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EVALUATION OF CONTAMINATION INGRESS FOR BUILT-IN-PLACE REFUGE ALTERNATIVES

T. Lutz, NIOSH, Pittsburgh, PA
J. Noll, NIOSH, Pittsburgh, PA
L. Yan, NIOSH, Pittsburgh, PA

ABSTRACT

Mine disasters, such as fires and explosions, can create a hazardous atmosphere due to the generation of carbon monoxide (CO). After a mine disaster, contaminated mine air can enter the refuge alternative (RA) as miners enter. Most built-in-place (BIP) RAs use an air delivery system to provide an unlimited supply of breathable air through a borehole which also serves to purge contaminants. In order to determine what levels of contaminants enter the RA, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted testing in NIOSH's Pittsburgh Experimental Mine using groups of 5, 15, and 30 subjects entering the RA. The experiment used sulfur hexafluoride (SF_6) as a tracer gas that was released into the air outside of the BIP RA to establish a uniform concentration. After the human subjects entered the BIP RA, the SF_6 levels inside the RA were measured to quantify how much of the tracer gas entered the BIP RA. In tests conducted while the borehole air supply was left off as test subjects entered, interior contaminant levels were less than 3% of the exterior concentration. In tests conducted with the borehole air supply activated as test subjects entered, the interior contaminant levels were measured at less than 2% of the exterior concentration. Considering a mine disaster can result in 10,000 ppm of CO in the mine atmosphere, these percentages indicate that unhealthy CO concentrations that may lead to headaches, dizziness, and loss of judgement can occur in a BIP RA. This information will help mines make decisions concerning air locks, air delivery systems and a determination if purging mechanisms are necessary.

INTRODUCTION

The Mine Improvement and New Emergency Response Act of 2006 (MINER Act) was enacted in the wake of three mine explosions/fires that claimed 19 lives that year. Intended to help improve underground coal mine accident preparedness, the MINER Act includes provisions that target mine safety issues in areas such as emergency response planning, adoption of new technology, training and education, and enforcement of mine safety standards (MSHA, 2006). Section 13 of the MINER Act specifically directs the National Institute for Occupational Safety and Health (NIOSH) to provide for research into the effectiveness and viability of RAs for underground coal mines. This mandate culminated in the 2009 adoption of changes to the 30 CFR mining health and safety regulations, requiring underground coal mines to provide RAs capable of maintaining a life-sustaining environment for persons trapped underground. Such RAs can be either pre-fabricated or BIP shelters. The regulatory changes also include provisions establishing requirements for Mine Safety and Health Administration (MSHA) approval of RAs and their components, and among these provisions are numerous criteria for providing a safe, breathable atmosphere within RAs.

Contamination ingress is one issue being investigated by NIOSH to ensure a safe atmosphere for miners after an accident, disaster, or other emergency. Contamination ingress can occur during the process of miner entry into a refuge alternative. After a mine disaster, the mine air could be contaminated with carbon monoxide. Carbon monoxide from the mine air may enter the refuge alternative as miners enter the RA. NIOSH conducted research to determine the percentage of the mine air's carbon monoxide concentration that might be present within a mobile refuge alternative due to miner entry and discovered that the ingress concentration of CO could be as high as thousands of ppm (NIOSH, 2014). During research and testing, when five miners entered the tent-type mobile RA, the concentration of CO inside the RA was about half of the outside air concentration; with a steel rigid-type mobile RA, the concentration of CO in the RA would be about 20% of the outside air concentration. Considering the possible concentration outside of the RA of 10,000 ppm CO, this would mean that the concentration of CO inside the RA's airlock could be in the thousands of ppm and purging would be an important step in providing a safe atmosphere.

In addition to mobile RAs, built-in-place (BIP) RAs are being installed in U.S. underground coal mines (NIOSH, 2015). A BIP RA is generally much larger than a mobile RA and locating a BIP RA in a mine usually entails developing a room by sealing off a section of the mine. The BIP RAs offer the potential to provide miners with an improved psychological and physiological environment, both because the available air makes the space more comfortable and also because of the larger amount of space provided per occupant. BIP RAs are required to have a cache of self-contained-self rescuers (SCSRs) inside to allow miners to continue breathing safely prior to purging contaminants. Boreholes or protected compressed airline air supply systems also provide a much higher probability of there being communications to the RA. Due to the increase in size and the difference in air delivery systems, it is important to determine the effects of contamination ingress with this type of RA as with mobile RAs.

Contamination ingress into an RA from a contaminated atmosphere that may have been created by an explosion or fire in the mine is a very important factor in the design of a BIP RA. The research conducted in the NIOSH Experimental Mine in Pittsburgh quantified the amount of contaminant that enters the BIP when miners enter it from a contaminated atmosphere. The tracer gas sulfur hexafluoride (SF_6) was used in place of CO so that human subjects would not be harmed during the testing. SF_6 closely approximates CO dispersion characteristics when used as a tracer gas. The testing was conducted following the NIOSH Institutional Review Board approved protocol. For the total of six tests, the number of human subjects was 5, 15, and 30 and the air delivery system was activated in three of the tests and then turned off for the other three tests. This testing will aid in future research on purging to determine the amount of time/airflow that is required to reduce the contaminant level inside an RA to a safe level.

TEST SETUP

The layout of the BIP RA in the NIOSH Experimental Mine (see Figure 1 and Figure 2) shows the contamination ingress test area. The RA is sized for a maximum of 60 miners with the ability to be partitioned into a 30-person capacity RA, using a temporary wall. The ingress tests were conducted with the temporary wall installed as shown in Figure 3. The borehole air supply was plumbed to enter Section 1 at the lower corner, and the air outlet is located diagonally opposite near the top of the BIP RA.

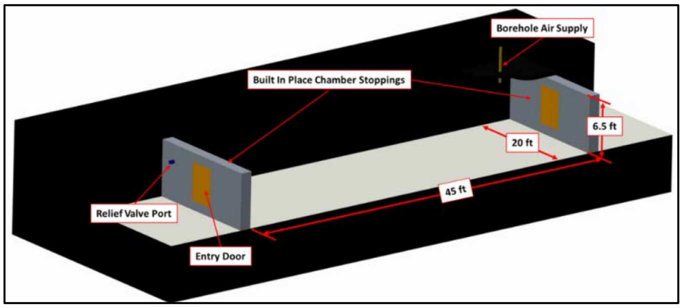

Figure 1. The layout of a BIP RA in the NIOSH Experimental Mine.

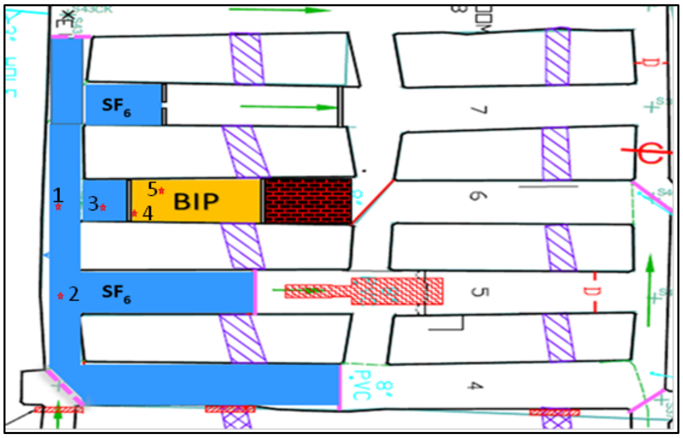

Figure 2. Location of 60-person BIP RA within the NIOSH Experimental Mine. The red star marks denote the sampling locations (numbered 1-5) inside and outside the BIP RA. The blue area is the SF_6 atmosphere outside of the RA.

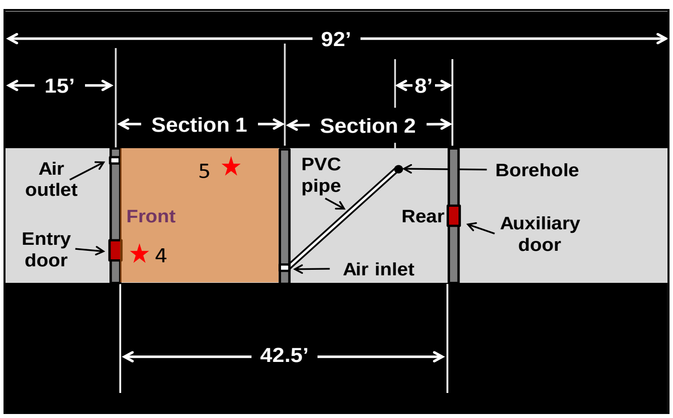

Figure 3. Overhead view of a NIOSH 60-person BIP RA. The BIP was divided into two sections, Section 1 and Section 2. The contamination ingress test was conducted in Section 1. The red star marks denote the sampling locations within the BIP RA.

TEST PROCEDURE

The contamination ingress tests were conducted in Section 1. The borehole air supply, which is located in Section 2, provided fresh air to Section 1 through the PVC pipe and air inlet. The entry door and air outlet were closed. The air inlet was blocked, isolating the interior BIP RA air from the fresh air outside of the mine. Before the SF_6 was released, its concentration was measured, using vacutainers (see Figure 4), inside and outside the BIP RA at various locations (locations 1 through 5) as shown in Figure 2. The SF_6 was then released inside of the enclosed test area (blue area in Figure 2), and fans were used to disperse the gas and create a uniform concentration. The interior SF_6 concentrations were measured 10, 20, and 30 minutes after the release at locations 4 and 5, shown in Figure 3. The exterior SF_6 concentrations were measured 10, 20, and 30 minutes after the release at locations 1, 2, and 3, shown in Figure 2. After the last measurements were taken, the borehole air supply was activated for three tests when subjects entered with the air delivery system, and was deactivated for the three tests when subjects entered without the air delivery system. The front door of the BIP RA was then opened, and all human subjects (5, 15, or 30) entered the BIP RA through the opened door. Once all subjects entered into the BIP RA, the door was closed. The interior SF_6 concentrations were measured 1, 5, and 10 minutes after the door was closed at locations 4 and 5. After the last samples were taken, the human subjects evacuated the area.

Figure 4. Vacutainers used to collect SF_6 concentration samples inside and outside of the RA.

RESULTS

As seen in Table 1, when there was no airflow inside the BIP RA after 5 or 15 subjects entered the chamber, less than 2% of SF_6 penetrated inside the RA. The exact concentration of the SF_6 that entered the chamber was so low that it could not be measured for it was below the limit of quantification (LOQ) of the analytical method, which is 3 parts per billion (ppb). Three ppb of SF_6 would indicate a 2% ingress for the experiment with 5 subjects entering the chamber and 1.5% ingress when 15 subjects entered the chamber. Due to the limitations of the sensors and equipment, these are the maximum ingress percentages that could be observed but they could actually be lower. After 30 subjects entered the chamber, 3% of the SF_6 penetrated inside the RA. In this case, the concentration of SF_6 inside was above the LOQ. The process of inserting SF_6 outside of the chamber and measuring the amount that penetrated inside the chamber can provide a good estimate of how much contaminant, such as carbon monoxide, would enter the chamber in a disaster situation, such as a fire. Therefore, if a BIP RA without an air delivery system operating is designed for 30 miners and all miners entered the chamber at the same time, 3% of the contaminated air concentration outside of the BIP could penetrate into the chamber.

Table 1. Percent of Gas that Penetrated into BIP RA after People Entered without Air Delivery System.

Number of people	Outside concentration (ppb)	Inside concentration (ppb)	% Ingress
5	152	<3	<2
15	205	<3	<1.5
30	122	4	3

The same experiments were repeated when the air delivery system was operating in the BIP RA. As shown in Table 2, similar results were observed with or without the air delivery system which was supplying approximately 375 SCFM of air. Again, the concentration of SF_6 was below the LOQ, indicating that the ingress of this gas was of some value less than 2% after 5 and 15 human subjects entered the BIP RA. After 30 subjects entered the BIP RA, 2% of the tracer gas penetrated into the RA using the measured values. The penetration of gas was less when the air delivery system was on. Without the air delivery system 3% of gas entered the chamber but with the air delivery systems 2% entered.

Table 2. Percent of Gas that Penetrated into BIP RA after People Entered with Air Delivery System.

Number of people	Outside concentration (ppb)	Inside concentration (ppb)	% Ingress
5	139	<3	<2
15	150	<3	<2
30	238	5	2

DISCUSSION

When 5 or 15 subjects enter the chamber, less than 2% of the contaminant may enter the chamber. There is no data on the concentration of CO immediately after a fire or explosion. However, some limited data on the CO concentration a few days after a disaster shows the concentration of CO to be around 10,000 ppm (NIOSH, 2014). This could result in 200 ppm of CO in the chamber prior to purging. This would be above the desired levels of CO (25 ppm or less) inside a BIP RA according to the 30 CFR (U. S. Government, 2008). As seen in Table 3, at 200 ppm, miners are not in danger of death but could have headaches and more importantly loss of judgement in a time of crisis. We could not measure in our tests less than a 2% contamination level so we cannot quantify exactly what contaminant is present with 5 or 15 subjects. This is because the concentrations used in the testing were extremely low (ppb) outside of the chamber as required by the approved human subject test protocol.

Table 3. Health Effects of Carbon Monoxide Exposure (NIOSH, 2014).

Concentration (ppm)	Symptoms
35	Headache and dizziness within six to eight hours of constant exposure.
100	Slight headache in two to three hours.
200	Slight headache within two to three hours; loss of judgment.
400	Frontal headache within one to two hours.
800	Dizziness, nausea, and convulsions within 45 min; insensible within 2 hours.
1,600	Headache, tachycardia, dizziness, and nausea within 20 min; death in less than 2 hours.
3,200	Headache, dizziness, and nausea in five to ten minutes. Death within 30 minutes.
6,400	Headache and dizziness in one to two minutes. Convulsions, respiratory arrest, and death in less than 20 minutes.
12,800	Unconsciousness after 2–3 breaths. Death in less than three minutes.

The contamination present after 30 subjects entered the BIP RA was measured. The ingress percentages (2% and 3%) are low, but the resultant atmosphere could be 200–300 ppm CO according to the data. This is above the desired concentration of CO in a BIP which is not life-threatening but could have negative side effects. If the air exchange rate (the time for the air flow amount to equal the volume of air in chamber) is 8 minutes for the RA, four air exchanges would reduce the contamination by a factor of 12 and take 32 minutes. Each air exchange reduces the contaminant level by approximately 50% (NIOSH, 2014). If the CO concentration starts at 300 ppm, 25 ppm or less would be achieved in 32 minutes.

LIMITATIONS

The specific conditions of the human subjects entering the BIP RA can vary from the actual conditions that may occur in an emergency situation. Miners may enter at different intervals and the time to enter could affect the CO ingress. The SF_6 levels used for the ingress testing were in the ppb range, following the approved NIOSH protocol which was at the lower limits of detection and quantification of the instrumentation used. Also, CO levels following a disaster may vary from the levels used to calculate the ingress quantity in this research.

CONCLUSIONS

When 30 subjects enter a BIP, the concentration of CO can be approximately 3% of the outside concentration. Considering that a mine disaster can result in 10,000 ppm CO in the mine atmosphere, the concentration of CO inside the chamber could be as high as 300 ppm. While this level is not deadly, it may lead to headaches, dizziness, and loss of judgment in a few hours should there be a delay in starting the blower/fan.

Purging will be required to reduce the CO levels to the targeted level of 25 ppm or lower according to the CFR (U. S. Government, 2008). For concentration of 300 ppm or less, the air delivery system for the BIP RA tested should be able to purge the CO to below 25 ppm levels within 32 minutes. This information illustrates the importance of mines to immediately implement their Emergency Response Plans (ERPs) and turn on blowers from the outside. Also, the information will help mines make decisions concerning air locks, air delivery systems, storing additional SCSRs, and a determination if purging mechanisms are necessary.

DISCLAIMER

Mention of a company name or product does not constitute an endorsement by the National Institute for Occupational Safety and Health (NIOSH). The findings and conclusions in this report are those of the authors and do not necessarily represent the views of NIOSH.

ACKNOWLEDGEMENTS

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REFERENCES

1. MSHA, 2006, Mine Improvement and New Emergency Response Act of 2006 (MINER Act), United State Department of Labor, https://arlweb.msha.gov/MinerAct/MinerActSingleSource.asp.

2. NIOSH, 2014, “Investigation of purging and airlock contamination of mobile refuge alternatives.” By Bauer, E.R., Matty, T.J., Thimons, E.D., Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 2014-116, RI 9694.

3. NIOSH, 2015, “Facilitating the use of built-in-place refuge alternatives in mines.” By Trackemas, J.D., Thimons, E.D., Bauer, E.R., Sapko, M.J., Zipf, R.K., Schall, J., Rubinstein, E., Finfinger, G.L., Patts, L.D., LaBranche, N., Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2015-114, RI 9698.

4. U.S. Government, 2008, Part V, Department of Labor, Mine Safety and Health Administration, 30 CFR Parts 7 and 75, Refuge Alternatives for Underground Coal, Mines; Final Rule, https://arlweb.msha.gov/REGS/FEDREG/FINAL/2008finl/E8-30669.pdf