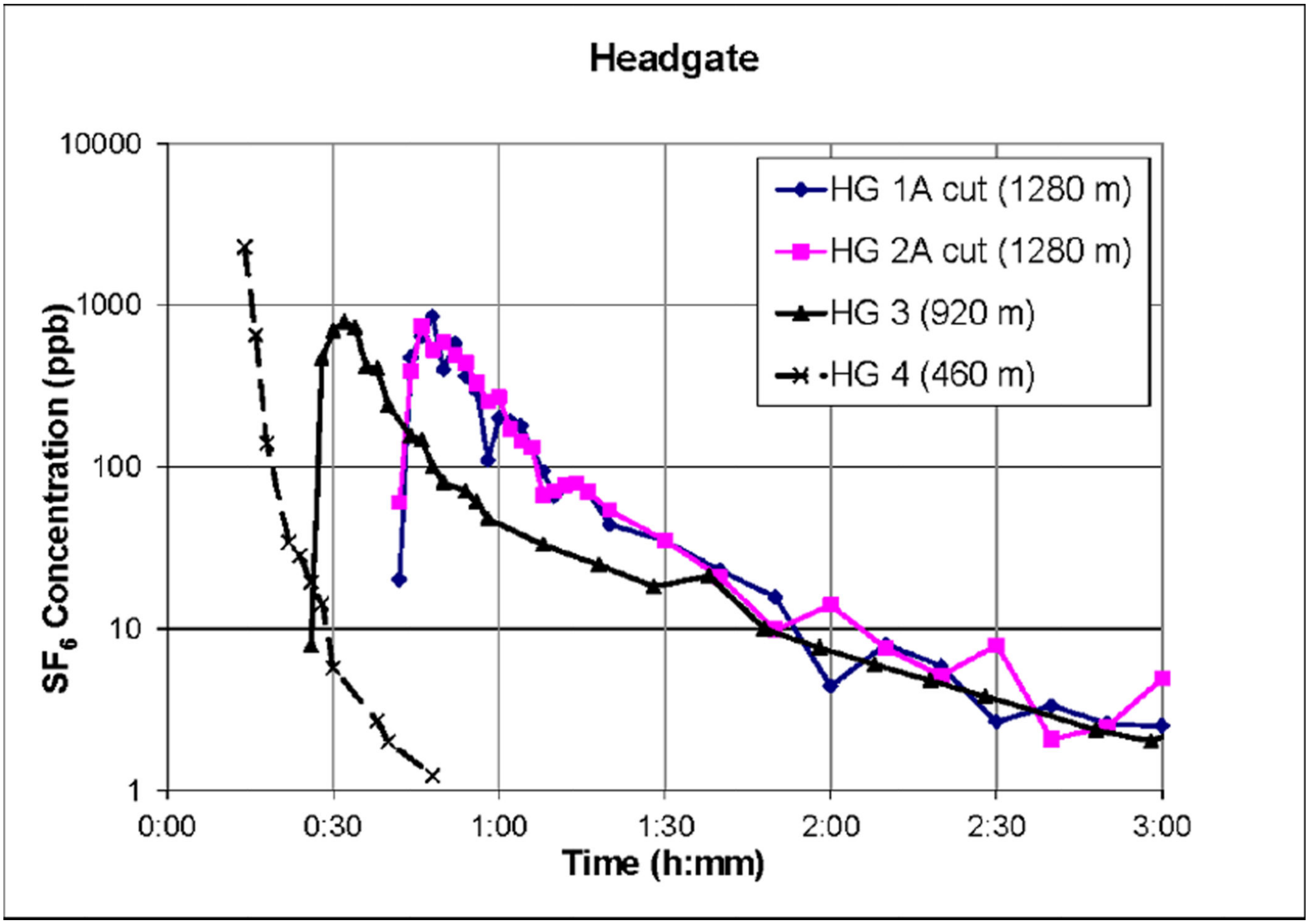

Figure 8.

Test 2, HG corrected with HG 1 and HG 2 lines cut at 1280 metres, relabelled HG 1A and HG 2A (see online version for colours)

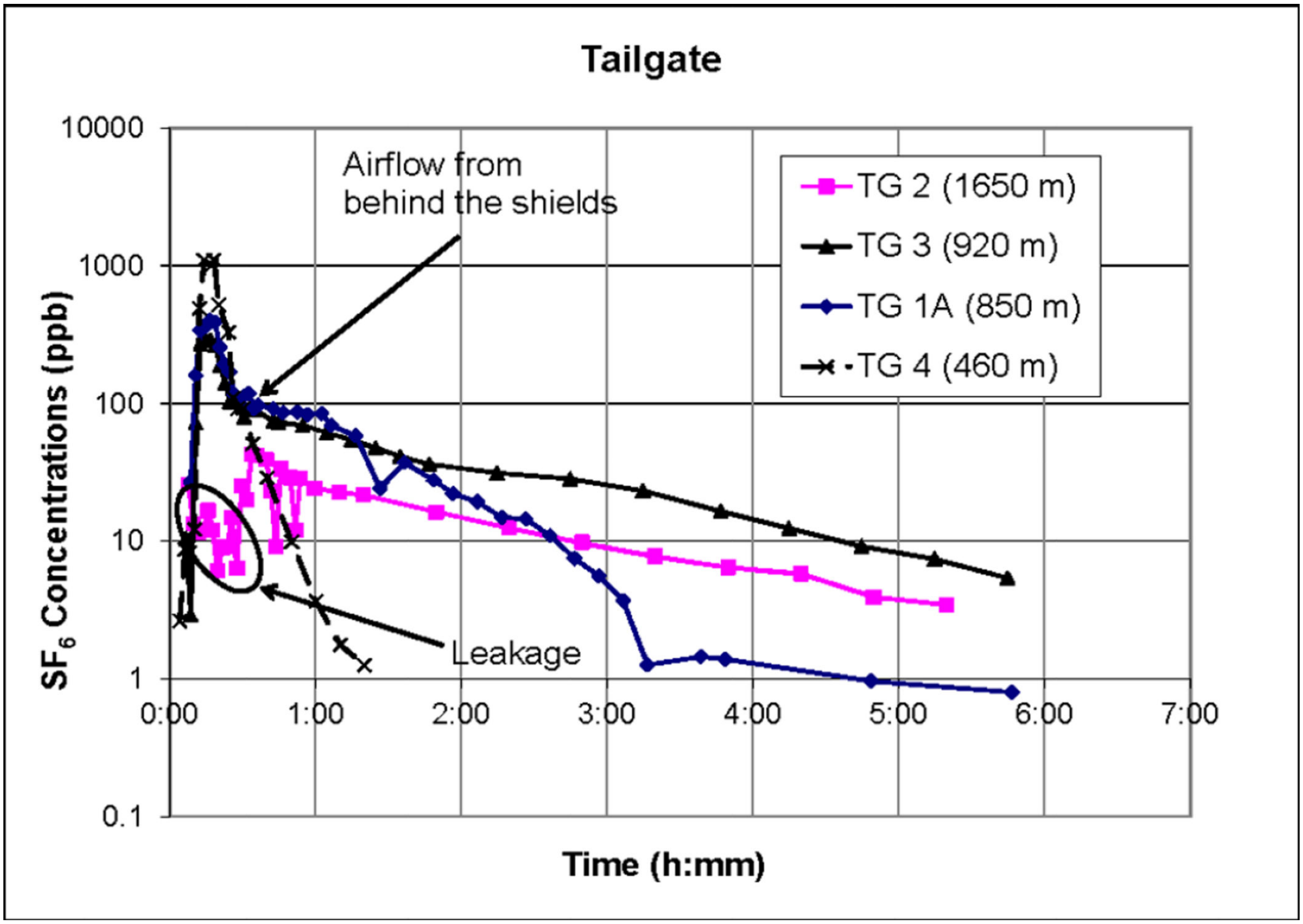

Figure 9.

Test 2 tailgate with tube leakage shown in TG 2 (see online version for colours)

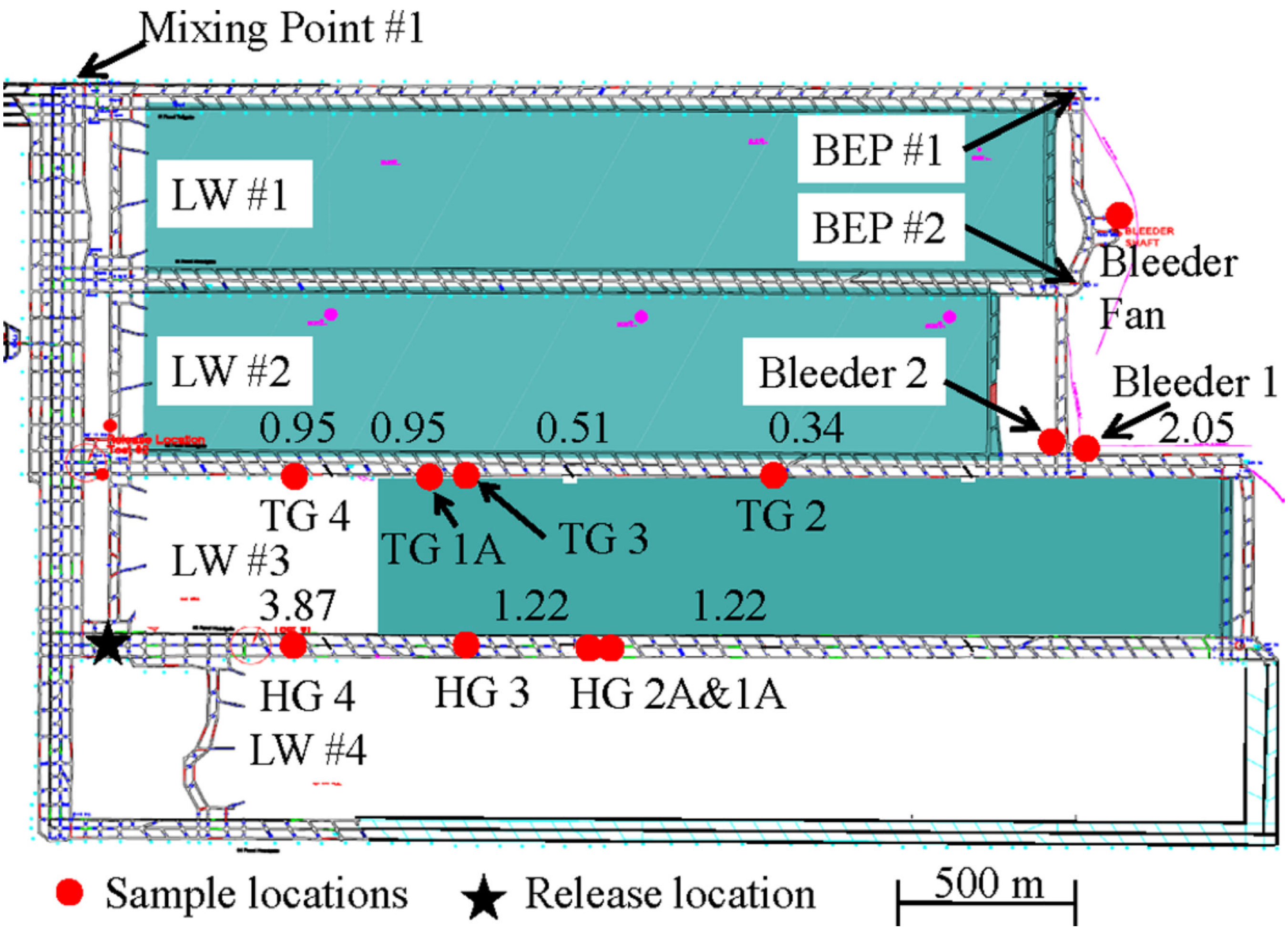

Figure 10.

Test 2 showing calculated airflow velocities between sample locations in the supported #3 entry (m/s) (see online version for colours)

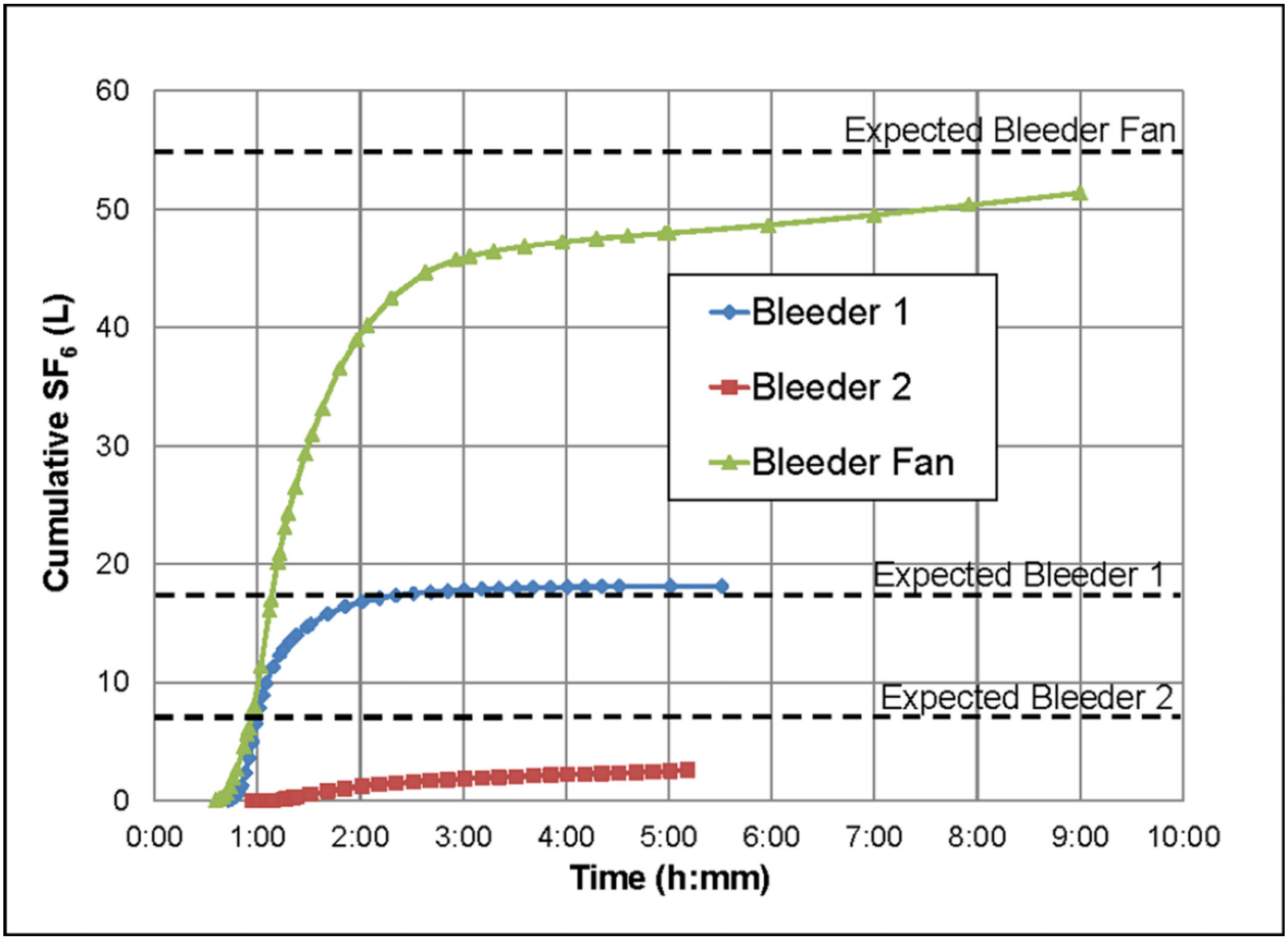

Figure 11.

Test 2 cumulative tracer gas recovery totals along with expected recovery amounts (see online version for colours)

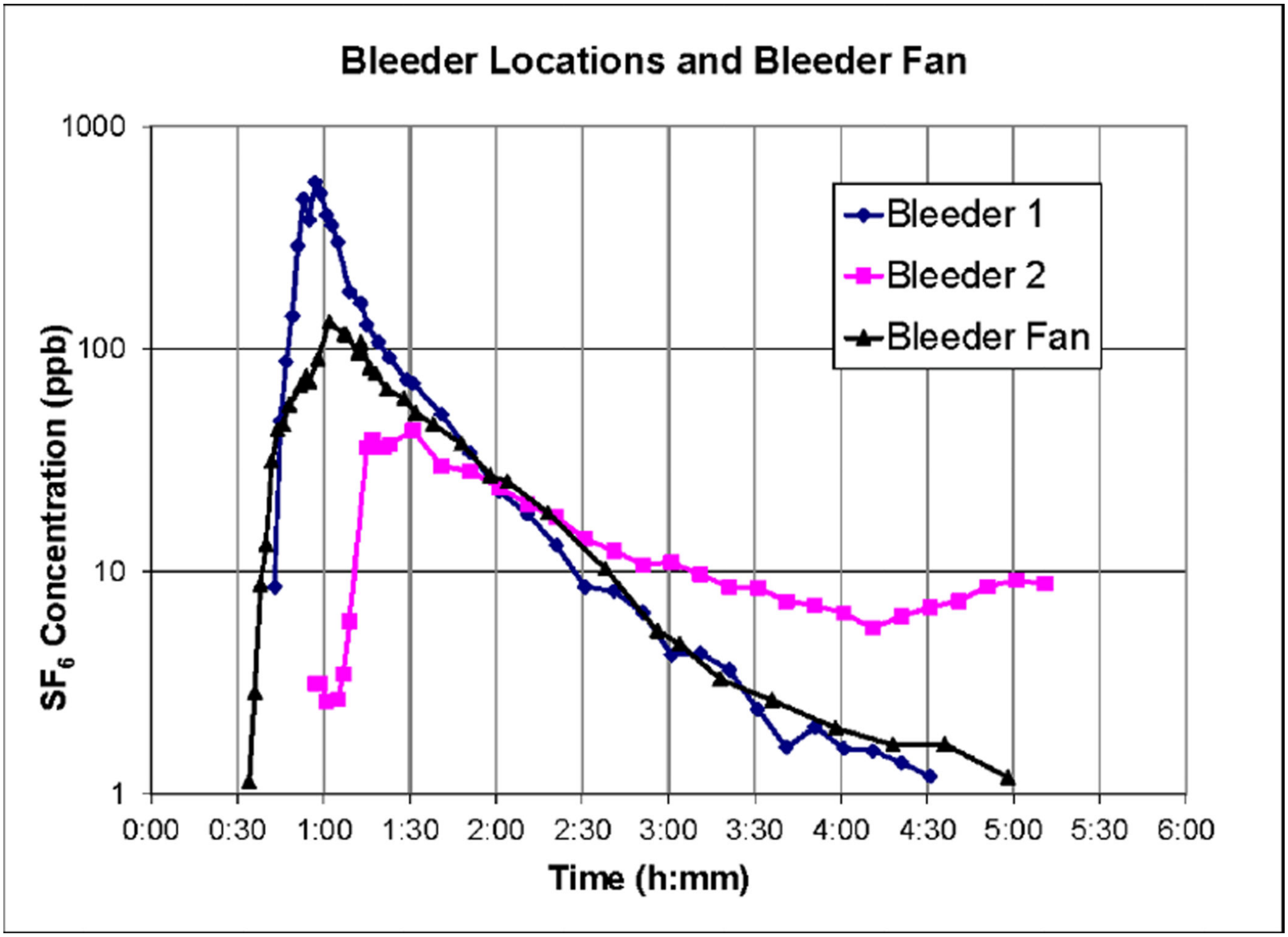

Figure 12.

Test 2 – note that Bleeder 2 recovery is low because the entire tracer slug has yet to arrive indicated by the rising at time 4:10 (see online version for colours)

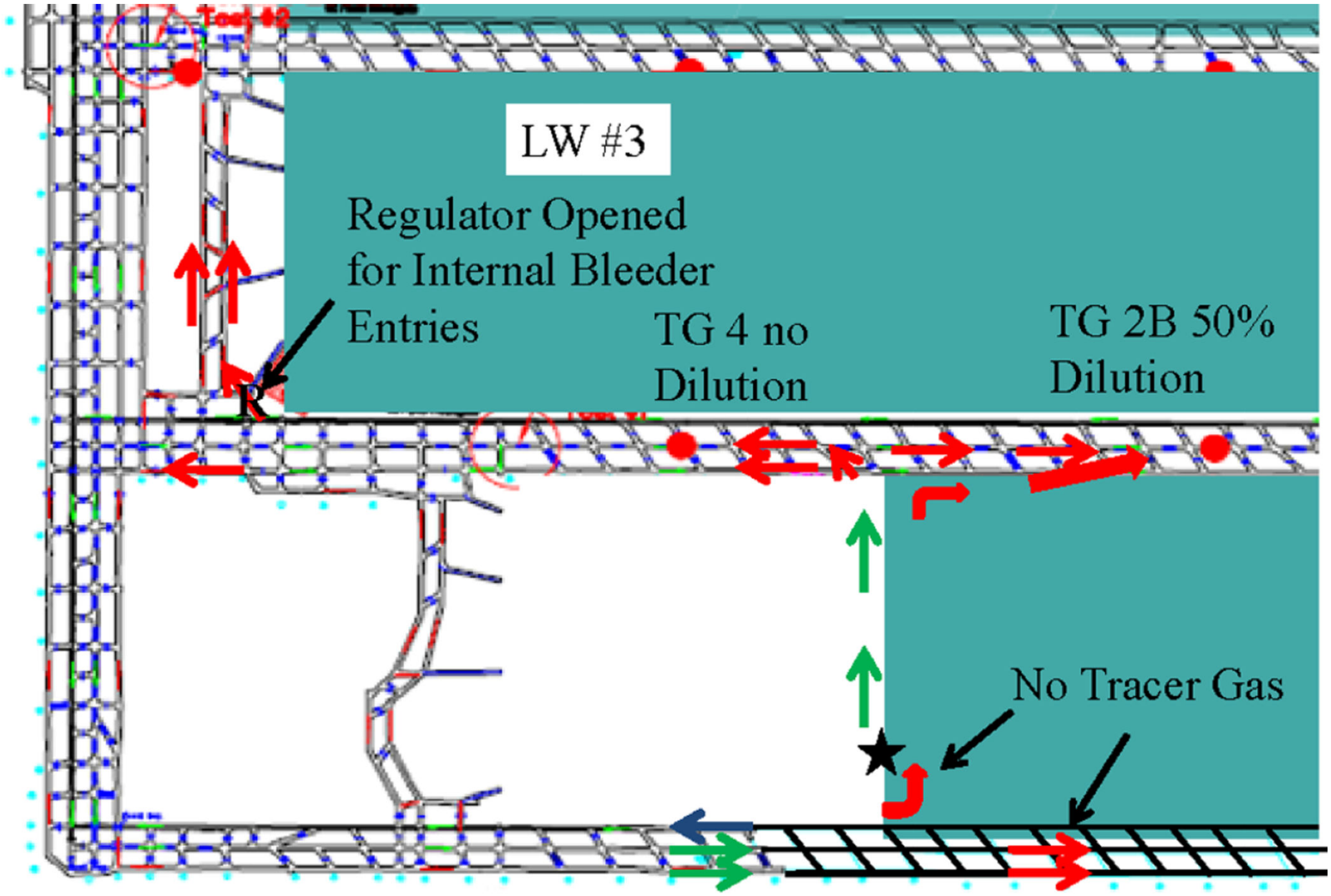

Figure 13.

Test 3 tracer gas-free airflow behind shields and the location of the internal bleeder regulator (see online version for colours)

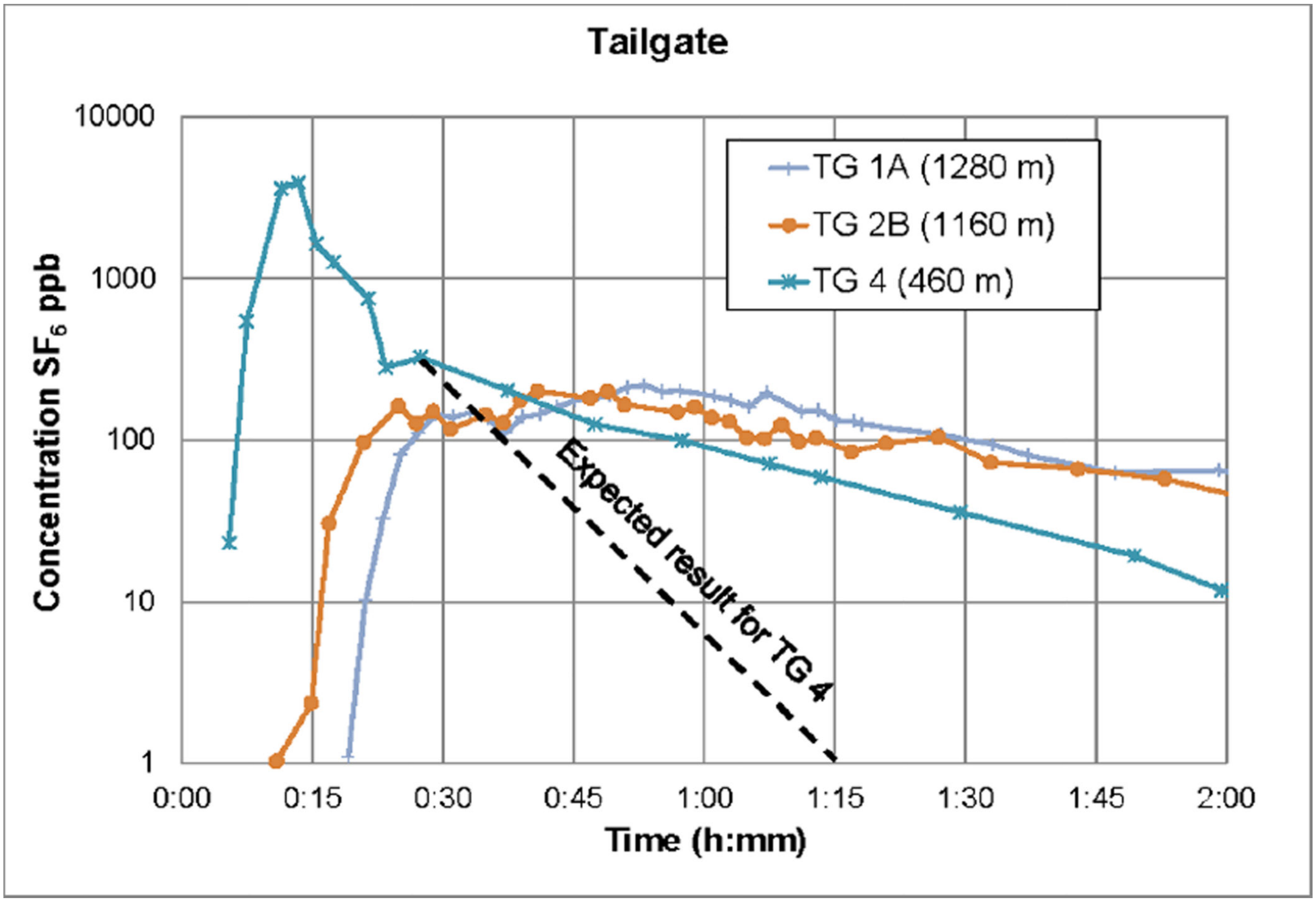

Figure 14.

Test 3 tailgate sample concentrations and tubing lengths (see online version for colours)

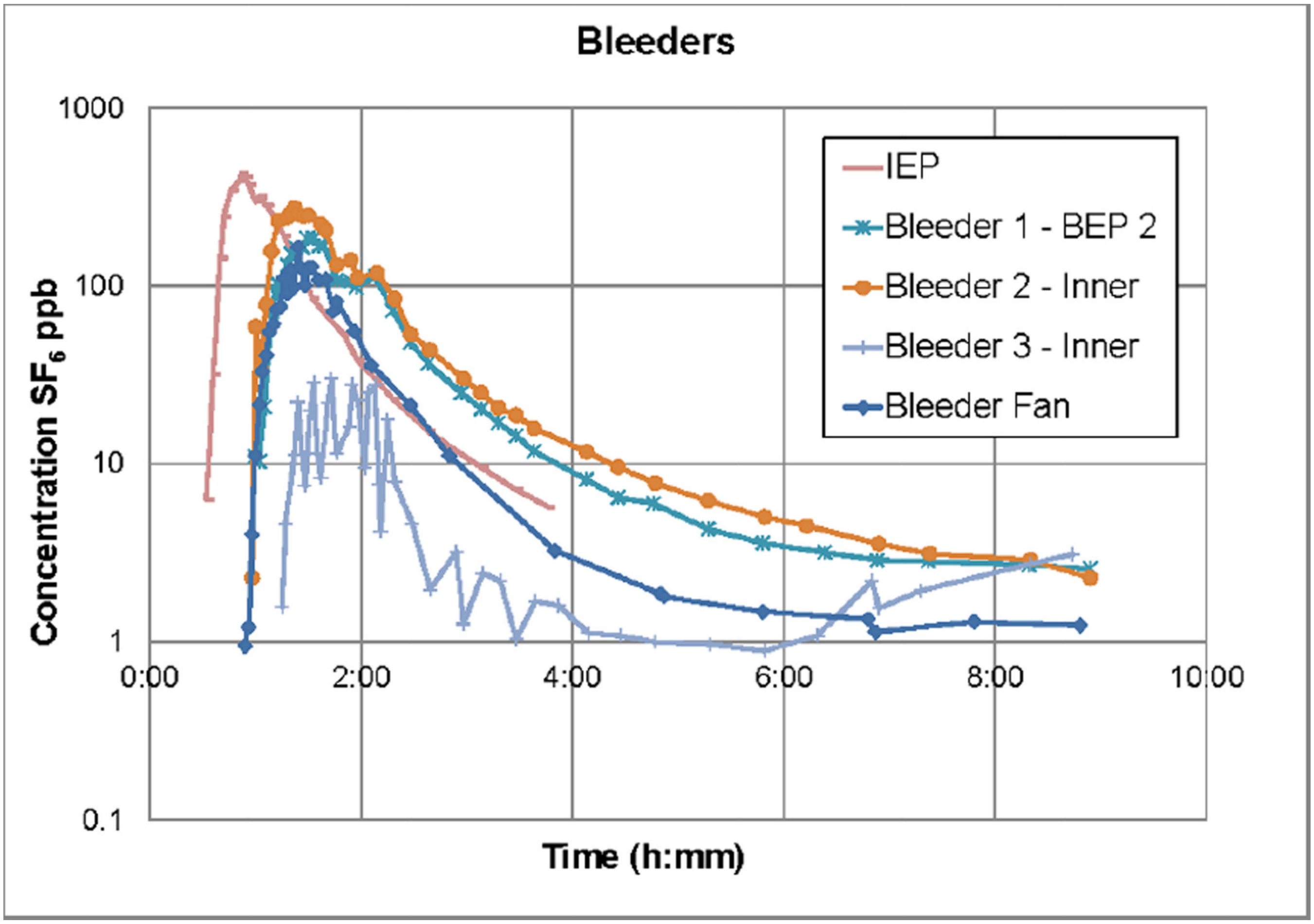

Figure 15.
Test 3 bleeder concentrations and IEP (see online version for colours)

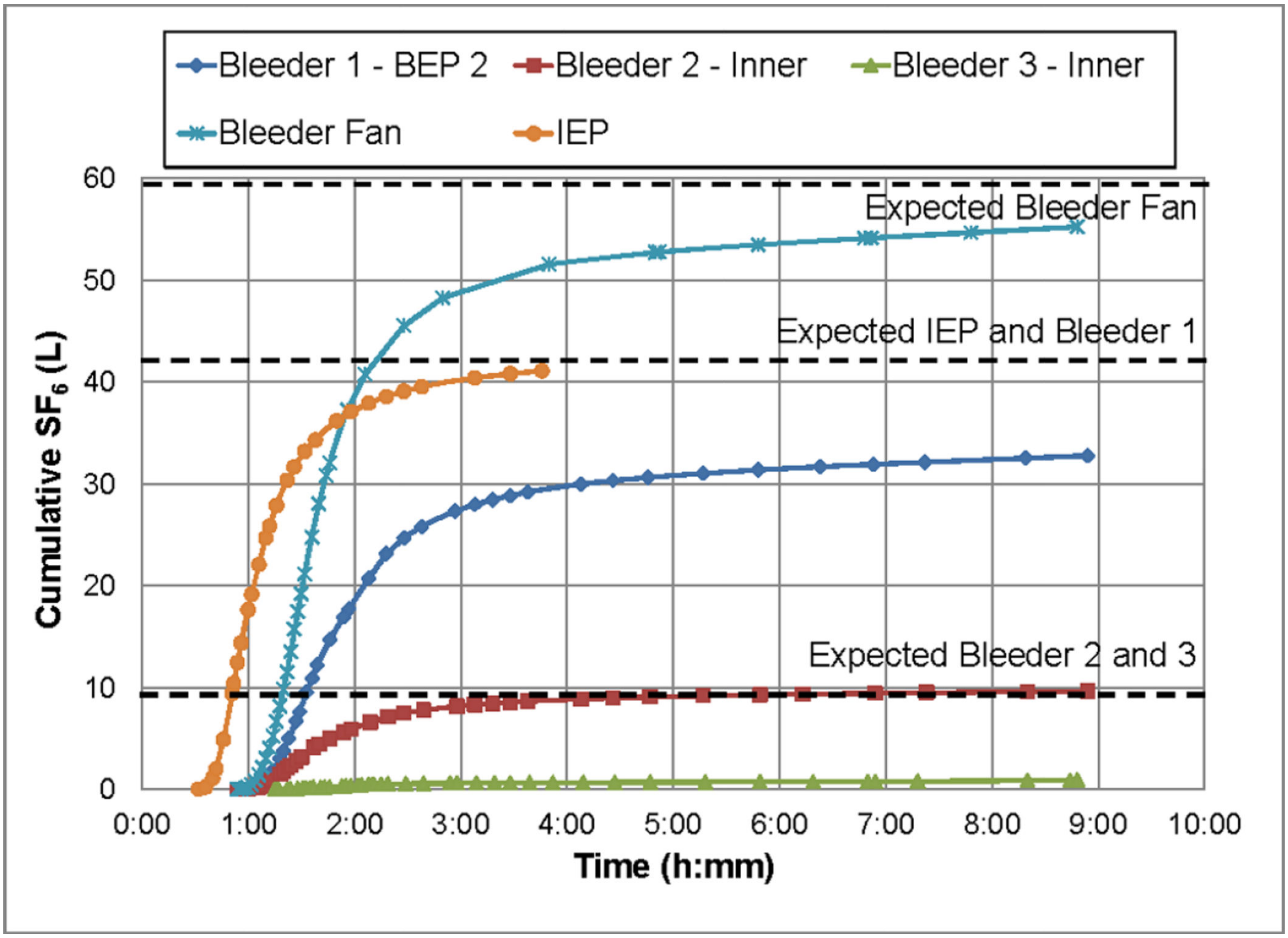

Figure 16.

Test 3 cumulative tracer gas at sampling locations (see online version for colours)

Table 1

Initial tube length, volume, and calculated transit times in the tubes for Test 1

Location	***Length m* (ft)**	***Pump rate*** **(L/min (ft^3/min))**	***Volume L* (ft^3)**	***Transit time* (min)**
Headgate				
HG1	2290 (7500)	3.08 (0.109)	194 (6.85)	62.9
HG2	1830 (6000)	3.65 (0.129)	155 (5.47)	42.4
HG3	920 (3000)	4.15 (0.147)	77.4 (2.73)	18.7
HG4	460 (1500)	4.9 (0.173)	38.7 (1.37)	7.9
Tailgate				
TG1	2100 (6900)	3.25 (0.115)	178 (6.29)	54.8
TG2	1650 (5400)	3.3 (0.117)	139 (4.91)	42.2
TG3	920 (3000)	3.45 (0.122)	77.4 (2.73)	22.4
TG4	460 (1500)	4.3 (0.152)	38.7 (1.37)	9.0

Table 2

Test 2 tube lengths, volumes, and calculated transit times in the tubes

Location	***Length m* (ft)**	***Volume L* (ft^3)**	***Pump rate*** **(L/min (ft^3/min))**	***Transit time*** **(min)**
Headgate				
HG 1A	1280 (4200)	108 (3.82)	3.75 (0.132)	28.9
HG 2A	1280 (4200)	108 (3.82)	3.69 (0.130)	29.4
HG 3	920 (3000)	77 (2.73)	4.34 (0.153)	17.8
HG 4	460 (1500)	39 (1.37	4.78 (0.169)	8.1
Tailgate				
TG 1A	850 (2800)	72 (2.55)	4.71 (0.167)	15.3
TG 2	1650 (5400)	139 (4.92)	3.64 (0.129)	38.2
TG 3	920 (3000)	77 (2.73)	4.50 (0.159)	17.2
TG 4	460 (1500)	39 (1.37)	5.00 (0.177)	7.7

Table 3

Test 3 tube lengths, volumes, and transit times

Location	***Length m* (ft)**	***Volume L* (ft^3)**	***Pump rate* (L/min (ft^3/min))**	***Transit time* (min)**
Tailgate				
TG 3B	0	0	Line cut	0.0
TG 1A	1280 (4200)	108 (3.83)	3.75 (0.132)	28.9
TG 2B	1160 (3800)	98 (3.46)	3.75 (0.132)	26.1
TG 4	460 (1500)	39 (1.37)	4.04 (0.143)	9.6

Table 4

Test 2 tracer measure and expected recovery totals, bold air quantity values are from network models or based on arrival times

Location	***Air quantity* (m^3/s)**	***Comments***	***Measured* SF_6 (L)**	***Expected* SF_6 (L)**	***Recovery of excepted* SF_6 (%)**
Release point	97	Entry 2	68.8	68.8	
HG 4	85	Entries 2 and 3	45.7	60.4	76
HG 3	32	Entries 2 and 3	21.3	22.7	94
HG 2	32	Entries 2 and 3	22.2	22.7	98
HG 1	32	Entries 2 and 3	21.5	22.7	95
TG 4	14	Entry 3	9.9	10.2	97
TG 1A	*19*	Entries 2 and 3	13.2	13.7	96
TG 3	*19*	Entries 2 and 3	14.7	13.7	107
TG 2	*19*	Entries 2 and 3	4.5	13.7	33
Bleeder 1	24	Outer bleeder	18.1	17.2	105
Bleeder 2	12	Inner bleeder	2.6	8.3	31
Bleeder fan	127	Surface	52.2	54.8	95

Table 5

Test 3 tracer measure and expected recovery totals, bold air quantity values are from network models or based on arrival times

Location	***Air quantity*** **(m^3/s)**	**Comments**	***Measured SF$_6$*** **(L)**	***Expected SF$_6$*** **(L)**	***Recovery of excepted SF$_6$*** **(%)**
Release point	35	Shield 19 LW #4		69.4	
TG 4	21	Entries 2 and 3	50.7	41.6	122
TG 2B	*14*	Entries 2 and 3	12.1	26.8	45
TG 1A	*14*	Entries 2 and 3	13.7	26.8	51
TG 3A	0	Line cut		0.0	
IEP	41	Panel 1 TG Entry 2	41.1	41.6	99
Bleeder 1 New	43	BEP 2	32.8	41.6	79
Bleeder 2 New	9	Inner bleeder	9.6	9.4	103
Bleeder 3 New	9	Inner bleeder	0.9	9.2	10
Bleeder Fan	127	Surface fan	55.2	60.1	92