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# Case study of controlled recirculation at a Wyoming trona mine

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## Abstract

Controlled recirculation has been used in the metal/nonmetal mining industry for energy savings when heating and cooling air, in undersea mining and for increasing airflow to mining areas. For safe and effective use of controlled district recirculation, adequate airflow to dilute contaminants must exist prior to implementation, ventilation circuit parameters must be accurately quantified, ventilation network modeling must be up to date, emergency planning scenarios must be performed and effective monitoring and control systems must be installed and used. Safety and health issues that must be considered and may be improved through the use of controlled district recirculation include blasting fumes, dust, diesel emissions, radon and contaminants from mine fires. Controlled recirculation methods are expected to become more widely used as mines reach greater working depths, requiring that these health and safety issues be well understood. The U.S. National Institute for Occupational Safety and Health (NIOSH) conducted two controlled recirculation tests over three days at a Wyoming trona mine, utilizing an inline booster fan to improve airflow to a remote and difficult-to-ventilate development section. Test results were used to determine the effect that recirculation had on air qualities and quantities measured in that section and in other adjacent areas. Pre-test conditions, including ventilation quantities and pressures, were modeled using VnetPC. During each test, ventilation quantities and pressures were measured, as well as levels of total dust. Sulfur hexafluoride ($SF_6$) tracer gas was used to simulate a mine contaminant to monitor recirculation wave cycles. Results showed good correlation between the model results and measured values for airflows, pressure differentials, tracer gas arrival times, mine gasses and dust levels.

### Keywords

Ventilation; Dust control; Air quality; Health and safety; Trona

## Introduction

Controlled district recirculation has been effectively used in U.S. metal and nonmetal mines. Marks and Shaffner (1989) document its use at the Homestake Mine, SD, where return air was recirculated from the exhaust shaft through an underground cooling spray chamber and

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returned to deep, hot mine workings. Controlled district recirculation can be an important consideration, as active workings progress deeper or extend a considerable distance undersea (Hannon, 1987). Mine return air is often of good quality, and controlled recirculation can augment airflow to mining areas, improving miner safety and health, working conditions and providing operational savings (Hall et al., 1987; Meyer, 1993; Pritchard, 1995). Robinson (1989) showed that additional air quantity at coal mining faces and in development sections can improve mixing of face methane emissions, reducing the risk of explosion. Safety and health issues associated with controlled recirculation include blasting fumes (Wu, 2001), dust control (Hardcastle, 1985), face and section methane dilution (Longson et al., 1987), diesel emissions (Hall et al., 1987; Cecala et al., 1991), mine monitoring (Saindon, 1987) and mine fires (Cecala et al., 1991). The U.S. National Institute for Occupational Safety and Health (NIOSH) investigated several of these health and safety issues related to controlled district recirculation systems through field testing at a nonmetal trona mine in Wyoming.

The Mine Safety and Health Administration (MSHA) defines trona operations as Gassy Type III metal/ nonmetal operations that liberate methane, often in significant amounts (Pritchard et al., 2004). The mining process and equipment are very similar to room-and-pillar coal mining, with permissible face equipment inby and diesel-powered, rubber-tired support equipment outby. Ore is mined by a continuous miner or longwall system, hauled from the face to feeder breakers by shuttle cars, transported to the shaft by conveyor belts and hoisted in skips to the surface. Typical mining depth is 450 m (1,500 ft). Recirculation of return air from mining areas is not permitted due to MSHA *30 CFR* Part 57 Subpart T gassy mine regulations (*CFR*, 2011) and Wyoming State Statutes, which incorporate MSHA laws (Wyoming Statutes, 2011). The primary source of methane is oil shale above and below the trona bed. Emissions during development are minor and decay rapidly, but are significant where caving takes place, such as during longwall retreat. Emissions arise from fragmented oil shale from the immediate roof and from floor cracks due to heaving. Sealing of mined-out areas has been used in the past but is not presently practiced.

Previous testing used a booster fan at the Wyoming trona mine operation to increase airflow to a remote mining panel (Pritchard et al., 2012). The study examined the impacts of booster fan use on ventilation airflow quantity and quality in a mining district consisting of an idle test panel, a longwall retreat panel and three outby longwall development panels (Fig. 1).

Those tests showed that booster fan operation dramatically increased airflow in the idle panel from 5 $m^3/s$ (10,000 cfm) to 14.2 $m^3/s$ (30,000 cfm) and, finally, to 23.6 $m^3/s$ (50,000 cfm). Results showed a reduction in outby airflow by approximately the same amount that the booster fan increased airflow to the test panel. Also, the booster fan overpressurized the panel return airway, causing a high percentage of the additional test panel airflow to leak back into fresh air. Those test results showed that booster fans may provide a potential option to increase section airflow, but outby recirculation effects must be considered.

## Controlled recirculation test design

NIOSH used the same trona mine and test location for two additional controlled district recirculation tests over three working shifts. Baseline readings were taken during the first shift, with testing conducted during the last two. The booster fan, shown in Fig. 2, increased airflow by recirculating return air through an open stopping/regulator (“R”) at the panel return corner. It was hypothesized that local recirculated air would affect the outby longwall and development panel airflows less than the previous booster fan test, due to lower booster fan-induced pressure in the ventilation circuit. Recirculated airflows of 50% and 100% greater than the present 4.7 $m^3$/s were tested while monitoring for dust, ventilation airflows and differential pressures to assess the health and safety aspects of controlled recirculation. The recirculated airflows of 7.1 and 9.4 $m^3$/s (15,000 and 20,000 cfm) were at the high end of practical controlled recirculation levels in order to show “worst case” scenarios.

Prior to the previous booster fan test, a mine network model was developed using VnetPC software from the engineering consulting firm Mine Ventilation Services. The model was then updated and analyzed to examine the impact of recirculation. The analysis indicated that the recirculation would show negligible effects on outby active mining section airflows. Theoretically, allowing the inline fan to perform as a controlled recirculation fan instead of as a pure booster fan, which increased test panel circuit pressure and airflow, would not affect the remainder of the ventilation circuit nearly as much.

The testing occurred in an isolated room-and-pillar panel development at the south end of the submain that was idle, had no active production and was not considered return air, which would have prohibited recirculation in a gassy mine. The test panel was a three-entry development approximately 2.5 m (8 ft) high by 4.3 m (14 ft) wide, 1,500 m (5,000 ft) long, with two intake entries and a single return separated by styrofoam block stoppings. Using standard areas and scaled lengths, approximate airflow transit times through the test panel from booster fan to the face and back to the recirculation point were calculated to be 1.9 hours, with the booster fan operating at 7.1 $m^3$/s (15,000 cfm) and 1.4 hours when operating at 9.4 $m^3$/s (20,000 cfm). Controlled recirculation would be induced by an inline 1.5-m (60-in.) diameter, 93-kW (125-hp), booster fan with airflow adjusted by a variable frequency drive (VFD) controller. Outby panels included a longwall retreat panel and three longwall development panels (Fig. 1). Active mining was on the opposite (west) side of the submain, sharing a common intake with the test area but having separate returns. The longwall return was on a separate bleeder circuit and development sections used the submain west returns flowing north. The recirculation area used the east submain return, joining the west return to the north. Submain airflows and pressure differentials were measured prior to and during tests to gauge the effects of district recirculation on the local ventilation circuit. Personal data rams (PDRs) (Volkwein et al., 2004) were used to monitor total dust in four locations: outby the fan, six crosscuts inby the fan, 12 crosscuts inby the fan, and at the outby end of the test panel return just prior to the recirculation regulator opening. Dust levels were monitored to determine the amount of dust settling at different points in the ventilation circuit and to quantify the amount of dust entering the intake air. As a rule, recirculated air should not contain higher dust concentrations than intake air (Cecala et al., 1991).

Other than total dust, no additional contaminant sources were expected due to panel inactivity. To simulate such sources, a steady-state release of $SF_6$ tracer gas was performed (Timko et al., 1982). A continuous $SF_6$ release apparatus placed just outby the booster fan was assembled consisting of a lecture canister of gas, regulator, an adjustable valve to act as a variable critical orifice and a magnehelic pressure gauge attached to both ends of a laminar flow element (LFE). $SF_6$ flow rates were measured with the calibrated magnehelic gauge using a secondary standard relating flow to measured pressure loss across the small diameter LFE. Gas canister pressure was reduced using the regulator to a point at which the valve could regulate the tracer gas. $SF_6$ release rates of 480 cc/min were calculated for test panel airflow to provide the necessary gas chromatography analysis concentration range and to allow adequate gas flow for the eight-hour test period. $SF_6$ samples were taken at the test panel intake and exhaust locations.

## Controlled recirculation tests

The airflow quantity in the test panel measured on Day 1 during normal mine operation was 4.3 $m^3$/s (9,100 cfm), close to the modeled 4.7 $m^3$/s (10,000 cfm) value. Airflow rates for the following two days were a 50% and 100% increase above baseline airflow. Controlled recirculation Test 1 was plagued by multiple mine power interruptions, compromising its value. Thus, contaminant and $SF_6$ data were not used. Test 2 airflow was 7.1 $m^3$/s (14,900 cfm) and that test experienced only one brief local mine power outage. Airflow and pressure differential readings for Test 2 are shown in Tables 1 and 2, respectively.

### Controlled recirculation Test 2 results

The booster fan increased the baseline airflow of 4.3 $m^3$/s by 63% (the increase was actually 75% during the test in that panel intake baseline airflow had dropped slightly to 4 $m^3$/s), corresponding to a recirculation percentage of 44% (3.1 $m^3/s \div 7\ m^3/s$). Airflow readings prior to and during the test showed a negligible effect of the controlled recirculation on the submain intake, longwall intake, and longwall development section (HG #6, 7 and 8) airflows, thus validating modeling data (Table 1). Detailed pressure differential readings across various submain stoppings/mandoors (Table 2) showed good correlation to relative pressure changes when comparing modeling to measured readings. The various differences are explained below.

Longwall airflow gradually dropped by 7.2 $m^3$/s (15,000 cfm) over the three days of testing as the longwall passed through an intersection, increasing submain circuit resistance, which reduced longwall and submain intake airflow. The outby development panels showed a slight airflow increase during this period due to the longwall resistance increase. Because longwall development panels and the test panel shared a common return further outby, this higher airflow may have contributed to lowering the outby recirculation panel airflow from 4.4 to 4 $m^3$/s. Deviations noted in test airflows are a reminder of daily ventilation system variations and must be taken into consideration during mine ventilation planning.

Measured submain differential pressures shown in Table 2 also showed negligible change except on the East Return. The controlled recirculation entry was not opened to full entry width (see regulator in Fig. 2), causing some minor backpressure in the controlled recirculation system. This is evidenced by the lower pressure differentials across the East Return in Table 2 and the reduced airflow in Table 1. Higher longwall system resistance from passing through the intake crosscut and lower intake submain airflow correlates with other lower pressures measured. Modeled pressure differentials correlated well, especially at the inby end of the ventilation circuit, where differential pressures were low and airflows were often variable.

Dust levels at 12 XC inby the fan at the third monitoring location showed spikes from outby mobile equipment and foot traffic, which were elevated at the beginning of the shift and tailed off afterward, as shown in the activity peak in Fig. 3. All three monitoring locations from XC 1 to XC 12 had the same total dust concentration of 0.50 mg/m$^3$, with minimal dust settling in this 400-m (1,300-ft) zone. Figure 4 shows the average total dust concentration at the return location regulator (Fig. 2) prior to recirculation as 0.16 mg/m$^3$, with many concentration spikes. During the field studies, results showed it became important not to locate dust monitoring equipment downwind from activity, as local foot traffic disturbed floor dust while checking monitors, causing localized dust concentration spikes. Even with the induced spikes, approximately 70% of the total dust settled in the remainder of the intake and the 3,100-m-long (10,000-ft-long) return, highlighting the valuable contribution of return airways as dust settling zones and emphasizing the importance of selecting the correct recirculation point. Previous work (Cecala et al., 1991; Hardcastle, 1985) indicates that the recirculation fan should be located a minimum of 600 to 915 m (2,000 to 3,000 ft) from an active mining area for this reason.

Comparing the activity peak dust level in Fig. 3 with the corresponding peak in Fig. 4 shows a transit time of approximately two hours through the panel, corresponding to the pre-test calculated panel $SF_6$ circulation time.

Figure 5 shows contaminant surrogate $SF_6$ concentrations at the return sampling point prior to recirculation. Anticipated concentrations would increase to 200 ppb at Wave 1 after the 1.9-hour test panel transit time, asymptotically approaching 330 ppb after a few recirculation cycles. Results show that $SF_6$ was released at about twice the 480 cc/min design rate due to instrumentation issues, as shown in the upper $SF_6$ line. The gradual increase in measured concentration instead of instantaneous arrival was due to $SF_6$ mixing and diffusion as it traveled the 3,100-m (10,000-ft) distance from fan to recirculation point in the pre-existing test panel air volume. The delayed mixing process was nearing expected values after wave three.

$SF_6$ testing results and recirculation calculations confirm that contaminant concentrations rise to a defined level based on the percentage of air recirculated with constant face emission rates (Robinson, 1989). Figure 6 shows that, even with previously stated $SF_6$ mixing issues, the return concentration does not exceed the original nonrecirculated concentration and corresponds well with calculations. Intake contaminant concentrations increased after three recirculation cycles, to approximately 40% of total return concentration, near the ultimate test intake recirculation percentage value of 44%, which would have been attained in a few additional cycles.

## Summary and conclusions

A series of tests were performed in a room-and-pillar environment to examine the effectiveness of controlled recirculation on improving airflow quantity and quality in a remote mining panel, and to assess the impacts on airflows in adjacent active areas. These tests used an inline booster fan to increase the 4.3-$m^3$/s panel airflow by 50% and 100%. Recirculation was controlled by opening a regulator installed between panel intake and return at the panel mouth. Pretest modeling showed similarities to in-mine controlled recirculation test-measured airflows and pressure differentials, with negligible effects on airflows in adjacent areas. Controlled recirculation involved no leakage from return to intake outby the test panel, and no change in airflow quantities in the outby mining sections.

Recirculated air contained less total dust by virtue of return airway settling. Negligible dust settled out in the first 400 m (1,300 ft) of the panel intake, but the concentration was reduced by 70% in the remainder of the intake and the 3,000-m (10,000-ft) return distance prior to recirculation. Recirculation in an active mining panel would have to be studied prior to implementation, but previous studies have indicated that return air often has lower dust levels than intake air. Steady-state $SF_6$ testing was also conducted to simulate contaminants such as diesel DPM and showed that intake contaminant concentrations approached a level corresponding to the percentage of recirculated air.

Test results showed that test panel airflow quantity could be improved with predictable increases in contaminant levels based upon knowledge of panel contaminant emissions and recirculation percentage. Dust levels were dependent upon ambient concentrations and available settling distances. In-line recirculation had minimal effect on outby panel airflows.

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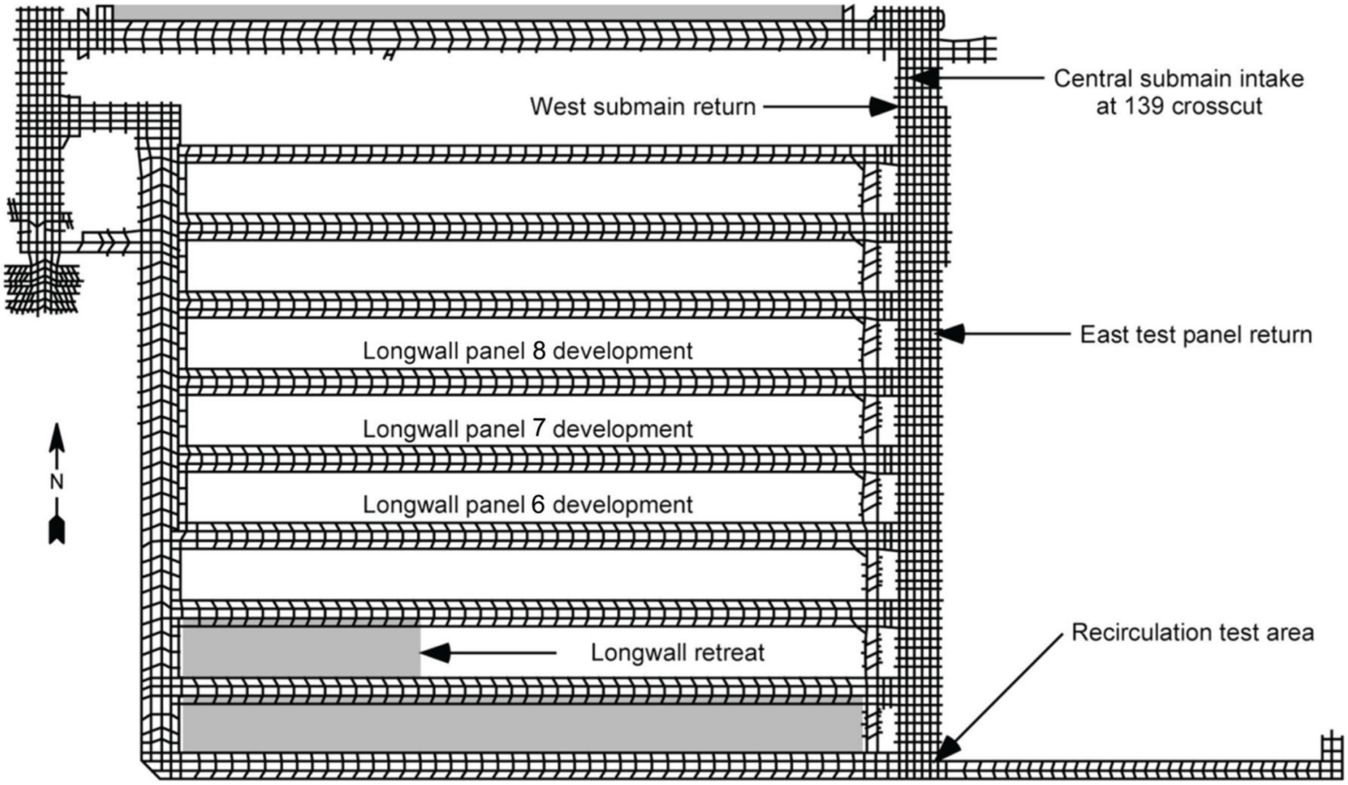

**Figure 1.**

Booster fan/controlled recirculation test area.

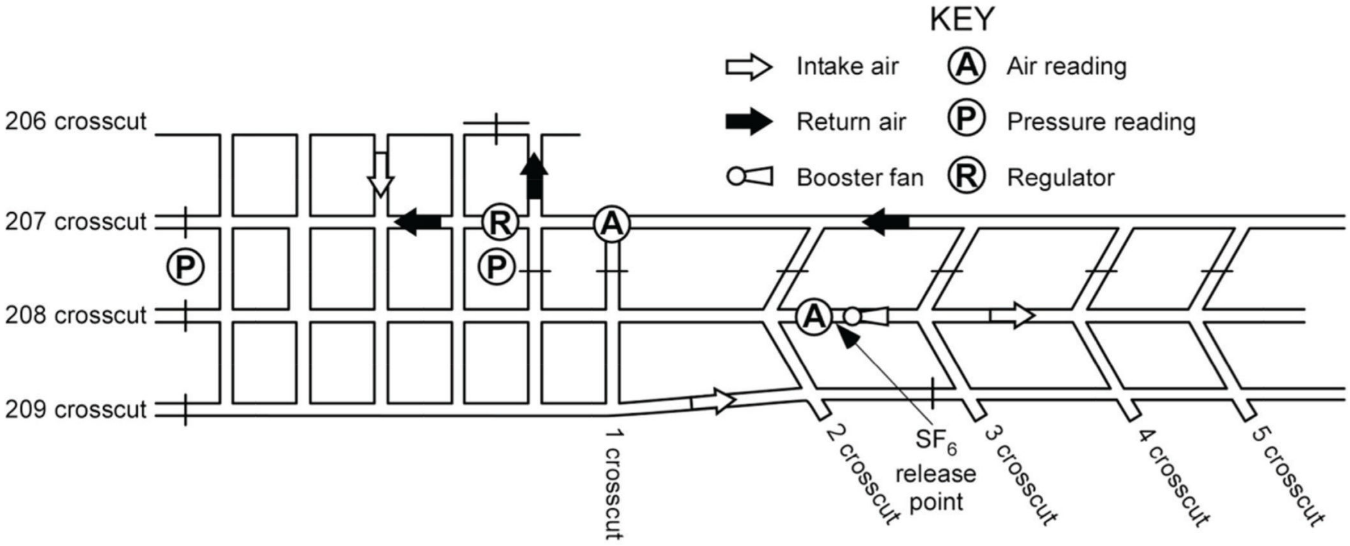

**Figure 2.**

Booster fan/controlled recirculation test panel detail from Fig. 1.

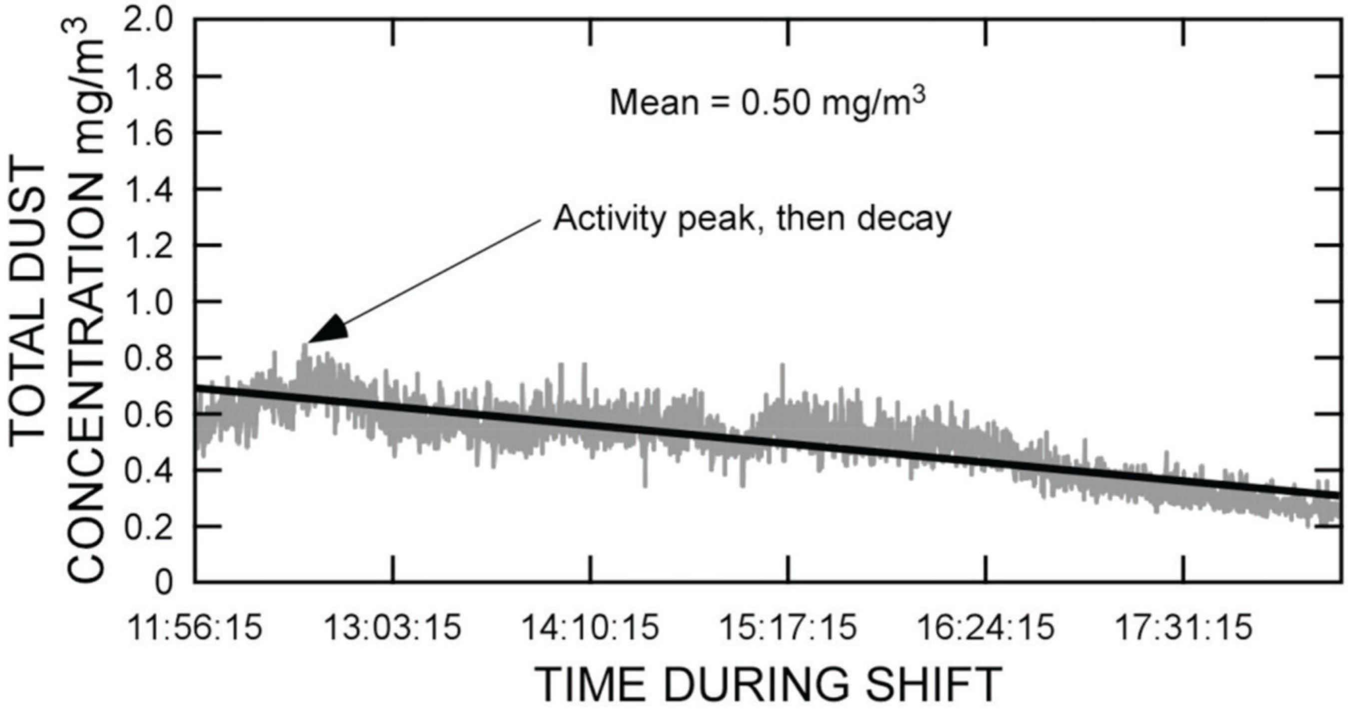

**Figure 3.**

Total dust concentrations at 12 XC inby booster fan.

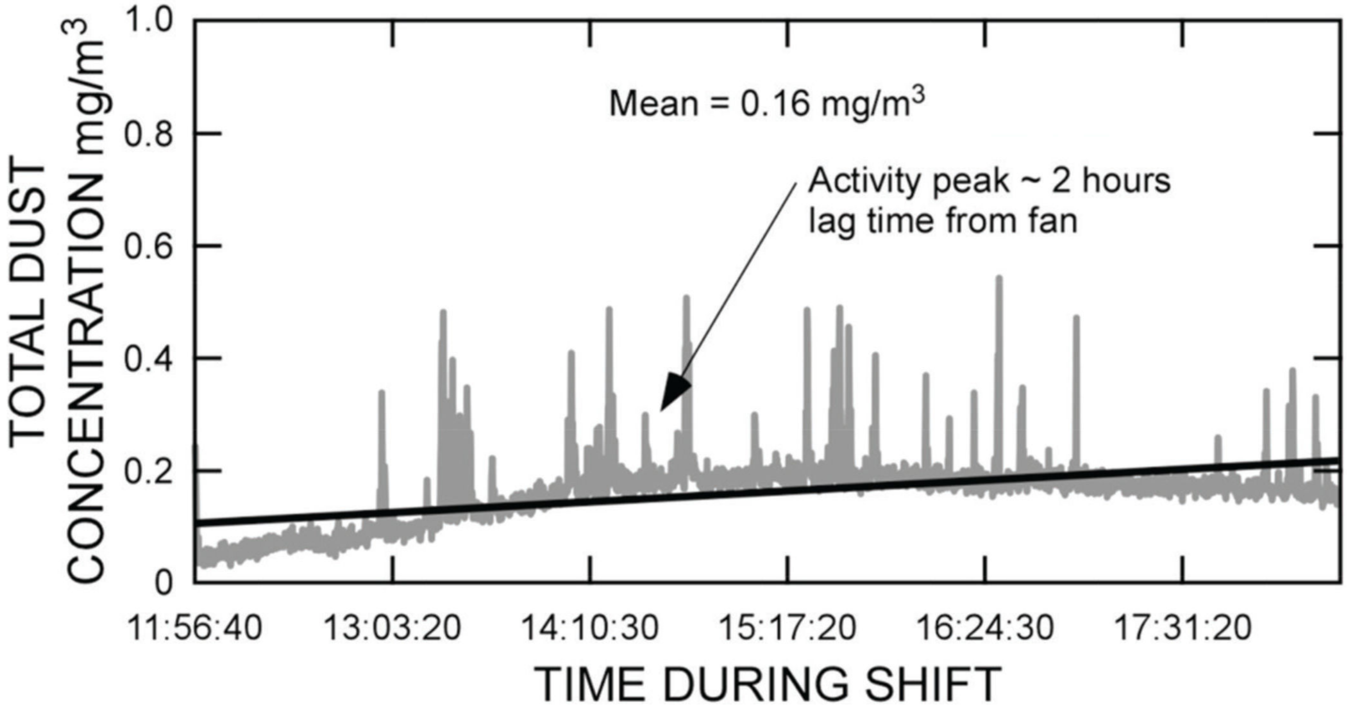

**Figure 4.**

Return dust concentration prior to recirculation point, with time lag and activity spikes.

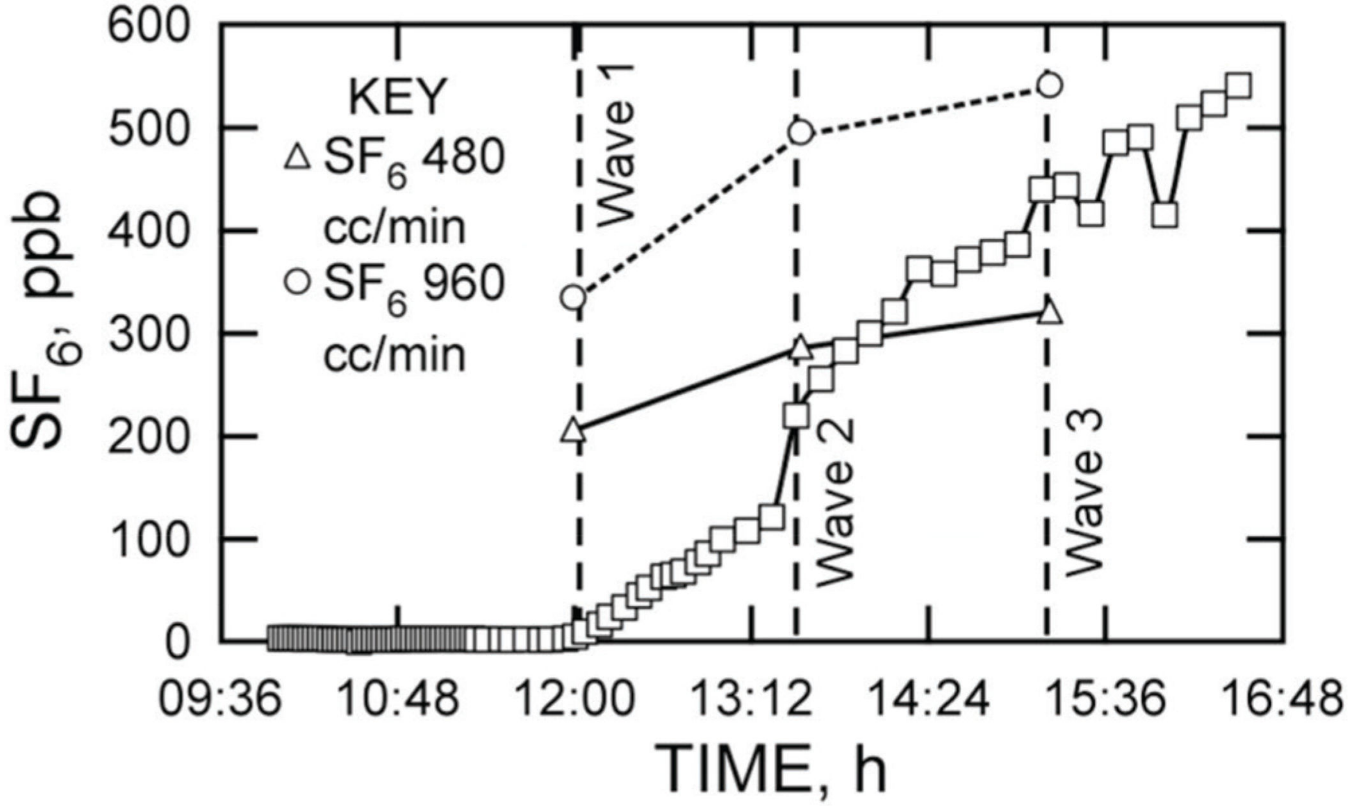

**Figure 5.**

Measured return location of $SF_6$ tracer gas concentration (ppb) vs. time. $SF_6$ planned release of 480 cc/min vs. higher estimated 960 cc/min rate concentrations. Wave arrival times are based on calculated system transient time of 1.9 hrs.

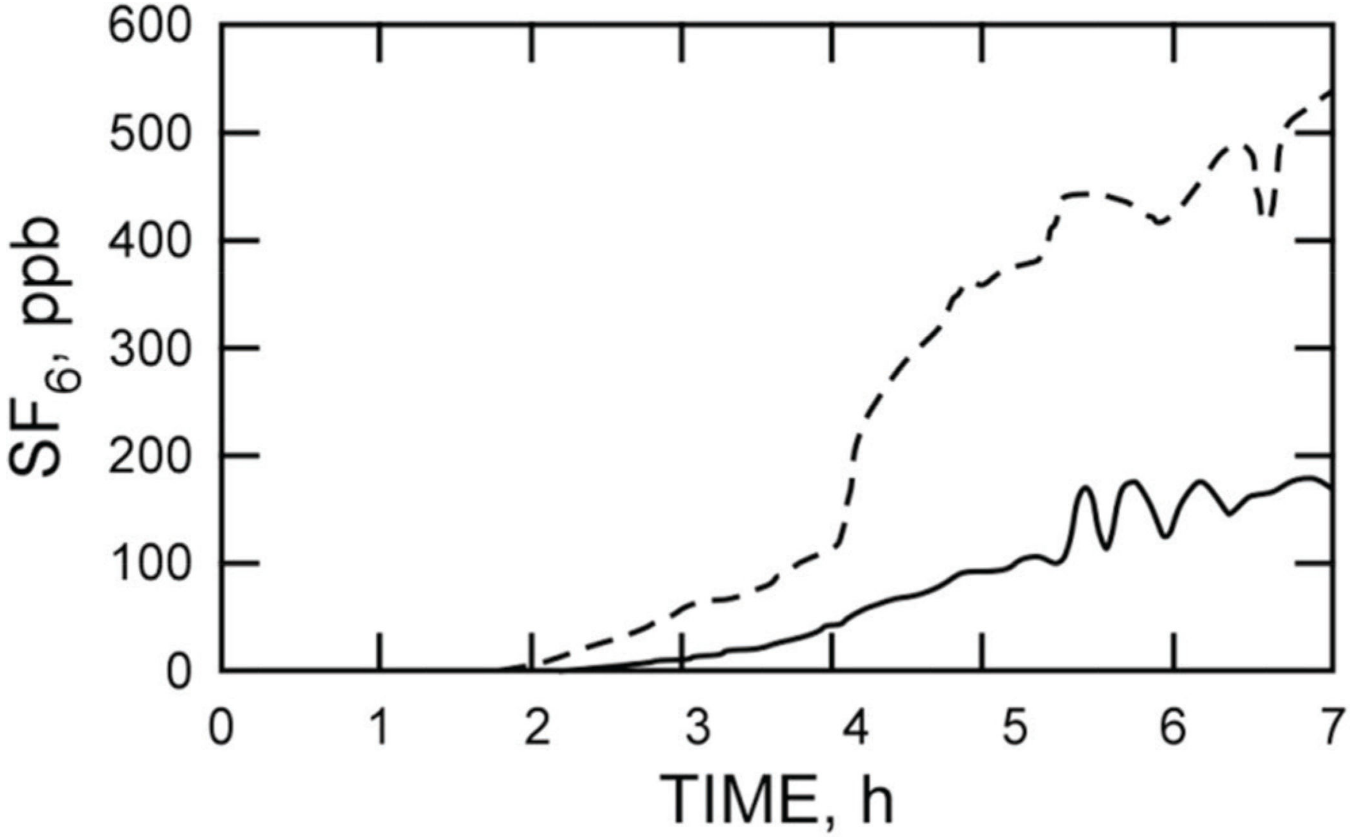

**Figure 6.**

Relative relationship between SF$_6$ intake (solid) and return SF$_6$ concentration (dashed) with time.

## Table 1

Controlled recirculation base, test and modeled airflow ($m^3/s$).

| Location | Base Measured $m^3/s$ | Test 2 Measured $m^3/s$ | Base Model $m^3/s$ | Test 2 Model $m^3/s$ |
|---|---|---|---|---|
| **Test area intake** | 4.3 | 7.1 | 4.5 | 7.1 |
| **Test area return** | 4.3 | 7.0 | 4.5 | 7.0 |
| **Test area return outby** | 4.4 | 4.0 | 4.7 | 4.7 |
| **Longwall intake** | 72.9 | 65.7 | 73.5 | 73.5 |
| **HG #6 return** | 15.7 | 15.8 | 18.4 | 18.4 |
| **HG #7 return** | 16.4 | 16.5 | 19.8 | 19.8 |
| **HG #8 return** | 9.2 | 10.1 | 10.4 | 10.4 |
| **West return outby** | 11.1 | 11.4 | 12.7 | 12.7 |
| **Submain intake outby** | 122.9 | 115.8 | 134.6 | 134.6 |
| **East return outby** | 6.0 | 5.5 | 6.6 | 6.6 |

## Table 2

Detailed differential pressures in controlled recirculation circuit for base, test and model. Note: Crosscut (XC) values increase from 139 at the north end (Fig. 1) to 207 at the south end.

| Location | Base Measured Pa | Test 2 Measured Pa | Base Model Pa | Test 2 Model Pa |
|---|---|---|---|---|
| 207 XC - West | 195 | 199 | 223 | 223 |
| 182 XC - West | 58 | 57 | 64 | 64 |
| 174 XC - West | 72 | 69 | 71 | 71 |
| 174 XC - East | 46 | 35 | 69 | 67 |
| 165 XC - West | 235 | 213 | 211 | 211 |
| 139 XC - West | 344 | 310 | 372 | 372 |
| 139 XC - East | 205 | 173 | 298 | 286 |