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INSTITUTING A FILTRATION/PRESSURIZATION SYSTEM TO REDUCE DUST CONCENTRATIONS IN A CONTROL ROOM AT A MINERAL PROCESSING PLANT

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ABSTRACT

NIOSH has observed that many control rooms and operator compartments in the US mining industry do not have filtration systems capable of maintaining low dust concentrations in these areas. In this study at a mineral processing plant, to reduce respirable dust concentrations in a control room which had no cleaning system for intake air, a filtration/pressurization system originally designed for enclosed cabs was modified and installed. Eighty-seven percent of submicron particles were reduced by the system at static conditions, meaning that greater than eighty-seven percent of respirable dust particles should be reduced. The particle size distribution for respirable dust particles are greater than for submicron particles, and filtration systems usually are more efficient in capturing the larger particles. A positive pressure near 0.02 inches of water gauge was produced which is an important component for an effective system and minimizes particles (e.g. dust) from entering into the room. The intake airflow was around 118 cfm, which is greater than the airflow suggested by ASHRAE for acceptable indoor air quality.

INTRODUCTION

Chronic overexposure to respirable silica dust (particle diameter < 10 microns) leads to a progressive lung disease known as silicosis. Workers who develop silicosis have an increased incidence of lung cancer and pulmonary disorders. In June 1997, the International Agency for Research on Cancer (1) found sufficient evidence to declare that inhaled crystalline silica in the form of quartz and cristobalite is carcinogenic. Mining is one of the leading industries for occupational exposure to silica dust (2-7). Control rooms located in dusty areas in some mines are of particular concern (8).

Many mineral processing operations utilize operator's compartments and/or control rooms to house workers who are performing particular job functions. Most industrial processing mills have rooms where a worker looks out over the facility and has direct control over the product flow throughout the entire building. In addition, primary crusher operators are often located in a compartment from which they are able to view the primary crushing function. Their job is to control when trucks dump into the primary jaw crusher and the rate of feed of the ore from the hopper into the crusher. Many of these control rooms and operator booths do not have filtration systems capable of cleaning air entering the control room or booth, which can result in elevated concentrations of dust in the room or booth. To reduce the dust concentrations in these rooms, it would make sense to clean the entering air with filtration/pressurization units similar to those proven to provide a clean environment in enclosed cabs.

A filtration/pressurization unit designed for enclosed cabs was modified to operate in the control room at a milling processing plant. This paper describes how well the system functioned and the quality of the air resulting from its implementation.

Background on Filtration and Pressurization Systems

Extensive research has been performed by National Institute for Occupational Safety and Health's (NIOSH) Office of Mine Safety and Health Research (OMSHR) on filtration/pressurization systems for enclosed cabs of mobile equipment for a number of years (9). Early on in this research effort, a number of different in-cab dust sources were identified that increased the equipment operator's respirable exposure and included such things as dust laden work clothing, work boots, control panels, and dust on the inside walls of the enclosed cab (10-13). A comprehensive laboratory study also was performed to evaluate the various factors and parameters that are critical for an effective filtration and pressurization system in an enclosed cab (14-16).

The field and laboratory studies determined that the two most significant components for an effective system are: 1) a competent filtration system comprised of a pressurized intake and a recirculation component, and 2) an enclosure with sufficient structural integrity to achieve positive pressurization. An effective pressurized intake air component provides numerous important functions in an optimized system. First, it provides the required amount of outside air to ensure the equipment operator has acceptable indoor air quality (17). Secondly, it creates enough positive pressurization to stop contaminants from being drawn into an enclosure. High-efficiency intake filters are necessary for an effective design. For enclosures for mining applications, a Minimum Efficiency Reporting Value – 16 (MERV-16) intake mechanical filter has worked very well for reducing dust and diesel particulate matter while providing the necessary airflow, pressure, and filter life (18,19).

A recirculation system is a very important component for any filtration and pressurization system design and there are a wide range of operating parameters that can be used in an effective system. First, the filtration efficiency of the recirculation filter should range between a MERV-14 and a MERV-16 filter. The mining conditions should dictate the actual filter efficiency rating chosen and should be based upon such things as: dust type, silica content, dust sources and levels in an enclosure, and how often miners enter or exit the area. Finally, it must be remembered that the ultimate effectiveness of the recirculation system is based on the reductions achieved through multiple cycles of filtering the interior cab air (15-16).

To ensure enclosure integrity, testing has shown that the installation of new door gaskets and seals as well as plugging and sealing cracks and holes in the shell of the enclosure have a major impact on increasing enclosure pressurization. Further, to prevent dust-laden air from infiltrating into the enclosure, the enclosure's static pressure must be higher than the wind's velocity pressure (20).

The use of a uni-directional airflow pattern should also be considered whenever possible to maximize the air quality at the operator's breathing zone inside the enclosure. In systems not using a uni-directional design, both the intake and discharge for the recirculation air are normally located in the roof. Unfortunately, this location causes the dust-laden air within the enclosure to be pulled directly over the worker as it is drawn into the ventilation system. Further, in many designs, the contaminated return air and the clean filtered air are ducted within inches of each other at the ceiling. This poor design allows for recirculated air to be short-circuited and allows dust-laden return air to be pulled directly back into the ventilation system and over the operator's breathing zone. A more effective design is to draw the recirculated air from the bottom of the enclosure, away from the worker's breathing zone (21).

The information and knowledge obtained from these previous enclosed cab research efforts can be adapted for control rooms. Although operator compartments and control rooms are somewhat similar to enclosed cabs on mobile mining equipment, there are key differences that need to be considered and evaluated for determining the optimal system design, as follows:

- Enclosed vehicle cabs are constantly being stressed and subjected to leakage issues by the equipment movement. Operator compartments and control rooms are static and not subjected to these factors.
- Enclosed cabs on mobile equipment are generally designed with integrated heating, ventilation, and air conditioning (HVAC) units with built-in filtration systems. Operator compartments and control rooms often do not have HVAC systems, which would require a different design.
- Control rooms can be much larger than operator cabs, thus impacting intake pressurizer design considerations such as intake airflows. In addition, there can be more of a tendency for workers to congregate in these areas and enclosures since they are larger in size. This contributes to a number of different factors that must be considered for an effective and safe design, with one particular issue being maintaining air quality, especially in regards to CO_2 levels.
- Operators in enclosed cabs of mobile mining equipment have a greater tendency to open and close the cab door, and/or enter and exit the cab on a much more frequent basis than operators in compartments or control rooms. This would impact how quickly the filtration system needs to handle new contaminants.

METHODS

Baseline Measurements

Before the filtration/pressurization unit was installed, measurements were taken to obtain the initial or baseline evaluation of the control room. Since the respirable dust measurements could be affected by opening the door, particle count data was collected for 15 minutes during break times. This was done four times over the two days of testing. Pressure measurements were taken inside the control room to determine if positive pressure existed since positive pressure can hinder dust from being drawn into the room. Below are details on each type of measurement.

Particle counting measurements

Two model ARTI/Met One HHPC-6 particle counters or two TSI OPS 3330 were used to record the inside and outside cab particle size concentrations for one-minute periods over a 15-minute test. Once completed, the instruments were switched and the 15-minute test was repeated again to eliminate the effects of instrument bias. This was repeated for a total of four tests.

The test medium was airborne particles present in the ambient air surrounding the control room. The last 10 minutes of data from each test were used to calculate the average outside and inside concentrations of the control room during the steady-state conditions. The protection factors were determined from the cumulative submicron (0.3-1.0 µm) particle concentrations because most of the ambient air particles resided in this size range. A protection factor for each test replicate was determined by dividing the average outside particle concentration by the average inside particle concentration at the operating test condition. The protection factor represents a reduction ratio of all the exterior and interior particles removed by the filtration system. In addition to protection factor, percent efficiency in reducing particles was determined using the equation 1 below:

(Equation 1)

$$\%\ efficiency = \frac{outside\ concentration - inside\ concentration}{outside\ concentration} x\ 100$$

In order to determine the precision of the data, the 95% confidence limit was calculated using the equation 2 below:

(Equation 2)

$$95\%\ confidence\ limit = \pm t\ x\ \frac{s}{\sqrt{N}}$$

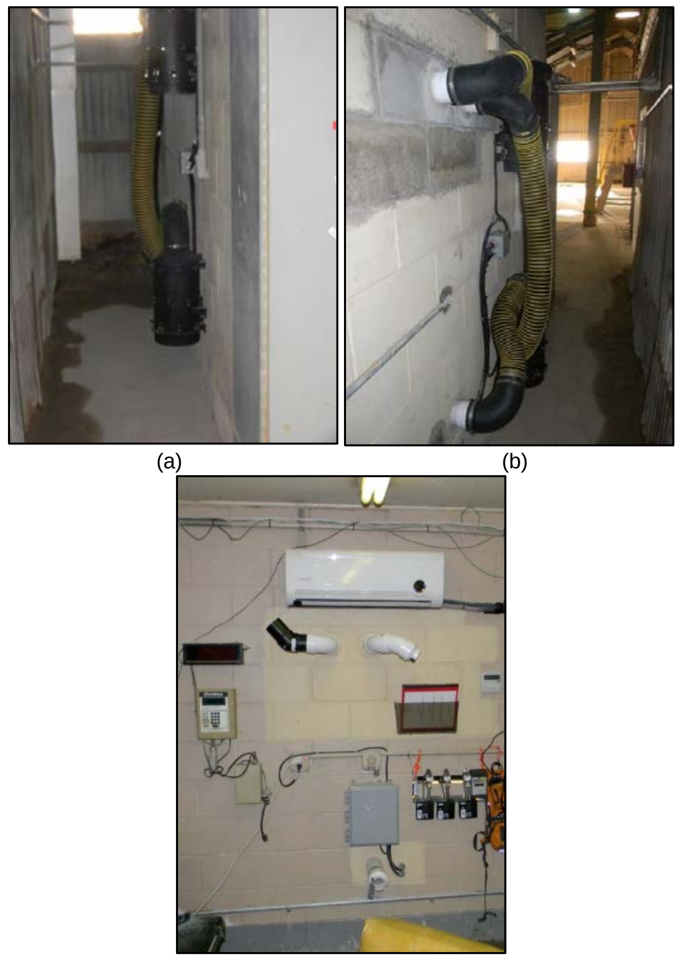
Where *t* is the t factor for the degrees of freedom, *s* is the standard deviation, and *N* is the number of samples.

Pressure Measurements:

All cab pressure measurements were taken with DP-CALC micro-manometers, Model 5825 (TSI, Incorporated, Shoreview, MN). These pressure measurements were taken every minute and recorded on the unit's internal data-logger. After each day of testing, the data was downloaded to a laptop computer and stored as an Excel data file.

Installation of Filtration/Pressurization Unit

The following designs (see Figure 1) were made to the control room to provide clean air and positive pressure:



(a) (b) (c)

Figure 1. (a) and (b) Pictures of the filtration/pressurization units on the outside of the control room and (c) picture of the control room interior. The top left PVC pipe coming in is the intake (filtered air) to the recirculation, the top right is the filtered outside air or intake, and the tubing near the floor is the intake for the recirclation.

- The control room was a block room (10 ft by 18 ft by 8 ft—about 1500 ft^3) with a vestibule entrance. It contained a window air conditioner and a wall heater. The window air conditioner was removed because it allowed an exchange of inside and outside air, which could prevent achieving positive pressure. A ductless air conditioner (AmericAir 9,000 Btu. R410A 110 Volt Heat Pump Inverter Ductless Split System) was installed instead.
- A RESPA-CF Vortex Hyperflow unit was installed to provide filtered air and pressurization to the control room. The

RESPA-CF unit is designed for enclosed cabs on a piece of mobile equipment. It is used by original equipment manufacturers as part of their cab systems and can also be installed onto existing enclosed cabs. It contains a powered cyclone pre-selector to eliminate large particles before passing through the filter to extend the life of the filter. After passing through the pre-selector, the air passes through a filter (HEPA or MERV-16), and a fan pushes air through the filter and into the control room resulting in positive pressure.

- The RESPA-CF units were designed for a 24-V power supply. A converter encased in a protective enclosure had to be connected to allow 120-V power to be used.
- As mentioned earlier, previous studies have shown that a recirculation component (air from the room is passed through a filter and back into the room) was found to be crucial for enclosed cabs to limit exposure to re-entrained dust. A second Sy-Klone CFX unit was installed to recirculate and filter the air in the room.
- MERV-16 filters were used in these units because in the mining environment, they have been shown to be efficient in reducing respirable dust and to have a sufficient lifespan (19).
- A unidirectional design was used where the filtered air from the Sy-Klone units entered the room at a 5' level but was directed upward towards the ceiling. The recirculation pick-up point within the room was near the floor and was approximately one foot from the floor. This design was implemented to provide a uni-directional airflow pattern within the control room.

Post-Analysis

Filtration/pressurization systems are designed to provide clean air to a control room and produce a positive pressure to prevent dust from entering the area. It is also important for the system to provide acceptable indoor air quality and not to induce a noise hazard. In this study, the following measurements were taken to determine the capability of the system installed in the control room:

- efficiency of the system to reduce submicron particles
- positive pressure
- airflow
- carbon dioxide concentrations
- noise levels

The same particle counting and pressure measurements collected for baseline testing were repeated once the filtration/pressurization system was operational. In addition, to obtain visual evidence of positive pressure in the control room, smoke was produced using Sensidyne smoke tubes, and the path of the smoke was recorded (and pictures were taken) when the system was on and off.

Airflow measurements were also collected since outside air was brought to the room mechanically. Airflow readings were measured for the intake and recirculation circuits of the control room's filtration system. A vane anemometer (Davis Instruments, Vernon Hills, IL) over the intake and recirculation filter inlet area was used to determine air velocity. The cubic feet per minute (CFM) was calculated using the velocity and area of outlet. Carbon dioxide (CO_2) measurements were collected with a Vaisala M70 monitor to ensure safe levels of CO_2 and to determine if there was acceptable air quality given that carbon dioxide is used as a surrogate for bio-aerosols (17,22). A sample was collected every minute for one shift. The average concentration was calculated as well as the 95% confidence limit (see equation above) for the shift when the system was on. In addition, the CO_2 concentration vs. time was plotted.

Noise measurements were taken with the Spark 705 dosimeter to measure the effect of the filtration/pressurization system on noise levels. A sample was collected every 10 seconds for an entire shift. At the end of the shift, the system was shut down for an hour to record the noise when the two RESPA-CF units were turned off. The average Leq (Equivalent Continuous Sound Level) and 95% confidence limit were calculated for when the system was on and off.

After one year, testing was repeated for two days. This was performed to evaluate the system after the dust had collected on the filter because the efficiency of a mechanical filter increases with filter loading. A t-test using Sigma Plot 12.0 was performed comparing the efficiencies of the particle counters after initial installation and one year later to determine if there was statistical significance between values.

RESULTS AND DISCUSSION

Efficiency of the system to reduce sub-micron particles

The filtration/pressurization system demonstrated significant reductions (over 87%) in submicron particles. To determine efficiency of the system and remove particles without the influence of opening and closing the door and of workers' stirring up particles inside the room, particle counting measurements were performed inside and outside of the control room when the control room was not being used. Since dust was not generated, the test medium was airborne particles less than 1 µm inside and outside of the room. As seen in Table 1 for baseline testing, without the filtration/pressurization unit, more particles were inside the room than outside, and the variability between tests was high (as seen with a high confidence limit of 29). Clearly, the air was not being cleaned before entering the room.

Table 1. Protection Factor/Efficiency of the Control Room via Particle Counting.

Sample	Description	Protection Factor	Efficiency (%)
Baseline	No filtration	0.79+0.17	-36+29
Post 1	the first two days of operating the filtration pressurization unit	8±	87±4
Post 2	one year after installation of filtration pressurization unit	25±15	94±4

The filtration/pressurization system introduced clean air into the room while preventing dusty air from being drawn in, resulting in substantially fewer particles in the control room. When the unit was first installed, the average protection factor (PF) was 8 (87% reduction in submicron particles) with much less variability between tests than the baseline testing. After one year, the PF increased to 25 (94% reduction in submicron particles). The filters used in this system were mechanical, which will increase in efficiency as they load with dust. In this case, the PF increased from 8 to 25 (an efficiency increase from 87 to 94%), which was statistically significant (a t-test [p=0.031] demonstrated statistical significance between the two means).

Respirable dust is larger than the submicron particles used as the test medium in this study. Since filters are usually more efficient with larger particle sizes, the protection factor/efficiency of the filter to capture respirable dust should be equal to or greater than the protection factor/efficiency to capture submicron particles. Therefore, when the room is closed, the PF for respirable dust would be expected to be equal to or greater than 8 (87% reduction in respirable dust) at first and then increase to equal to or greater than 25 (94% reduction in respirable dust) as the filter begins to load.

The PFs for this system were significant and are similar to ones observed in some enclosed cabs (PF of 10) (18). An increase in intake airflow may improve the positive pressure inside the cab and result in an improved PF. In addition, a two-filter intake system where air passes through an intake filter and a final filter (both MERV 16) before entering the cab has been shown to provide PFs as high as 1000 (23). Designing the system after this model may provide better PFs than recorded in this study. It could also have an impact on airflow and pressure

Ability of the system to induce positive pressure

The system induced a positive pressure to prevent particles from entering the room. As seen in Figure 2, there was no positive pressure before the system was installed and a slight positive pressure after installation, preventing dust from being drawn into the control room. The amount of pressure decreased after one year. The pressure is directly related to the intake airflow. Since the intake air went from 118 to 80 cfm, this pressure decrease was expected. The pressure was between 0.01 and 0.02. Higher pressures would have been preferred, but the levels of pressure achieved have been shown to be sufficient in some enclosed cabs (19). This was visually observed with smoke tubes. As seen in Figure 3, the smoke did not leave the room but was stagnant when no system was operating. Conversely, when the system was on, the smoke was drawn out of the room, meaning there was positive pressure.

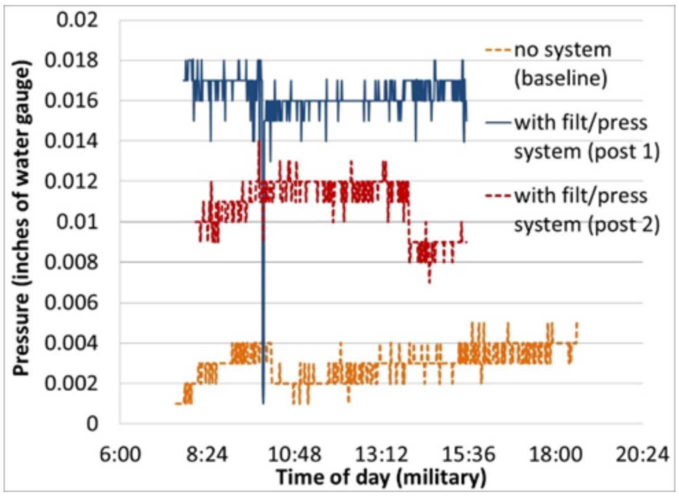


Figure 2. Pressure inside the control room over a shift with and without the filtration/pressurization unit.

a b

Figure 3. (a) Picture of the emissions from a smoke tube lingering inside the room because there is no positive pressure (system off). (b) Picture of smoke leaving the room since positive pressure is causing contaminant to be pushed out of room (system on).

Ability of the system to achieve acceptable indoor air quality

The airflow into the room was 118 cfm when the filtration/pressurization system was initially installed. One to two workers usually occupy this room; therefore, the airflow was higher than the ASHRAE-recommended ventilation rate for acceptable indoor air quality for offices and labs (20 cfm per person) (17) as well as the ASABE minimum airflow standard for enclosed cabs (25 cfm/person) (24). The airflow also resulted in safe levels of carbon dioxide (average level of 773±16 with a maximum of 1510 ppm). Even the maximum concentration was well below the OSHA TWA of 5,000 ppm and STEL of 30,000 ppm. Carbon dioxide concentrations were also used to identify and manage adequate ventilation because they can indicate build-up of other contaminants such as bio-aerosols, which can result in human discomfort (17,22). For carbon dioxide, ASHRAE considers 1,000 ppm when outside air is 300 ppm (or 1,100 ppm with 400 ppm outside air) and below as a guideline to indicate adequate ventilation and acceptable indoor air quality (17). As seen in Figure 4, adequate ventilation was provided to the control room; the carbon dioxide concentrations were usually below 1,100 ppm.

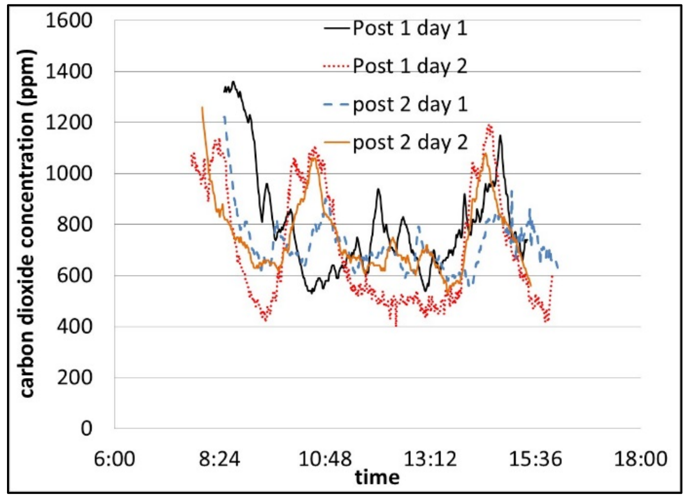


Figure 4. Carbon dioxide concentrations inside the control room while the filtration/pressurization unit is operating.

After one year, the airflow decreased to 80 cfm, which was still higher than the ASHRAE-recommended ventilation. The carbon dioxide levels were still safe with the average at 754±10 ppm and the maximum at 1,470 ppm. As seen in Figure 4, except for a few short peaks, the concentration of carbon dioxide met the ASHRAE recommendation for acceptable air quality. Eventually, the airflow will decrease to unacceptable levels, indicating the need for a filter change.

Effect of the system on noise levels

Because of the fans in both RESPA-CF units, the control room (one for intake air and one for recirculation) as part of the filtration/pressurization system, noise levels were measured. As expected, there was an increase in noise with the system. When the system was off, the sound level was 63±0.1 dBA, which increased to 74±0.4 dBA when the system was initially installed. After one year of loading the filter, the noise was measured at 72±0.2 dBA, indicating very little change. While the noise level was not considered to be harmful and is similar to the noise experienced in some cabs of mobile equipment, some workers found the increase in noise levels to be noticeable. Therefore, a next step for this system would be to develop methods to reduce noise.

CONCLUSION

In this study at a mineral processing plant, installing a filtration/pressurization unit similar to what is used in enclosed cabs in a control room was successful. Reductions in submicron particles of over 87% were observed. Positive pressure to help prevent dust from being drawn into the control room was produced, and the airflow was high enough to produce safe levels of carbon dioxide and acceptable air quality. As the filter begins to load, the airflow will decrease and the efficiency will increase. In this case, after one year, the reductions in particles rose from 87% to 94% and the airflow decreased from 118 to 80 cfm. Although the airflow still provided acceptable indoor air quality, eventually it will not provide the desired ventilation and the filter will need to be changed.

A negative impact of this filtration/pressurization system was the increase of noise (from 63 to 74 dBA). The noise level was not dangerous to health but the increased noise level was a source of frustration or viewed as a nuisance by some workers. Therefore, current effort is underway to investigate methods for reducing the noise in these applications.

What follows is a list of factors derived from this study to consider when designing a filtration/pressurization unit for a control room or operator's booth.

- **Power requirements**: A converter had to be used to supply power since the filtration/pressurization unit operated off of 24-V DC, but there was only 120-V AC power.

Pressurization/filtration units operating on 120-V AC may be available soon.

- **HVAC**: The most important requirement of an HVAC system used with a filtration/pressurization unit is that it does not allow an exchange of air inside and outside of the control room or booth. In this case, an electric wall heater and ductless air conditioner were used. One could also integrate the HVAC system with the filtration/pressurization unit.
- **Integrity of room or booth**: How well the room is sealed should be determined before installing a filtration/pressurization unit. The control room in this study was a block building and well-sealed.
- **Size of room**: Two units worked well for the size of the study room to provide enough intake and recirculation air. However, more positive pressure may be beneficial and this could be provided with more intake air. For larger-sized rooms, more intake air may be needed.
- **Type of filter**: A MERV-16 filter worked well in this case. A HEPA filter should also reduce dust well but may be more restrictive to airflow.
- **System indicator**: An system indicator device would be beneficial to notify the worker when there is a problem with the system or when the filter needs to be changed. NIOSH is currently studying the use of pressure monitors to accomplish this task.
- **Noise**: Some noise dampening should be considered while designing the system for a control room or operator booth.
- **Uni-directional design**: The intake air was brought into the room at the top and the recirculation air was drawn from the bottom in order to achieve the benefits of a uni-directional design.
- **Protection factor of system**: The PFs for this system were significant and are similar to ones observed in some enclosed cabs.

DISCLAIMER

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

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