

## REDUCING RESPIRABLE DUST EXPOSURE OF WORKERS USING AN IMPROVED CLOTHES CLEANING PROCESS

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A quick, safe, and effective method has been developed that allows workers to clean their dust laden work clothing periodically throughout the day. For the mining industry, this technique is much more effective than the current federally approved method of using a vacuuming system. This newly designed method is relatively inexpensive and can be easily installed at any operation to allow workers to clean their clothing without contaminating the worker, the work environment, or co-workers to elevated respirable dust levels. This clothes cleaning process uses an air spray manifold to blow dust from a worker's clothing in an enclosed booth, which confines the dust for capture and removal by a baghouse dust collector. Since the air exhausted by the dust collector causes the booth to be under negative pressure, no measurable quantities of dust were ever measured escaping from the booth to contaminate the work environment and/or other workers. The worker performing the cleaning process is required to wear a half-mask fit-tested respirator with an N100 filter, hearing protection, and full seal goggles. Dust samples taken inside the respirator of test personnel performing the clothes cleaning process showed very minimal to no respirable dust. This clothes cleaning process was performed in less than 20 seconds and was significantly cleaner than either the federally approved method of vacuuming, or the most common method of using a single compressed air hose. It was also determined during this research that polyester-cotton blend coveralls clean more effectively than coveralls which are 100 percent cotton. The newly designed clothes cleaning process has potential application to any industry where workers' clothing becomes contaminated with most any type of dust or product.

**Key Words:** silica, respirable dust, work clothing, clothes cleaning, air spray manifold, cleaning booth

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## 1. Introduction

Health and safety specialists are constantly investigating new methods and techniques to lower respirable dust exposures to workers in the mining industry. When mining operations are processing products containing quartz or silica bearing material, minimizing workers' dust exposures is even more critical. The serious health hazard of silica dust has been known for many decades.<sup>1,2</sup> The 1997 ruling by the International Agency for Research on Cancer (IARC) which stated that inhaled crystalline silica from occupational sources is considered a (group 1) human carcinogen has further emphasized the importance of the silica health hazard.<sup>3</sup>

The silica health hazard has long been acknowledged by the federal regulatory agencies in that the Permissible Exposure Limit (PEL) and the Threshold Limit Value (TLV) are at much lower levels than for most other types of dusts. The current federal dust standard for the metal/non-metal mining industry is set at a level of 10 mg of total dust for the "nuisance" dust standard.<sup>4</sup> When silica is thought to be present, a respirable dust sample is analyzed using the X-ray diffraction technique to determine the percentage of silica. When more than 1 pct. silica is determined, a reduced Permissible Exposure Limit (PEL) standard is then implemented, which is based upon a 100 microgram silica level. Even at this level, the American Conference of Governmental Industrial Hygienists (ACGIH) and the National Institute of Occupational Safety and Health (NIOSH) are recommending that the crystalline silica level be further reduced to 0.05mg/m<sup>3</sup> or 50 micrograms.

Over the past few decades, a substantial amount of engineering technology has been developed to lower respirable dust exposures (silica) to workers at mineral processing plants. This control technology has addressed a vast array of different approaches and techniques to address the major dust contamination of equipment and procedures within these processing plants. Even though many of these dust control techniques have proven to be successful in lowering dust levels, many workers' exposures still exceed their PEL and health and safety specialists are continually investigating new and novel approaches to further reduce respirable dust exposures.

One area of known worker exposure throughout all industries is from contaminated work clothing.<sup>10-13</sup> For the minerals processing industry, a former U.S. Bureau of Mines report documented a number of workers that experienced a 10-fold increase in dust exposure over previous levels from an occurrence that significantly soiled the worker's clothing.<sup>14</sup> The respirable dust concentrations at the workers' lapel after these occurrences indicated that their Time Weighted Average (TWA) concentration would exceed the Permissible Exposure Limit (PEL) in two hours or less. As these individuals performed their work duties, dust was continuously emitted from their clothing and the only way to eliminate this dust source was to clean or change their work clothing. Contaminated work clothing is not only a hazard to the worker themselves, but a number of studies have also discussed the potential for taking the contaminant home and exposing family members.<sup>15-16</sup>

There are two federal regulations that affect the cleaning of clothes during the work

day for the United States mining industry. The first is a mining regulation established by the Mine Safety and Health Administration (MSHA) in 30 CFR Part 56.13020 which 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." A second regulation is a general industry standard established by the Occupational Safety and Health Administration (OSHA) in 29 CFR 1910.242(b), stating 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 this, the only current federally approved method to perform clothes cleaning for the U.S. 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 and time consuming task to perform. In addition, it is nearly impossible to effectively clean one's back without additional help from a co-worker. Because of this, few workers actually use this technique and prefer to use a single compressed air hose to blow dust from their work clothing, even though this a prohibited method of cleaning. Normally this is performed at pressures higher than 206.8 kPa (30 psi) in the open work area which not only exposes the worker, but also creates a significant dust cloud in the work environment, ultimately exposing co-workers. The goal of this research was to develop a safe, effective, and economical method for removing dust from work clothing. This research ultimately led to the design of the clothes cleaning process.

## 2. Methods

This section of the manuscript will be sub-divided into different areas to describe the work performed in this research effort. The first part describes the engineering design and equipment necessary for the newly developed clothes cleaning process. This is followed by the instrumentation and test setup used to evaluate the effectiveness of three cleaning techniques evaluated in this research effort, being: 1) the MSHA approved method of using a HEPA vacuuming system, 2) the most popular but prohibited method of using a single handheld compressed air nozzle, and 3) the newly developed clothes cleaning process using an air spray manifold in a cleaning booth. The next part details the weighing procedure used to evaluate and compare the cleaning effectiveness of the three cleaning methods. The last area describes the test plan and statistical methods used to analyze the results of testing in this research study.

### 2.1. Clothes cleaning system design

The clothes cleaning system consists of four major components: a cleaning booth, an air reservoir, an air spray manifold, and an exhaust ventilation system. The cleaning booth had a base dimension of 121.9 cm (48 in) by 106.7 cm (42 in) and provided the worker sufficient space to effectively perform any of the three clothes cleaning techniques (vacuum, air hose, and air spray manifold). A standard size door was located on the front that allowed entry and egress from the cleaning booth. Above the door was an open gra-

te that provided an intake for the ventilation airflow. This grate was 26.7 cm (10 1/2-in) high and ran the entire width of the enclosure. A return air plenum located on the very bottom-back wall of the booth was ducted to the baghouse dust collector system. Figure 1 indicates the specific dimensions for the booth used in this testing and the airflow pattern with the ventilating air coming in at the top front and exiting at the bottom back.

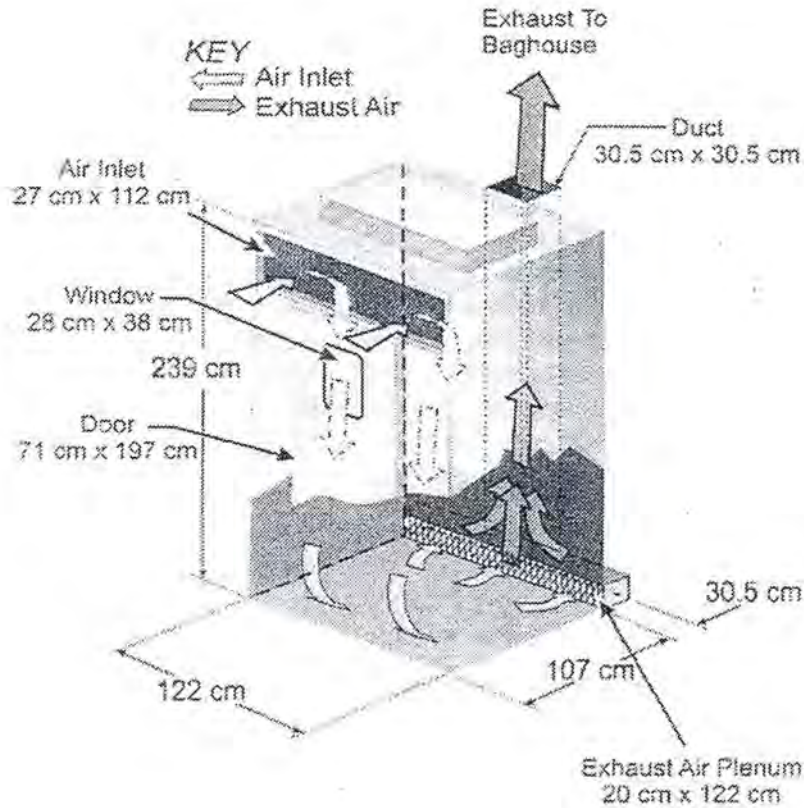


Fig. 1. Dimensions and airflow pattern for booth used for clothes cleaning process.

The second major component to this system was the air reservoir, which was necessary to supply the required air volume to the air nozzles used in the spray manifold. The size requirement for the air reservoir was calculated based upon the design of air spray manifold A with 18 air nozzles. To supply compressed air to these nozzles, a 0.45 m<sup>3</sup> (120-gallon) air reservoir tank was necessary. This reservoir tank held 38.1, 54.9, 71.3 m<sup>3</sup> (125, 180, and 234 ft<sup>3</sup>) of air at pressures of 689.5, 1034.2, 1379.0 kPa (100, 150, and 200 psi), respectively. This reservoir was pressurized by an existing compressor at the field test site grinding mill that was in-place to supply compressed air to a number of different mill applications. This air reservoir was typically pressurized to the 1034.2 kPa (150 psi) level but this could vary somewhat based upon what other applications were

being used within the grinding mill. The air reservoir was located directly behind the cleaning booth and hard piped to the air spray manifold located inside the booth.

For this report, only the final two air spray manifolds tested in this research effort will be presented, identified as air manifold A and B. Over the course of this research, the manifold was constantly modified and improved during various laboratory and field tests. In the early stages of development, the manifold was divided into different sections which significantly increased the cleaning time as each section was manually sequenced. The air spray nozzles were also spaced at greater distances creating areas of effective and ineffective clothes cleaning, illustrated by the stripes present on the coveralls. With each test, the air spray manifold was further improved and became more effective at cleaning a worker's soiled clothing. The final two designs of the air spray manifold were fabricated from 3.8 cm (1-1/2 in) schedule 40 steel pipe that was capped at the base. The air spray manifold was manually actuated by the worker performing the cleaning process by opening a ball valve located on the top of the manifold. For both manifold designs, the bottom nozzle was a circular design located 15.2 cm (6-in) from the floor. This nozzle was used in coordination with a ball-type adjustable fitting so as to be directed downwards to clean the individual's work shoes or boots. During a laboratory test, this circular design was shown to be more effective for cleaning at greater distances which was the case for using this nozzle to clean the individual's safety boots. In the first design (manifold A), there were 18 air nozzles spaced on 7.6 cm (3 in) centers (Figure 2). All of these air nozzles were the circular design, which required an air volume of 0.0091 m<sup>3</sup>/sec (19.2 ft<sup>3</sup>/min) at 206.8 kPa (30 psi).

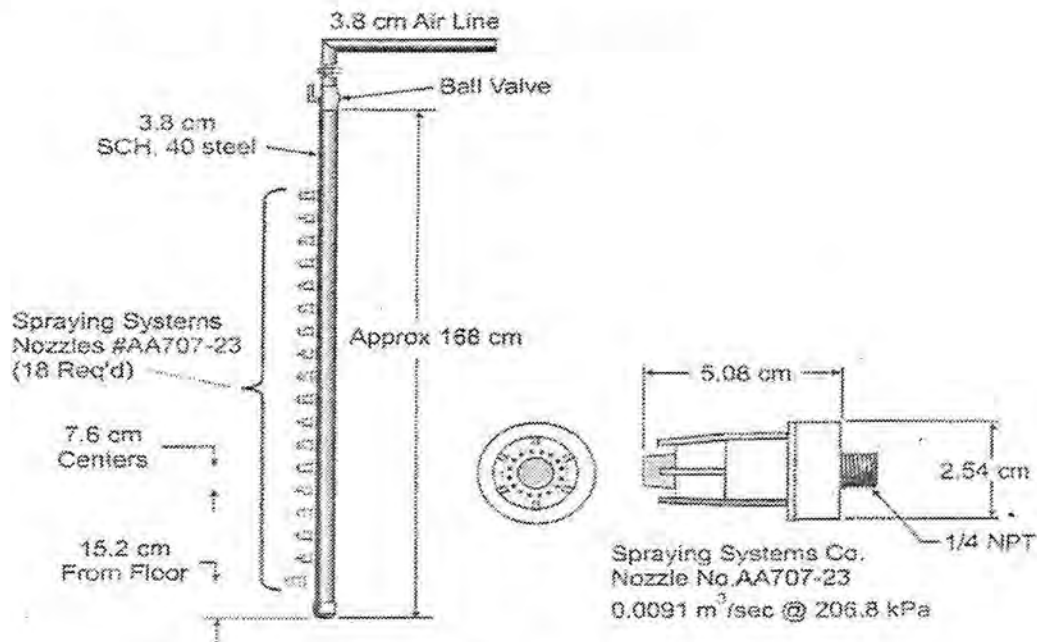


Fig. 2. Manifold A design with 18 air nozzles spaced on 7.6 cm centers.

After field test I which evaluated air spray manifold A, there continued to be some minor striping on the coveralls and another laboratory study was performed in an effort to completely eliminate this effect. Based upon the results of this testing, spray manifold B was designed which was composed of 27 spray nozzles spaced at 5.1 cm (2 in) apart, Figure 3. The bottom nozzle continued to be the circular design but the other 26 nozzles were flat-fan type sprays. During laboratory testing, these flat fan nozzles were shown to be more effective at the close cleaning distances that were found to be used during field testing. These 27 nozzles delivered slightly less than 0.24 m<sup>3</sup>/sec (500 ft<sup>3</sup>/min) of air.

Since the air reservoir holds 54.9 m<sup>3</sup> (180 ft<sup>3</sup>) of air at 1034.2 kPa (150 psi), the tank would be depleted in approximately 22 seconds. There would be a recharge time before the next individual could perform this clothes cleaning process which would be dependant on a company's air compressor capacity.

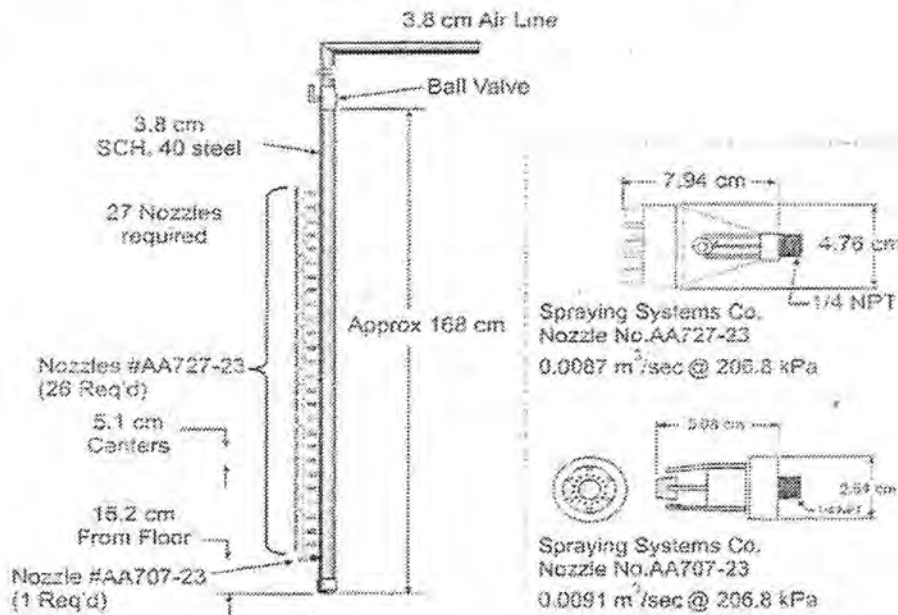


Fig. 3. Manifold B design with 27 air nozzles spaced on 5.1 cm centers.

It is critical that the cleaning booth be ventilated under negative pressure at all times so as to not allow any dust liberated during the clothes cleaning process to escape from the booth. During the research performed at the field test site, the plant had excess baghouse capacity that was used for the cleaning booth and far exceeded the requirements for this application. An exhaust air volume of 2.08 m<sup>3</sup>/sec (4,400 ft<sup>3</sup>/min) with a negative static pressure of 0.41 cm (0.16 in) H<sub>2</sub>O was consistently measured in the cleaning booth during this testing, which was more than sufficient to keep the booth under negative pressure during the air spray manifold cleaning process.

## *2.2. Test instrumentation*

Gravimetric dust sampling consisted of a sampling pump, flexible Tygon tubing, the 10-mm Dorr-Oliver cyclone, and a filter. 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 silica 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. The two gravimetric filters at each sample location were averaged together to provide an average respirable dust concentration for each location.

The instantaneous monitor used at all three sample locations was the MIE Inc. Personal Data RAM (PDR). This is a real-time aerosol sampler that measures the respirable dust concentration based upon the light scatter of particles drawn through an internal sensing chamber. The respirable dust levels were recorded on an internal datalogger 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 second and this required the data to be downloaded twice per day (lunch time and after shift). After the respirable dust traveled through the instrument, it was 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 was then divided by the PDR value to determine a correction factor. This value was then multiplied by all the individual measurements taken with the PDR device, which was then used to calculate the various average respirable dust concentrations during various segments during testing. Using both types of respirable dust monitoring equipment provided a good profile of the average dust concentrations throughout the sampling period, as well as variations and changes in respirable dust concentrations during the evaluation of the three different cleaning techniques.

## *2.3. Testing setup*

There were three dust sampling locations used for this research effort:

- Inside the half-mask respirator of the individual performing clothes cleaning
- Inside the cleaning booth
- Immediately outside the cleaning booth

The respirable dust exposure of the person performing the clothes cleaning testing was monitored inside the PPE (half-mask respirator) for all field studies. In the early stages of this research, a full-face shield helmet type powered air purifying respirator (PAPR) was used as the personal protective device (3M Positive Pressure Headgear L-700 series). A number of shortcomings were identified during this testing with the PAPR device. The most significant shortcoming was the dust laden air from within the

booth during the cleaning process was being forced into the helmet along the facial seal from the air spray manifold. Another problem with the helmet was that the adjustable head liner kept malfunctioning. Numerous replacements were tried but it appeared that the dust build-up on the ratcheting mechanism of the head liner caused it to malfunction. Because of the problems being encountered, an evaluation was performed during a preliminary test to compare respirable dust concentrations in the breathing zone of the PAPR helmet and the half-mask respirator with N100 filters, which had been fit tested for both test subjects. During this testing, the half-mask respirator proved to be superior from a dust standpoint and thus was the only respiratory personal protective device used for the remainder of the study and presented in this report. In addition, the half-mask respirator eliminated the other major concerns with the PAPR helmet with the most significant one being the health issue of multiple wearers using the same helmet.

Two different brands of half-mask respirators were used throughout the course of this research and both types provided very similar levels of performance. Both test subjects were fit-tested with both brands of half mask respirators using the TSI Porta-Count Method before any testing was performed. This Portacount method is a direct measurement using a portable condensation nuclei counter to determine the wearer's equivalent fit factor during dynamic moving and breathing exercises that are designed to stress the respirators seals in order to simulate anticipated work activity.<sup>17</sup> Both test subjects exceeded the required protection factor level of 100 during this respirator fit-testing. In addition, fit-testing adaptors were purchased from both respirator manufacturers and were used to determine respirable dust levels inside the face piece of the respirator during field testing of the three clothes cleaning methods. A special sampling chamber was also fabricated of clear plexiglass and used for this testing. Tygon tubing was connected from the barb fitting on the respirator to this sampling chamber which 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, Figure 4. Since the PDR instrument was being used in the active sampling mode, a sampling pump was 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. 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.

The second dust sampling location was inside the clothes cleaning booth. A sample rack was attached to the inside wall of the booth and was composed of two gravimetric sampling units and a PDR instantaneous dust sampling instrument.

The third dust sampling location was immediately outside the clothes cleaning booth and provided information as to any leakage or contamination from the booth to the outside mill. The outside sample location used the identical test setup as the inside booth location.

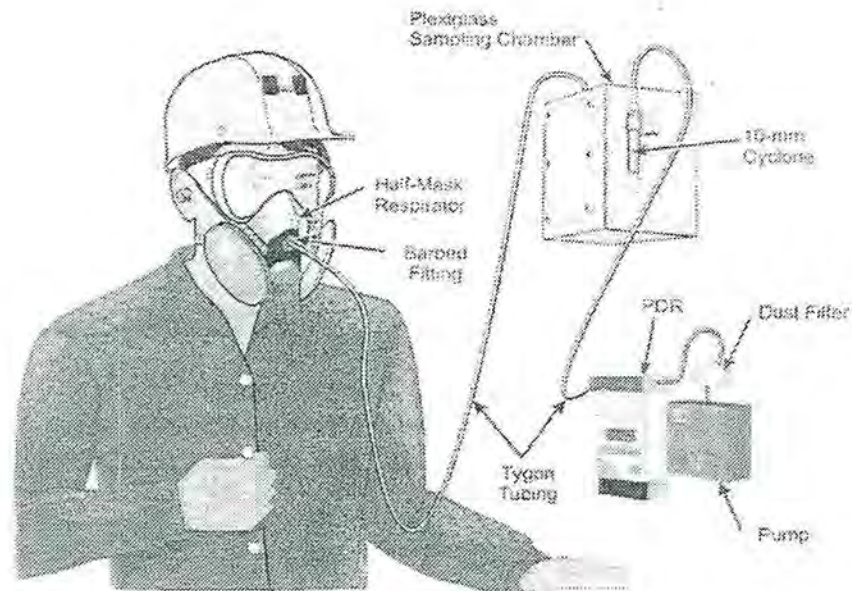


Fig. 4. Sampling setup to obtain respirable dust measurement inside 1/2-mask respirator.

#### 2.4. Weighing procedures for coveralls

The two most popular types of fabric material coveralls were evaluated in this research study: (100 per cent cotton and a polyester-cotton blend type (65 per cent polyester/35 per cent cotton)). The same two test subjects were used in both of the field tests presented in this report. In addition, each test subject used their own sets of coveralls for the entire series of tests. A very detailed coverall weighing procedure was performed with the goal of quantifying the effectiveness of each of the three cleaning methods at removing dust soiled on the two types of coveralls for both test subjects. This detailed weighing process is explained in Appendix A. For this process, it was necessary to account for the amount of dust that was lost when the coveralls were placed in plastic bags during the weighing process and the amount of dust that was lost when the test subjects were donning and removing the coveralls, before and after the cleaning process.

This detailed weighing process also provided the amount of product that was removed from each type of coverall during the evaluation of the three cleaning methods.

#### 2.5. Test plan

Results from the last two field tests performed in this research effort will be presented in this report. Test I was performed during April 28 – May 1, 2003 and evaluated all three cleaning methods. Air spray manifold A with eighteen air nozzles was evaluated in this first study. Both subjects performed testing using both coverall fabric types for the three cleaning methods. Table I shows the overall test sequence used in an effort to minimi-

ze test bias. Three runs completed one sequence. The coveralls were laundered after each sequence and it took three sequences to complete one test. By using this sampling protocol, each cleaning technique was evaluated in all three run positions after the coveralls were laundered. Obviously after the first run, the coveralls never returned to a completely clean status until after being laundered.

After field test 1 was completed, another laboratory study was performed in an attempt to completely eliminate the striping effect with the air spray manifold. Air spray manifold B was designed and field test 2 was performed November 18-19, 2003. There appeared to be no advantage to repeating the vacuuming and air hose tests, so only the air spray manifold B testing was performed. All of the coveralls used in this test were evaluated for three runs before being laundered (Table 1).

Table 1. Sample sequence of cleaning technique cleaning order to minimize test bias.

	Sequence #1	Sequence #2	Sequence #3
Run #1	Vacuuming	Air hose	Air manifold
Run #2	Air hose	Air manifold	Vacuuming
Run #3	Air manifold	Vacuuming	Air hose

### 2.6. Statistical analysis

A two-way analysis of variance (ANOVA) was performed on the amount of dust remaining on the coveralls after cleaning. The main effects were coverall material (cotton vs. polyester/cotton blend) and the cleaning techniques (vacuum, air hose, and air spray manifold). When a significant main effect was found for the cleaning technique, a test of pair wise comparisons for group means was performed to determine which means were significantly different from each other. Because the sample sizes were unequal, Tukey's Studentized Range Test for multiple comparisons was used. Before conducting the ANOVA, the distributional properties of the dependent variable were evaluated. It was noted that the distribution contained some outlying observations. Consequently, the analysis was done using both the untransformed and the log-transformed data. The results were identical; therefore, only the results for the untransformed data are reported.

An independent samples t-test was used to test for differences in the amount of dust remaining on the coveralls between air spray manifold design A and B. This subset of the data showed a deviation from normality; thus the analysis was again performed using both transformed and untransformed versions of the dependent variable. The conclusion was the same for each analysis. The results for the untransformed variable are reported. The statistical analysis was conducted using SAS (SAS Institute Inc., Cary, NC). Results were considered statistically significant if the p-value of the test was  $< .05$ .

### 3. Results

There were 96 coveralls analyses performed in field test 1 and 48 for field test 2. Figure 5 combines the results from both tests and indicates the amount of product remaining on the coveralls for each of the three cleaning techniques. Both coverall materials were

analyzed separately for all analyses performed in this report. This graph clearly shows that the newly designed clothes cleaning process using the air spray manifold was the most effective technique at removing the dust from both coverall types, followed by the vacuuming technique. The air hose was the least effective of the techniques for both types of coveralls.

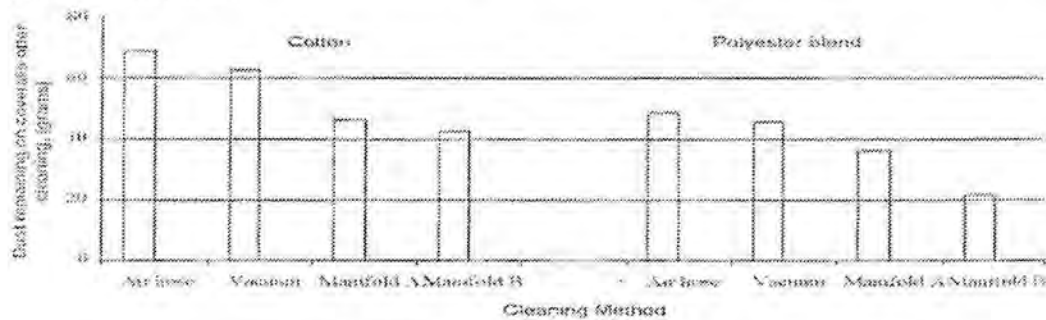


Fig. 5. Amount of dust remaining on coveralls from three clothes cleaning techniques with two coverall types.

The new clothes cleaning process was very efficient because all the worker needed to do was to slowly spin around in front of the air spray manifold. With the nozzles spaced on 5.1 cm (2 in) centers for manifold B, visually there appeared to be very effective cleaning for all areas of the worker's clothing. Two areas that took some special attention were cleaning the inside of the arms and legs. Once an individual was able to quickly learn a simple technique to clean these areas, the entire process was very brief and simple to perform.

This was not the case for the other two techniques. Both the vacuuming and single compressed air hose techniques were very arduous for the individual performing the clothes cleaning technique. For vacuuming, the suction hose was manually moved by the test subject in an attempt to suck the dust from their clothing. The fabric material was continuously being sucked into the nozzle causing it to stick. The test subjects would then pull the nozzle from the clothing and move it to another area, which would again cause the nozzle to stick. This cycle was repeated until the cleaning task was completed. The cleaning technique with the single air hose was basically the same process except that the air nozzle never became attached to the fabric material. Frustration and fatigue levels were definitely significant factors with both individuals performing these two clothes cleaning techniques.

Another factor that impacted both the vacuuming and air hose techniques was the inability of the worker's to clean the back portions of their legs and back since it is impossible to visually determine how effective one is performing the process in these areas. Another issue for the vast majority of individuals is that it is physically impossible to effectively clean these areas. Figure 6 indicates the cleaning effectiveness for the back of one of the test subjects for all three cleaning techniques. These photos show the limitations to cleaning various areas with the vacuum or single air hose technique, while also indicating the effectiveness with the air spray manifold device.



*Fig. 6. Cleaning effectiveness (left to right): uncleaned coveralls, vacuuming, air hose.*



*Fig. 6. Con't. Cleaning effectiveness (left to right): air spray manifold A, air spray manifold B.*

Another factor clearly identified in Figure 5 is that the polyester-cotton blend coveralls cleaned more effectively than the 100 pct cotton coveralls for all three cleaning techniques. No attempt was made to look at the physical or chemical properties of the two fabrics but obviously the polyester/cotton material provided a much easier release of the dust particles whether being vacuumed or blown from the fabric using either the single air hose or the air spray manifold system. This fabric cleaning factor definitely needs to be considered when the clothes cleaning process starts to be implemented at work sites. Obviously, it is far more advantageous to have workers wear coveralls that dust may not as easily adhere to and that clean more effectively than other types that do not.

The average corrected respirable dust concentrations recorded by the PDR dust instruments at the three sample locations for each test sequence are shown in Table 2. All the odd number tests in this table correspond to testing performed by test subject #1, the even number tests correspond to those performed by test subject #2. This data supports a number of different significant areas of this research. One area is the effectiveness of containing all the dust generated during the clothes cleaning process to inside of the booth. For all tests, and more specifically for the air spray manifolds tests, the outside booth respirable dust concentration remained at, or near zero for the vast majority of sampling sequences. For those cases when dust was recorded, the dust sampling instrumentation was detecting dust that was believed to be generated in other areas of the mill and then drawn over the sampling location as it was pulled into the cleaning booth.

The inside booth sample location showed very low dust levels during the vacuuming testing, moderate levels during the air hose testing, and higher respirable dust levels during the air spray manifold testing. These results coincide exactly with what would be expected. These expected values even hold true

Table 2. Average corrected respirable dust levels at three sample locations.

<sup>a</sup> Denotes sample taken inside Personal Protective Device (1/2-mask respirator)

Vacuum					Air Hose				
Test#	Coverall# Type	Outside Booth, mg/m <sup>3</sup>	Inside Booth, mg/m <sup>3</sup>	Inside PPD <sup>a</sup> mg/m <sup>3</sup>	Test#	Coverall# Type	Outside Booth, mg/m <sup>3</sup>	Inside Booth, mg/m <sup>3</sup>	Inside PPD <sup>a</sup> mg/m <sup>3</sup>
1	1/Cot	0.00	0.00	0.00	1	3/Cot	0.00	0.01	0.00
2	2/Cot	0.00	0.00	0.00	2	6/Cot	0.00	0.01	0.00
3	3/Poly	0.00	0.00	0.00	3	7/Poly	0.00	0.01	0.00
4	4/Poly	0.00	0.00	0.00	4	8/Poly	0.00	0.01	0.00
5	5/Cot	0.00	0.00	0.00	5	5/Cot	0.00	0.42	0.00
6	6/Cot	0.00	0.00	0.00	6	6/Cot	0.00	0.88	0.00
7	7/Poly	0.00	0.01	0.00	7	7/Poly	0.00	0.27	0.00
8	8/Poly	0.00	0.00	0.00	8	8/Poly	0.00	1.02	0.00
9	1/Cot	0.00	0.02	0.00	9	1/Cot	0.01	0.50	0.00
10	2/Cot	0.03	0.04	0.00	10	2/Cot	0.01	1.92	0.00
11	3/Poly	0.05	0.04	0.00	11	3/Poly	0.04	0.60	1.43
12	4/Poly	0.05	0.04	0.00	12	4/Poly	0.01	1.08	0.19
13	1/Cot	0.01	0.00	0.00	13	1/Cot	0.00	0.24	0.00
14	2/Cot	0.00	0.00	0.00	14	2/Cot	0.01	0.70	0.00
15	3/Poly	0.02	0.01	0.00	15	3/Poly	0.02	0.46	0.00
16	4/Poly	0.00	0.00	0.00	16	4/Poly	0.03	0.38	0.00
17	5/Cot	0.00	0.00	0.00	17	5/Cot	0.00	1.09	0.00
18	6/Cot	0.00	0.01	0.00	18	6/Cot	1.00	1.19	0.00
19	7/Poly	0.00	0.01	0.00	19	7/Poly	0.00	1.32	0.00
20	8/Poly	0.00	0.00	0.00	20	8/Poly	0.00	0.86	0.00
21	5/Cot	0.00	0.01	0.00	21	5/Cot	0.00	1.54	0.00
22	6/Cot	0.00	0.00	0.00	22	6/Cot	0.10	2.12	0.00
23	7/Poly	0.00	0.00	0.00	23	7/Poly	0.00	0.38	0.00
24	8/Poly	0.62	0.03	0.00	24	8/Poly	0.00	0.49	0.00
Average dust		0.03	0.01	0.00	Average dust		0.05	0.74	0.07

Table 2. Cont'd. Average corrected respirable dust levels at three sample locations.

\* Denotes sample taken inside Personal Protective Device (H2-mask respirator)

Manifold A					Manifold B				
Test#	Coveralls/Type	Outside Booth, mg/m <sup>3</sup>	Inside Booth, mg/m <sup>3</sup>	Inside PPD <sup>a</sup> , mg/m <sup>3</sup>	Test#	Coveralls/Type	Outside Booth, mg/m <sup>3</sup>	Inside Booth, mg/m <sup>3</sup>	Inside PPD <sup>a</sup> , mg/m <sup>3</sup>
1	1/Cot	0.00	0.09	0.00	1	1/Cot	NA	NA	NA
2	2/Cot	0.00	0.19	0.00	2	2/Cot	0.00	32.33	0.11
3	3/Poly	0.00	0.09	0.00	3	3/Poly	0.00	46.05	0.05
4	4/Poly	0.00	0.17	0.00	4	4/Poly	0.00	52.43	0.01
5	5/Cot	0.00	10.13	0.00	5	5/Cot	0.00	71.75	0.07
6	6/Cot	0.00	8.91	0.52	6	6/Cot	15.78	95.44	0.03
7	7/Poly	0.00	5.56	0.00	7	7/Poly	0.00	96.54	0.02
8	8/Poly	0.00	13.17	1.63	8	8/Poly	0.00	77.01	0.05
9	1/Cot	0.00	9.46	0.00	9	9/Poly	0.00	51.03	0.00
10	2/Cot	0.00	13.94	0.52	10	10/Poly	0.00	106.75	0.10
11	3/Poly	0.03	7.14	0.00	11	11/Poly	0.00	60.13	0.02
12	4/Poly	0.05	5.58	0.00	12	12/Poly	0.00	83.08	0.03
13	9/Poly	0.00	10.94	0.04	13	1/Cot	0.00	31.19	0.25
14	10/Poly	0.28	14.70	0.00	14	2/Cot	0.00	89.94	0.07
15	11/Poly	0.00	17.45	0.00	15	3/Poly	0.00	25.12	0.08
16	12/Poly	0.00	7.31	0.00	16	4/Poly	0.00	61.05	0.05
17	9/Poly	0.00	9.80	0.00	17	5/Cot	0.00	46.74	0.03
18	10/Poly	0.02	10.23	0.00	18	6/Cot	4.65	19.37	0.01
19	11/Poly	0.00	11.98	0.00	19	7/Poly	0.00	21.40	0.03
20	12/Poly	0.06	13.19	0.06	20	8/Poly	0.00	17.39	0.03
21	9/Poly	0.03	13.52	0.00	21	9/Poly	2.06	50.24	0.03
22	10/Poly	0.09	14.09	0.00	22	10/Poly	0.00	26.10	0.04
23	11/Poly	0.03	10.19	0.00	23	11/Poly	0.00	38.55	0.04
24	12/Poly	0.27	8.32	0.00	24	12/Poly	0.00	57.27	0.03
25	1/Cot	0.00	16.30	0.00	25	1/Cot	0.01	41.06	0.23
26	2/Cot	0.00	15.65	0.00	26	2/Cot	0.01	54.06	0.00
27	3/Poly	0.00	10.01	0.00	27	3/Poly	0.01	39.93	0.00
28	4/Poly	0.00	12.77	0.03	28	4/Poly	0.01	38.14	0.03
29	9/Poly	0.00	6.84	0.00	29	5/Cot	0.01	47.19	0.00
30	10/Poly	0.00	12.78	0.21	30	6/Cot	0.00	63.57	0.00
31	11/Poly	0.00	10.21	0.00	31	7/Poly	0.01	39.86	0.01
32	12/Poly	0.00	17.04	0.17	32	8/Poly	0.00	23.19	0.00
33	9/Poly	0.00	9.88	0.00	33	9/Poly	0.01	41.78	0.00
34	10/Poly	0.14	9.16	0.03	34	10/Poly	0.04	42.12	0.00
35	11/Poly	0.00	10.01	0.00	35	11/Poly	0.01	26.90	0.00
36	12/Poly	0.00	13.86	0.00	36	12/Poly	0.01	53.61	0.03
37	5/Cot	0.00	16.51	0.21	37	1/Cot	0.01	43.70	0.00
38	6/Cot	0.25	12.42	0.00	38	2/Cot	0.02	92.63	0.01
39	7/Poly	0.07	10.06	0.00	39	3/Poly	0.01	30.55	0.00
40	8/Poly	0.02	6.59	0.00	40	4/Poly	0.01	36.03	0.00
41	9/Poly	0.00	5.20	0.00	41	5/Cot	0.02	35.47	0.03
42	10/Poly	0.00	21.53	0.23	42	6/Cot	0.04	105.90	0.00
43	11/Poly	0.00	15.56	0.00	43	7/Poly	0.01	20.99	0.00
44	12/Poly	0.00	12.53	0.00	44	8/Poly	0.02	36.14	0.00
45	5/Cot	0.00	14.93	0.00	45	9/Poly	0.01	44.25	0.00
46	6/Cot	0.00	14.67	0.00	46	10/Poly	0.01	24.37	0.00
47	7/Poly	0.00	8.38	0.00	47	11/Poly	0.01	30.63	0.00
48	8/Poly	0.00	8.66	0.00	48	12/Poly	0.02	37.02	0.03
Average dust		0.05	10.67	0.08	Average dust		0.49	50.47	0.03

When considering the increase in respirable dust levels when manifold B is compared to manifold A. Since manifold B has 27 air nozzles compared to 18 for manifold A, the dust will be blown from the coveralls much faster, increasing airborne respirable dust levels. Dust levels will be higher but the total cleaning duration is shorter.

Last, probably the most important area is the respirable dust levels inside the half-mask respirator of the test subjects. For the vacuuming system, respirable dust levels remained at zero for all test sequences. Except for four sequences with the air hose, levels also remained at zero. With the air spray manifold systems, over half of all test sequences also remained at zero respirable dust. The highest average respirable dust level recorded for the 96 sequences was  $0.52 \text{ mg/m}^3$ , although this was obviously not typical since the average for all sequences was  $0.03$  and  $0.02 \text{ mg/m}^3$  for manifold A and B, respectively. Again, it must be remembered that this is for an extremely short duration. Since the instantaneous PDR dust monitors were recording respirable dust concentrations every second, the extent of the dust cloud from the air spray manifold cleaning process within the booth usually lasted for less than 30 seconds. Based upon the recorded respirable dust concentrations measured inside the respirator and the length of this exposure, the results indicate the level of safety provided to the individual performing the clothes cleaning process with the newly developed system. In addition, there were very comparable results for both test subjects during all aspects of this testing.

A stop watch was used to record the cleaning time for each cleaning technique. Table 3 shows the average cleaning time for the three cleaning techniques evaluated in this study. Cleaning times are presented for both manifold A & B since the time was reduced with the additional air spray nozzles of manifold B. Times are also presented separately for the two coverall types because there were some minor differences between the two. This occurred because the cotton coveralls were not cleaned as easily and the test subjects spent more time in the cleaning process. Obviously, the test subjects manually performed the cleaning process using both the vacuuming and air hose techniques and the actual cleaning time was dependent on such factors as the individual's energy level, cleaning quickness, flexibility, size, fatigue, and their perceived level of cleaning. For the air spray manifold device, the test subject's ability to vary the cleaning time was limited because all the subject had to do was to spin around in front of the air spray manifold. The air spray manifold was by far the quickest method available for cleaning the work clothes.

Table 3. Average cleaning time and range for three clothes cleaning techniques.

Technique	Cleaning Time, (seconds)			
	Cotton		Polyester Blend	
	Average Time	Range	Average Time	Range
Vacuum	393	358-427	349	302-393
Air Hose	183	160-199	173	130-193
Manifold A	25	21-28	27	21-33
Manifold B	17	16-18	16	15-17

### 3.1. Statistical data analysis

The data collected during the two field tests were statistically analyzed to determine the effectiveness of the three clothes cleaning techniques and also to compare the coverall fabric materials. The amount of dust remaining on the coveralls after cleaning was analyzed with a 2 X 3 ANOVA, with coverall material and cleaning process as the independent variables. Summary statistics are presented in Table 4. The results of the ANOVA are shown in Table 5. The main effect for coverall material and the main effect for cleaning process were both statistically significant; the interaction effect was not. It was found that the polyester/cotton fabric material cleaned more effectively, or held less dust after cleaning than the pure cotton material. Subsequent to the ANOVA, Tukey's test was used to make all comparisons between the means of the different cleaning processes. Significant differences were found between the air spray manifold and air hose, and between the air spray manifold and vacuum. No difference was found when the air hose and vacuum processes were compared.

Table 4. Means and Standard Deviations for dust remaining on coveralls (grams) by material and cleaning process for Test 1.

Material	Process	n	Mean	SD
Cotton	Airhose	12	68.78	28.09
Cotton	Manifold A	12	46.24	12.53
Cotton	Vacuum	12	63.11	14.86
Polyester	Airhose	12	48.41	17.67
Polyester	Manifold A	36	36.17	12.04
Polyester	Vacuum	12	45.49	8.88

Table 5. Analysis of Variance (ANOVA) for amount of dust remaining on coveralls (grams) after cleaning for Test 1.

Source	df	Sum of squares	Mean square	F	p-value
Material	1	5199.91	5199.91	21.13	<.0001
Process	2	5000.71	2500.36	10.16	.0001
Material X Process	2	432.22	216.11	0.88	ns
Error	90	22148.67	246.10		

Because the manifold was significantly modified between the first and second field tests, the two different air spray manifold designs (A & B) were compared using a t-test. The cleaning effectiveness of air spray manifold B was significantly higher when compared to air spray manifold A. These results are shown in Table 6.

Table 6. Means, Standard Deviations, and t-value for amount of dust remaining on coveralls (grams) with Manifold A and B.

Manifold	N	Mean	SD	t	p-value
A	48	38.69	12.77	3.50	.0007
B	48	29.69	12.40		

In summary, significant differences were determined for the clothes cleaning process using the air spray manifold when compared to either vacuum or air hose techniques. In addition, a statistically significant difference was found when comparing the amount of dust removed by manifold B versus manifold A. Lastly, the polyester/cotton blend type coveralls across all cleaning techniques were significantly cleaner than the 100 pct cotton type.

#### 4. Discussion

It must be noted that the dust sampling location inside the half-mask respirator does not meet MSHA's compliance dust sampling regulations, in which the dust sample would be located on the individual's lapel. Because of this, when a compliance dust sample would be taken, the air spray manifold with the numerous air nozzles blowing dust from the workers clothing increases respirable dust levels in the cleaning booth and this would cause the worker's lapel dust sample to also increase. This increase would be proportional to the time and magnitude of the dust concentration inside the cleaning booth during the clothes cleaning process. Even with this increase, it is still far more advantageous to perform the clothes cleaning process using the air spray manifold than to allow the individual to continue to work with contaminated work clothing. Contaminated work clothing is a constant source of respirable dust to the worker throughout the workday. To create a short duration of increased worker respirable dust exposure during the clothes cleaning process is still much more advantageous than allowing the worker to be continually exposed from contaminated work clothes. For this testing, the respirable dust concentration inside the booth would represent the worker's exposure during the clothes cleaning process. Since this clothes cleaning process averaged approximately 18 seconds with air spray manifold B, the exposure would be for a very short duration. In terms of true exposure to the worker, since the worker is required to wear a fit-tested half mask respirator, very minimal exposure levels were recorded even during the actual cleaning process.

Another factor identified during testing was that the coveralls should only be cleaned a limited number of times before being laundered. The clothes cleaning process needs to be viewed as an interim method to be used during the workday and not as a replacement for laundering. This was most evident for coveralls with zippers, which became more difficult to use after being soiled a number of times. It should be noted though that the level of soiling for this testing was at a worst case scenario level and coveralls would rarely, if ever be soiled to this degree in an actual work situation.

During one of the field studies performed in this research effort, a dosimeter was used to determine sound level measurements associated with this clothes cleaning process. Since this installation was in a grinding mill, background sound levels were measured to be around 91 dB. Sound levels inside the booth were approximately 87 dB without the air spray manifold in use and 101 dB when used. Because of these sound levels, hearing protection was required at this operation for anyone performing the clothes cleaning process.

#### 4.1. Design modifications

With the final air spray manifold design (B), the flat fan nozzle design extends 7.9 cm (3-1/8 in) from the supply pipe and could easily be broken off if struck forcefully. Because of this, it is recommended that side barriers be installed to protect the air nozzles. During field testing, 2.54 cm (1 in) wood sheeting was used along both sides of the nozzles, providing an effective barrier to minimize the potential for nozzle damage.

The air spray manifold was designed for a person 1.8 m (6 ft) in height. Taller workers will have to stoop and drop their shoulders to effectively clean their upper body. When a person is shorter, the top air nozzles can be covered with deflectors to prevent the air sprays from directly hitting the individual's face. During the final field test, the top four nozzles were modified with deflectors attached to the side barriers fabricated from 10.2 cm (4 in) pipe that was cut in half and then into 5.1 cm (2 in) wide strips. Latches were attached on both sides of these deflectors so they could be locked in either the open or closed position, which can be seen in Figure 7.

It should be noted that the air spray manifold can be modified to account for height characteristics of workers at individual operations. Additional air nozzles could be added for taller workers; likewise, as many deflectors as necessary could be added to make the system applicable to the shortest individual working at a particular operation. If additional air nozzles are added or if an operation anticipates that workers will be using the clothes cleaning process one after another, a larger air receiver tank size of 0.91 m<sup>3</sup> (240 gallons) would be required to provide adequate cleaning time.

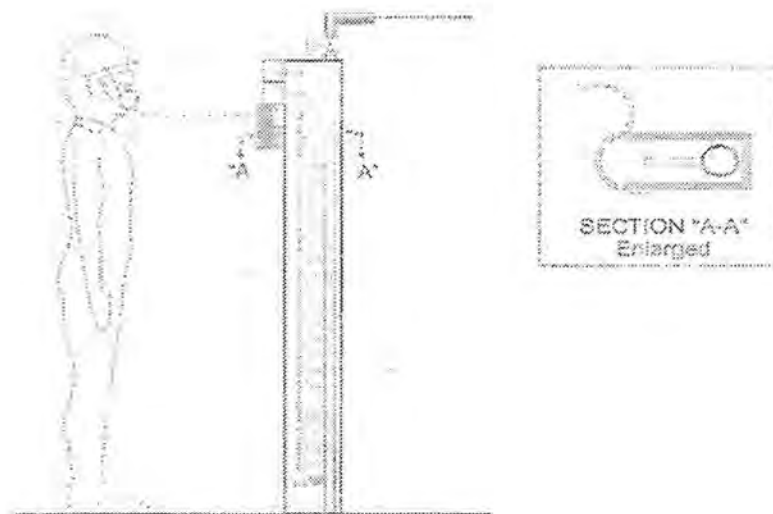


Fig. 7. Deflector device to shield face from air spray nozzle for shorter individuals.

## 4.2. Cost

A primary concern regarding any type of new technology is the cost of implementation. The following is an approximate cost for the various components necessary for the clothes cleaning process: cleaning booth: ~ \$1500- \$2000; air nozzles for spray manifold: ~ \$400; 0.45 m<sup>3</sup> (120-gallon) air reservoir tank: ~ \$600, or 0.91 m<sup>3</sup> (240-gallon) air reservoir tank ~ \$850; 3.8 cm (1.5 in) regulator: ~\$150; Fittings/pipe/misc. supplies: ~\$200. The cost of the unit should be in the \$2,800 to \$3,400 range, excluding the cost for the exhaust volume of air and duct work cost. At the field test site, an excess exhaust volume was available and used for this system. Most operations will not have this luxury and this detail will have to be built into the cost.

One modification that is being considered for operations without excess baghouse capacity is to utilize an exhaust fan to blow the dust-laden air up a stack to the outside of the facility. Since the amount of dust removed from a worker's clothing will be relatively minor in relation to the amount of air necessary to place the booth under negative pressure, the respirable dust concentration of air coming out of this stack most likely would be insignificant. Additional testing is being planned to verify if this is a viable alternative.

## 5. Conclusion

In an effort to further reduce dust and silica exposure to workers at mineral processing operations, a clothes cleaning process was recently developed. This process has been demonstrated to be a much more effective method to remove dust from a worker's clothing than methods currently used by workers. This process uses a compressed air nozzle manifold to blow dust from the worker's clothing in an enclosed booth. The booth confines the dust which is then captured by a baghouse dust collector. The clothes cleaning technique developed under this research effort was by far the most efficient method for cleaning soiled work clothing of the three methods tested. Since the air exhausted by the dust collector causes the booth to be under negative pressure, no dust escapes to contaminate the work environment or other workers.

The worker performing this cleaning process is required to wear a half-mask fit-tested respirator with an N100 filter, hearing protection, and full seal goggles. Respirable dust samples taken inside the respirator of the test personnel performing this clothes cleaning process showed minimal to no respirable dust exposure. In more than half of the 48 tests performed on air spray manifold B, the test subjects respirable dust concentration remained at 0.00 mg/m<sup>3</sup> inside the half-mask respirator. In the remainder of the tests, the value remained very low with an over-all average of 0.02 mg/m<sup>3</sup> for the entire test group.

A matrix of tests were performed during a field analysis at an operating mineral processing plant which showed that the clothes cleaning process was 40.8 pct. more effective than using the federally approved method of vacuuming and 50.6 pct. than the

commonly used method of using a single compressed air hose. The clothes cleaning process was also superior in its ability to uniformly remove dust from all areas of the coveralls used for testing.

Another factor that was considered during this study was the difference in cleaning effectiveness based upon two different coverall fabrics. This testing confirmed that there was a significant improvement with the cleaning effectiveness of the polyester/cotton blend coveralls when compared to the pure cotton type. This needs to be considered by operations considering implementing this new clothes cleaning process.

Another major benefit was that the complete cleaning process was performed in a fraction of the time. The average cleaning times were as follows: vacuuming: 317 seconds; air hose: 178 seconds; clothes cleaning process: 18 seconds.

This clothes cleaning process provides workers a quick, safe, and effective method to clean their dust laden work clothing periodically throughout the work day. It is relatively in-expensive and can be easily installed at any operation, allowing workers to clean their clothing without contaminating themselves or their co-workers. Although this process was designed for workers in the mining industry, it is applicable to any industry where contaminated work clothes are a problem.

## Appendix A

### Detailed description of coverall weighing process

In preparation for the tests, opaque lightweight plastic bags were sequentially numbered for both pre and post use. Two 1.2 m (4 ft) by 1.2 m (4 ft) pieces of colored plastic brattice were identically numbered and the coveralls being used by each test subject were also numbered. A 22.9 cm (9 in) by 33 cm (13 in) aluminum pan was then placed on an electronic scale and tared to zero. Each empty plastic bag and both clean pieces of brattice were then weighed separately and recorded. Each clean coverall was then inserted into one of the pre bags, re-weighed and this weight was recorded. The coveralls were then taken outside and soiled with limestone – rock dust. Since the test facility processed silica sand, it was decided to use crushed limestone (rock dust) as the clothes soiling contaminant, to lower the test personnel's exposure to silica during testing. Since crushed limestone has a similar size to the milled silica, it closely mimics the results for the silica dust. The soiled coveralls were put back into the pre-bag and then again re-weighed. While standing on a piece of pre-weighed brattice cloth, the test subject removed the coveralls from the plastic bag and put the coveralls on over this piece of brattice cloth. The empty plastic bag and brattice cloth containing product that fell off while donning the coveralls were then re-weighed and recorded. After one of the three cleaning methods was completed, the tester removed the coveralls while standing on a different piece of brattice cloth that was also pre-weighed. These coveralls were then placed into another pre-weighed plastic bag. The cleaned coveralls/bag and the post brattice cloth were then re-weighed to account for any product that fell while removing the

coveralls and placing them in the post plastic bag. 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 allowed for a cleaning effectiveness to be calculated for each of the three cleaning methods.

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