Reducing dust exposure from contaminated work clothing with a stand-alone cleaning system

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ABSTRACT: A few years ago, the National Institute for Occupational Safety and Health and Unimin Corporation developed a clothes cleaning system that is able to quickly, effectively, and safely remove dust from a worker's clothing without dust exposure to the worker, the work environment, or co-workers during the cleaning process. To perform the process, a worker enters a cleaning booth and activates an air spray manifold which blows the dust from the worker's clothing. Since the cleaning booth is under negative pressure, all the dust and product removed are contained. In the original design, this dust-laden air was exhausted to a dust collector system. However, since most operations do not have excess dust collector capacity, it was decided to determine an alternative method to provide for a stand-alone cleaning system. This was achieved by ducting the exhaust outside the plant and into the atmosphere. This technique was recently tested and shown to be a viable method to provide for a stand-alone clothes cleaning system.

1 Introduction

New methods are constantly being investigated to lower respirable dust exposures to workers in the mining industry. When the ore being processed contains quartz or silica-bearing material, the need to achieve low respirable dust levels is especially critical. One area of known high exposure can come from contaminated work clothing (Cohen and Positano, 1986; Fogh et al., 1999). A U.S. Bureau of Mines study documented a number of cases of high worker exposure from background dust sources in the minerals processing industry. This report highlighted two cases of a 10-fold increase in respirable dust from contaminated work clothing (Cecala and Thimons, 1986). Once the individual's clothing was contaminated, dust was continuously emitted from it and the only way to eliminate the dust source was for the worker to clean or change their clothing. Contaminated work clothing is not only a hazard to the worker themselves, but also contaminates co-workers and even family members when it is deposited in personal vehicles and at home when work clothes are not changed or cleaned at the end of the work shift (Chiaradia et al., 1997; NIOSH 97-125, 1997; Chan et al., 2000).

There are two federal regulations that affect the cleaning of work clothing for the US mining industry. The first regulation is a Mine Safety and Health Administration (MSHA) standard that states: "At no time shall compressed air be directed toward a person. When compressed air is used, all necessary precautions shall be taken to protect persons from injury" – 30 CFR Part 56.13020. A second regulation that is a general industry standard established by the Occupational Safety and Health Administration (OSHA) in 29 CFR 1910.242 9 (b), states that: "Compressed air shall not be used for cleaning purposes except where reduced to less than 206.8 kPa (30 psi) and then only with effective chip guard and personal protective equipment." Because of these regulations, the approved method for the US mining industry is to use a HEPA-filter vacuuming system. To perform this technique, a worker uses the vacuum hose and manually moves the nozzle over his/her soiled clothing in an attempt to remove the contamination. This is a very difficult, ineffective, and time-consuming task; therefore, few workers actually use this technique. In practice, the most common technique is to use a single compressed air hose to blow dust from the workers clothing, even though this is a prohibited method of cleaning. Normally this is performed at full line pressure, 552 to 689 kPa (80 to 100 psi), in an open work area which not only exposes the worker but also creates a significant dust cloud in the work environment and ultimately exposes co-workers.

In 2001, Unimin Corporation approached the National Institute for Occupational Safety and Health (NIOSH) to work in a cooperative effort with the goal of developing a safe and effective method for removing dust from soiled work clothes without exposing the worker, co-workers, or the work environment. Through work performed in 2002 and 2003 at Unimin's Marston facility in North Carolina and NIOSH's Pittsburgh Research Laboratory in Pennsylvania, a successful clothes cleaning system was developed. In 2004, a petition for modification was submitted to MSHA, which was approved and allowed for the use of the clothes cleaning system at the Marston facility. This approved system was composed of a "cleaning booth" that captured the product and dust removed from the worker's clothes during the cleaning process and then exhausted it to a Local Exhaust Ventilation (LEV) system. During numerous tests performed at this facility in the development of this system, it was verified that no dust escaped from the cleaning booth to contaminate co-workers or the work environment. It was also shown there was very minimal to no respirable dust exposure to the worker wearing a fit-tested ½-mask respirator while performing the cleaning process. In a matrix of tests that were performed during this field analysis, it was shown that the clothes cleaning technique was 40.8 pct more effective than vacuuming and 50.6 pct than the commonly used method of using a single compressed air hose to remove dust from the worker's clothing. The clothes cleaning process was also superior in its ability to uniformly remove dust from all areas of the coveralls used for testing (Pollock et al., 2006; Cecala et al., 2007).

After the completion of this successful effort, both Unimin and NIOSH realized that the vast majority of operations would not have the LEV capacity to keep the cleaning booth under negative pressure. Because of this, it was decided to perform a second phase of research to modify the design to develop a stand-alone system. After considering a number of different options, it was believed that the optimal design would be to exhaust the air from the cleaning booth to outside the plant and discharge it into the atmosphere through an exhaust stack. A similar technique that has been used for many years called a total mill ventilation system (TMV) also exhausts dust-laden air from within a structure to the outside atmosphere. For this system, clean air is brought in at the base of the facility and then sweeps through the building before being discharged at or near the roof of the structure. This TMV system is a common practice for most mineral processing plants today. Realizing that exhausting dust-laden air into the atmosphere will have environmental implications, the Environmental Protection Agency (EPA) was contacted to determine if there were any new regulations that would be relevant to this intended practice. Based on feedback from the EPA, the only regulation that addressed releasing the dust removed from a worker's clothing into the atmosphere would be the opacity standard, which is a subjective visual determination of the degree of a dust cloud exiting any exhaust duct or stack. When one considers the possible quantity of dust on a worker's clothing relative to the exhaust volume of air being drawn from the booth, any dust cloud viewed coming from the exhaust stack would be for a very short duration and should not be a concern from an environmental standpoint for this system.

Phase II of this research was performed at Unimin's Elco Facility, located in Elco (southern), Illinois which funded all aspects of this clothes cleaning system. In addition, all plant personnel involved in this research effort were extremely insightful and cooperative which allowed for various modifications to the design of the system to be tried in an effort to optimize the system. During the second phase of this research effort, SK Bowling Company[1] offered to fabricate the design developed during this research with the ultimate goal of being able to manufacture and sell the clothes cleaning booth system once the research was completed. SK Bowling Company built the unit that was tested during phase II of this research project and is currently offering this design for sale (http://www.cleanclothbooth.com/).

2 Clothes Cleaning System Design

The clothes cleaning system developed under this cooperative research effort consists of four major components: a cleaning booth, an air reservoir, an air spray manifold, and an exhaust ventilation system. The following discussion is the final optimized design determined during phase II of this research effort to develop a stand-alone system where the product cleaned from a worker's clothing is discharged through an exhaust stack outside the plant.

The cleaning booth is the first component to this system and has a base dimension of 122 by 107 cm (48 by 42 in). A standard size door is located on the front to allow ingress and egress from the cleaning booth. All intake air enters the cleaning booth through a 61-cm (24-in) cutout on the roof directly over where the worker performs the clothes cleaning process. The air flows directly down over the worker in the booth before flowing through an expanded metal grating on the floor. At this point, the air exits through a return air plenum at the bottom and back of the booth, transitioning to a 30.5-cm (12-in) duct. Once in the 30.5-cm duct, the dust-laden air is drawn outside the plant through a blower before being discharged from an exhaust stack into the atmosphere.

The second major component to this system, the air reservoir, supplies the required air volume necessary for the air nozzles used in the spray manifold. The size requirement for the air reservoir was calculated based upon the design of the air spray manifold. Although a 0.45-m^3 (120-gallon) reservoir was used during phase I of this research, it was decided to use a 0.90-m^3 (240-gallon) unit for this second phase. Knowing that the smaller reservoir was sufficient for only one cleaning cycle, it was felt that the benefit of multiple cleanings one after another far outweighed the additional cost and space requirement of the unit. The air reservoir was located next to the cleaning booth and hard-piped to the air spray manifold located inside the booth. Figure 1 shows the layout of the booth and the air reservoir.

The next main component of this system, the air spray manifold, was constantly modified and improved during various laboratory and field tests. During the approval process with MSHA during phase I, MSHA required that the manifold be designed for the average height of a US worker. The final design for the manifold is composed of

[1] Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

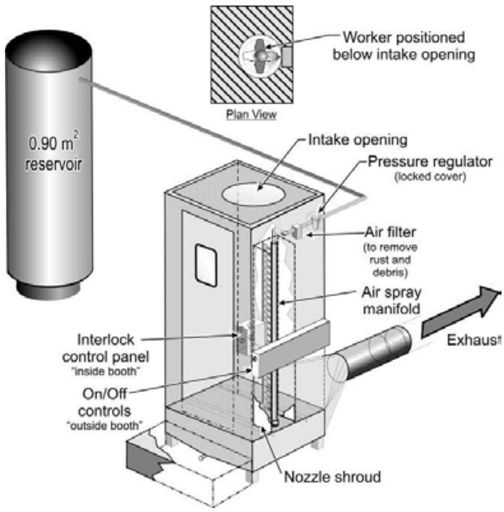

Figure 1. Clothes cleaning booth and air reservoir.

26 spray nozzles spaced at 5.1 cm (2 in) apart, as shown in Figure 2. These spray nozzles are designed to operate at 206.8 kPa (30 psi) and a regulator is used to ensure that the pressure is not exceeded. The top 25 spray nozzles are flat fan nozzles; the bottom nozzle is a circular design and was used for cleaning the individual's work boots.

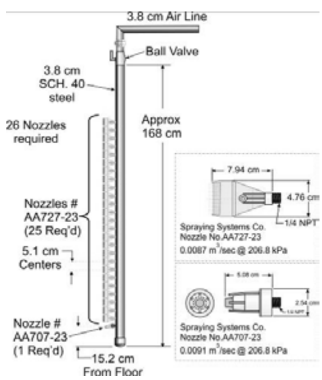

Figure 2. Air spray manifold design.

The fourth and final component is the exhaust ventilation system to keep the cleaning booth under negative pressure throughout the entire clothes cleaning process. As previously stated, the goal of the phase II effort was to design a stand-alone unit that would not need to be tied into an LEV system. After considering a number of different options, both Unimin and NIOSH believed that the optimal design would be to exhaust the dust-laden air from the cleaning booth to outside the plant where it would not contaminate other workers nor be entrained back into the plant. In the design stage of phase II of this research, Unimin's corporate engineering department evaluated all the requirements for the clothes cleaning process and the booth and determined that an exhaust volume of approximately 0.94 m^3/sec (2,000 cfm), at 20^o C and 101 kPa would be a targeted goal. It was believed that this exhaust volume would provide an adequate degree of safety to keep the booth under negative pressure at all times. During the testing of the system in August 2006, it was verified that 0.94 m^3/sec exhaust volume was adequate to maintain negative pressure throughout the entire clothes cleaning cycle.

3 Testing

3.1 Dust Sampling Instrumentation

Gravimetric dust sampling consisted of two sampling pumps, flexible Tygon tubing, the 10-mm Dorr-Oliver cyclone, and the dust filters. All dust samples were collected with the 10-mm cyclone, which classifies the respirable portion of dust. Each gravimetric sampler was calibrated to a flow rate of 1.7 L/min, the required flow rate established by the MSHA for the metal/nonmetal mining industry for respirable dust sampling. The respirable dust classified by the cyclone was deposited on a 37-mm dust filter cassette, which were pre- and post-weighed to the nearest 0.001 mg on a microbalance at the Pittsburgh Research Laboratory. For all sample locations except the one inside the PPE, the two gravimetric filter dust concentrations were averaged together to provide a single concentration for each location.

The instantaneous monitor used at all eight sample locations was the Personal Data RAM (pDR, Thermo Electron Corp , Franklin, MA). This is a real-time aerosol sampler that measures the respirable dust concentration based upon the light scatter of particles in an internal sensing chamber. The respirable dust levels were recorded on an internal data logger and were downloaded to a laptop computer at the end of each sampling period. Since the clothes cleaning process had such a short cleaning duration, the sample log time was set to every two seconds, which required the data to be downloaded every 4 hours. All of these instruments, except for the unit monitoring inside the respirator, were operated in the passive mode; for these instruments, the dust particles travel through the sampling chamber naturally without any mechanical assistance.

For measuring dust inside the respirator, the pDR instrument was operated in the active sampling mode. In this case, the air sample was mechanically pulled into the sensing chamber of the instrument and then deposited on a filter cassette, identical to that used with the gravimetric sampler. A new filter cassette was used for each sampling period.

The average gravimetric dust value at each sampling location was used to determine a correction factor for the pDR instantaneous dust monitor. This was performed by using the respirable dust concentration measured by the gravimetric samplers and determining the average respirable dust concentration for the pDR monitor for the exact sampling time period. A correction factor was then calculated by dividing the pDR average concentration value into the gravimetric value. This calculated correction factor was then multiplied by all the individual dust measurements taken with the pDR device in an Excel spreadsheet. Using both types of respirable dust monitoring equipment provided a good profile of the dust concentrations throughout the sampling period, as well as variations and changes in respirable dust concentrations during the evaluation of the clothes cleaning process.

3.2 Setup

Field testing was performed on phase II of this research effort during August 28-31, 2006. In order to validate a number of issues with the new system, a detailed test plan was established. This test plan was composed of eight different dust sampling locations in and around the clothes cleaning system. The following is a brief description of these various dust sampling locations.

The first sample location was to determine the respirable dust levels inside the half-mask respirator for both test subjects performing the clothes cleaning testing at this facility. Both of these test subjects were NIOSH employees and were fit-tested with their own North 7700 Silicone Half Mask Respirator prior to the field testing to ensure that the personal protective equipment (PPE) provided an acceptable level of protection (fit-factor). For the field tests, fit-testing adaptors were purchased from North and were used to determine respirable dust levels inside the face piece of the respirator during the clothes cleaning process. A special sampling chamber was also fabricated of clear Plexiglas and used for this testing. Tygon tubing connected from the respirator to this sampling chamber and was attached to the inside wall of the cleaning booth. A 10-mm Dorr-Oliver cyclone was located inside this sealed sampling chamber and was then connected to the pDR, also using Tygon tubing. Since the pDR instrument was being used in the active sampling mode, a sampling pump and filter were used to draw an air sample from inside the respirator to the sampling chamber, through the 10-mm cyclone, and finally into the pDR instrument (Figure 3). This allowed the respirable dust concentration inside the half-mask respirator to be determined and logged on the pDR's internal data logger during testing.

All of the remaining seven dust locations consisted of a pDR instantaneous dust monitor and two gravimetric sampling units on a sampling rack. The second dust sampling location was inside the clothes cleaning booth and was also attached to the wall. This provided the respirable dust concentration inside the cleaning booth during the clothes cleaning process, as well as a comparison to the respirable dust concentration inside the half-mask respirator for the two test subjects. The third dust sampling location was above the cleaning booth to

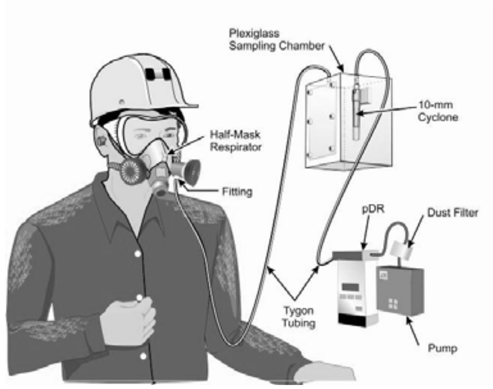

Figure 3. Sampling setup to obtain respirable dust sample inside half mask-respirator.

monitor the intake air flowing into the unit. This sample location could also detect leakage from the cleaning booth if the air spray manifold pressurized the booth to a degree that it caused respirable dust to be pushed out from the intake opening. The next three sample locations were positioned around the outside of the clothes cleaning booth to measure the potential of any dust leakage from the booth. These three sample locations were called: main right, main center, and main left. These locations were designated based on a person standing outside looking toward the booth.

The last two dust sampling locations were background A and B and were located inside an open garage door at the entrance to the bag loading mill area, as shown in Figure 4. After viewing the discharge duct for the exhaust fan, these two sample locations were chosen as the most likely locations where respirable dust could be re-entrained back into the mill building.

3.3 Weighing Procedures for Coveralls

As previously mentioned, two NIOSH test subjects were used for evaluating the clothes cleaning system. Both test subjects used their own sets of coveralls for the entire study which were a polyester-cotton blend material. The coveralls were manually soiled with dust by the researchers to a level which would be considered a worst case scenario. A detailed coverall weighing procedure was performed with the goal of quantifying the effectiveness of the clothes cleaning technique at removing dust soiled on the coveralls for both test subjects.

Through this pre- and post-weighing procedure, the amount of product added to the coverall was determined and the amount of product removed during the cleaning process was also calculated. This detailed weighing process was performed as accurately as possible to determine the amount of dust that was added to each coverall, and then the amount of dust removed by the air nozzles during the cleaning process in an effort to determine the system's effectiveness.

For each day of testing, all coveralls were laundered for a clean baseline measurement. Each pair of coveralls was used three times during the course of the day, and then laundered again for the next day of testing.

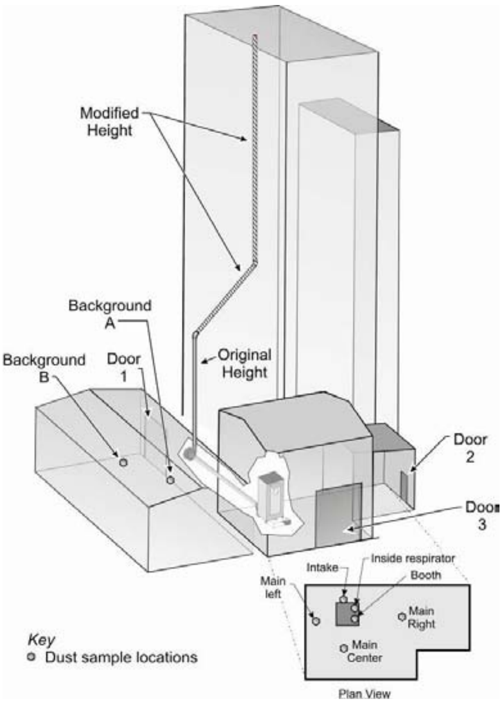

Figure 4 Dust sampling locations for testing and exhaust stack layout.

3.4 Test Plan

There were three areas of concern to be tested for this research effort: 1) ensure that test subjects were not over-exposed during the clothes cleaning process, 2) ensure that respirable dust was not escaping from the cleaning booth during the cleaning process, and 3) ensure that respirable dust being blown from the exhaust stack was not being entrained back into any buildings at the facility. All three of these areas were evaluated while performing clothes cleaning tests on the subjects in the cleaning booth. These tests were performed over a three-day period on August 28-31, 2006. The actual run time for each test was 18 seconds, being the time that the air spray manifold would be actuated with compressed air for the clothes cleaning process.

4 Results

There were 96 clothes cleaning tests performed during the study, 48 tests for each test subject. Table 1 provides the mean and standard deviation for the respirable dust concentration measured inside the respirator and inside the cleaning booth for the 18 seconds while the air spray manifold was activated during testing. This table also indicates an identical and extremely low respirable dust exposure inside the respirator for both test subjects. An interesting aspect to consider is the difference in respirable dust concentrations between the inside respirator and the inside cleaning booth location. This confirms the first objective of this research, which was to ensure that the test subjects were not over-exposed during the clothes cleaning process. When one compares the respirable dust concentrations inside the cleaning booth relative to those inside the respirators, it verifies that both test subjects remained at very low and acceptable dust levels for all tests.

Table 1. Mean and standard deviation of 18-second test for 48 tests for both test subjects.

	Inside Respirator	Inside Booth
Subject 1	0.01	752.33
Std Dev Sub 1	0.01	634.29
Subject 2	0.01	715.94
Std Dev Sub 2	0.02	609.92

It must be noted that the respirable dust concentration inside the cleaning booth exceeded the pDR instrument's range of detection (maximum of 400 mg/m^3). The values varied significantly from test to test as seen in the high standard deviation for both test subjects. Because of this, the dust concentration at the inside booth location should only be viewed as a relative value.

When considering the amount of dust added to the coveralls and the amount remaining after cleaning, the results of the 96 tests indicate that the system removed 83.1 pct of the dust on the worker's clothing during the cleaning process. Figure 5 shows the effectiveness of this cleaning process for one of the test subjects.

Table 2 presents the results for the other six sample locations. This table not only includes the 18 seconds for each clothes cleaning test, it also considers a time period of one minute after the test is completed. This should provide enough time to determine the impact of any dust leakage from the clothes cleaning booth or exhaust stack at the various sample locations. To verify the possibility of any impact, the results of this table, along with the individual traces of each of the tests (96) were examined to determine if any spikes occurred immediately following a clothes cleaning cycle. This was not the case from the first four locations evaluated, verifying that there was no respirable dust escaping from the cleaning booth.

The last area being evaluated was to ensure that respirable dust being blown from the exhaust stack of the cleaning booth was not being entrained back into any buildings at the test facility. From the traces of different

Figure 5. Before cleaning (top) and after cleaning (bottom) using clothes cleaning system.

Table 2. Mean and standard deviation of 18-second test and 1 minute afterward for 48 tests for both test subjects.

	Main Rgt	Main Cent	Main Left	Intake	Back A	Back B
Sub 1	0.02	0.01	0.02	0.01	0.60	0.17
StDev Sub 1	0.02	0.02	0.03	0.01	0.46	0.14
Sub 2	0.02	0.03	0.02	0.01	0.55	0.24
StDev Sub 2	0.02	0.03	0.04	0.01	0.45	0.19

pDR dust monitors, spikes shown at the inside booth location corresponded with spikes seen at the two background locations A and B. These background sample locations were inside a garage door to a packaging mill structure, which was the closest structure to the exhaust stack from the clothes cleaning system. The data in Table 2 for Background A and B also clearly demonstrates the problem. Once noting entrainment of dust back into a structure, it became necessary to redesign the exhaust stack.

After evaluating a number of different options, it was decided to extend the exhaust stack significantly higher in an effort to eliminate the entrainment of dust back into any structure. The original design had a 6.1-m (20- ft) section of vertical duct extending from the fan, as shown in Figure 4. After entrainment was found at the two background locations, the exhaust system was modified. A 45-degree elbow was connected to the end of the stack and then run over to a mill structure. Once reaching the structure, another 45-degree elbow was used to run 12.2 m (40 ft) vertically up the outside of the structure, and then discharge at the top of the structure. This modification extended the stack an additional 18.3 m (60 ft) in the air.

Testing of the new exhaust stack design was performed for three consecutive days being March 31 through April 2, 2007, in an effort to achieve different variations in weather and wind conditions for three consecutive days. For each day, four clothes cleaning cycles were performed over approximately a one-hour time period. In an effort to ensure that there was no entrainment into any structure, two additional sample locations were added for this testing (Doors 2 and 3, Figure 4). These twelve clothes cleaning tests did not indicate any increase in respirable dust at any of the sampling locations, Figure 6. Although there were fluctuations in respirable dust concentrations at all locations from day to day, there was no indication of elevated respirable dust concentrations immediately following a clothes cleaning cycle at any sample locations. This verifies that the redesign of the exhaust stack was effective and did not allow any entrainment of respirable dust back into any structures at this facility.

5 Conclusion

The clothes cleaning system designed in phase II of this research effort was a stand-alone system that proved to be very effective. One aspect that remained unchanged from the original design was the air spray manifold, which again was shown to be very effective at removing dust soiled on an individual's work clothes in a very short time period (18 seconds).

During phase I, this clothes cleaning system was shown to be much more effective than either the vacuuming or the single air hose method of cleaning soiled work clothes (Cecala et al., 2007). The cleaning booth was also redesigned during phase II to provide a more laminar flow which was also shown to be very effective. Field testing also showed that when the two test subjects were fit-tested with half-mask N-100 respirators, there was very minimal to no respirable dust exposure to the individual during the cleaning cycle.

The last area of this research effort was to ensure that the exhaust stack from the cleaning booth was not causing respirable dust to be entrained back into any of the structures at this facility. During the initial test, it was found that respirable dust was flowing through an open garage door into the packaging mill. After the exhaust stack was modified by extending it an additional 18.3 m in height, this situation was rectified.

Both Unimin and NIOSH believe that this clothes cleaning system significantly improves the health of workers by providing a quick and effective method for workers to clean dusty clothes during the workday without risk to worker safety. This phase II design should be applicable to any operation wishing to implement a clothes cleaning system. Although this system was originally designed to assist in meeting the stringent respirable dust standards for the silica sand industry, it would be applicable to all types of mining, as well as other industries.

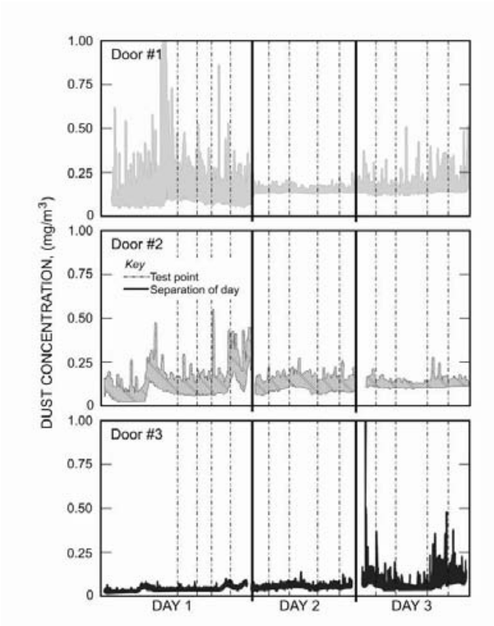

Figure 6. Dotted lines represent four clothes cleaning cycles for three test days to determine the possibility of recirculation of dust into any structures from the system's exhaust stack.

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