Attachment D.1

Exponent®

Public Comments on MSHA's Proposed Rule: Lowering Miner's Exposure to Respirable Coal Mine Dust, Including Continuous Personal Dust Monitors

RIN 1219-AB64

Laboratory Testing of Continuous Personal Dust Monitor (CPDM)

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Exponent

Public Comments MSHA's Proposed Rule: Lowering Miners' Exposure to Respirable Coal Mine Dust, Including Continuous Personal Dust Monitors
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Laboratory Testing of Continuous Personal Dust Monitor (CPDM)

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Attachment A E-Labs Environmental Test Report No. 2341-B (2011)
Talcum Powder Specification Sheet
Forensic Analytical Laboratory Report (2011)

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Executive Summary

Concerns have been raised about the reliability of the CPDM within underground coal-mine conditions, particularly in underground mining areas with elevated temperature and humidity levels. Although previous in-mine testing had been conducted, temperature and humidity levels were not reported (NIOSH 2006). To evaluate the CPDM performance, a variety of tests were developed to determine whether the CPDM units would perform reliably under a variety of physical and environmental conditions. The purpose of the testing was to determine whether the CPDM units produce reproducible data that are comparable to other monitoring devices under a range of environmental conditions that are found in underground mines.

Exponent identified a laboratory in Fredericksburg, Virginia (E-Labs, Inc.), that was available to provide the necessary equipment and technical expertise in testing electronic equipment. This laboratory has extensive experience performing military-specification testing for the government and major industries. Exponent consulted with mine personnel and worked with the laboratory to determine the types of tests to be conducted. Five types of tests were identified: 1) settling dust (talcum) tests under controlled temperature and humidity levels, 2) temperature and humidity tests without dust, 3) drop tests, 4) shock tests, and 5) electromagnetic interference tests. These tests were conducted at the laboratory facility under the supervision of Exponent personnel. Failures of the CPDM were classified as either self-reported errors by the CPDM unit based on the testing of its internal components, unusual airborne concentrations reported by a CPDM unit in a known, controlled environment or an excess variation of concentrations among multiple CPDM units under similar environments.

Prior to the laboratory tests, a series of ambient air tests were conducted in an office environment. The three CPDM units reported similar airborne concentrations at these normal temperature and humidity levels. At the laboratory, the first series of tests—the settling dust tests—were performed to determine how the three CPDM units would respond to more strenuous environmental conditions that can be present in an underground coal mine and to compare the results from the CPDM units to data from the traditional method of sampling using

the gravimetric sampler. Three CPDM units and a gravimetric sampler were placed inside a chamber under various combinations of elevated temperature (T), relative humidity level (RH), and dust concentration levels. Based on a series of tests, the CPDM units showed considerable differences in airborne concentrations compared to one another and compared to results from the standard gravimetric method. The differences between the measurements obtained by the CPDM unit and the gravimetric sampler ranged from 0.04 to 4.7 mg/m^3 over one-hour test periods. Airborne concentrations varied among the three CPDM units under the same environmental conditions by as much as 2.7 mg/m^3, but the variations from test to test were not consistent, meaning that one unit did not consistently show higher airborne concentrations compared to the other CPDM units. A consistent trend was not observed regarding the possible association of increased variability between the two sampling devices with increasing temperature or increasing humidity levels, in part because of the limited number of samples, but also because differences between the two methods (gravimetric versus CPDM) and among the three CPDM units were considered substantial, particularly considering the new proposed regulatory limit of 1.0 mg/m^3.

The three CPDM units were also subjected to additional temperature and humidity chamber tests without the application of dust. Again, variations among CPDM units were seen, with variations up to 0.6 mg/m^3.

The CPDM units were also subjected to a series of other physical tests, including drop tests, shock tests, and electromagnetic interference tests. Following military standard protocols, a CPDM unit did not report any errors when dropped from a height of 4 feet onto packed dirt. The same CPDM unit underwent a series of shock tests of up to 30 g-forces (or 30 times the acceleration due to gravity [g]). Under these drop and shock tests, the unit performed without any failures and unusual concentration levels were not observed.

The CPDM unit, however, experienced problems during electromagnetic interference (EMI) tests. The parameters of the EMI tests were based on our discussions with mine personnel and on available equipment at the laboratory during our visit. A band of radiofrequency signals ranging from 200 MHz to 1 GHz were applied to a CPDM unit at power levels of 5 Watts (W) and 10 W. At a power level of 5 W, the CPDM unit did not report any errors, although some unusual variation in dust concentrations occurred during the sweep of signals. When the power level increased to 10 W, the pump continued to operate at lower frequencies, but when a signal at 451 MHz and 10 W was applied, the motor ceased to operate and a flow fault occurred. More focused tests called threshold tests were conducted to identify the frequency and power level above which the pump on the CPDM unit would to cease to operate. These tests revealed that the motor would fail at different power levels (ranging from 6W to 10W) at particular frequencies between 451 MHz and 532 MHz. At these frequencies and power levels, despite the obvious failure of the CPDM motor, no errors were reported by the CPDM. The failure of the CPDM motor and the lack of reporting by the CPDM unit when EMI is applied are concerning. If a miner wearing this device were to enter an area where these signals are present, even momentarily, the CPDM could fault without reporting an error. These EMI tests evaluated a portion of the spectrum and potential exposures to electromagnetic signals that may exist within the mine. The mining environment should to be monitored to develop a full understanding of the electromagnetic signals that exist and to identify those that could potentially affect the operation of the CPDM.

These tests demonstrated that the CPDM does not respond reliably under all controlled conditions that can be encountered in an underground mine. Under elevated temperature and humidity conditions, the CPDM units reported airborne dust concentrations that differ, at times considerably, from concentrations determined by the traditional gravimetric sampler. Additionally, under the same test conditions, three CPDM units reported different airborne concentrations at elevated temperature and humidity levels but reported similar concentrations at lower levels of temperature and humidity. The variation among the CPDM units and variation between the CPDM units and the gravimetric sampler method exceeded the proposed regulatory limit of 1.0 mg/m^3 in some cases. The series of tests also showed that the internal components of the CPDM unit fail when it is surrounded by certain radiofrequency signals, at power levels less than 10 W, and that these failures are often not recorded by the CPDM.

In summary, these tests show that the CPDM is unreliable under certain conditions that can exist within an underground mine. These analyses indicate that further, more comprehensive evaluation by MSHA and NIOSH of the CPDM under similar conditions and with a larger number of CPDM units should be conducted, and the results of such tests should be fully disclosed. The purpose of the CPDM unit is to accurately report the airborne dust concentration to which a miner can be exposed. As shown by these tests, the CPDM does not operate reliably under certain mining conditions, and the unit reports airborne concentrations that conflict with results from accepted sampling and analytical methods at elevated temperatures and humidity levels. To avoid the possibility of inaccurate worker exposure readings with the CPDM, additional comprehensive testing of the CPDM unit is needed to confirm the unit's performance under a range of environmental conditions and EMI situations. This testing should include evaluation of the performance under varying temperature and humidity conditions and performance under varying field strengths resulting from power frequency and radiofrequency sources that are present in today's underground coal-mine environments.

1 Introduction

Concerns have been raised about the reliability of the Continuous Personal Dust Monitor (CPDM) under normal mine conditions, particularly underground mining areas with elevated temperature and humidity levels. NIOSH has published reports on laboratory and in-mine testing of precommercial CPDM units (NIOSH 2006 and Volkwein et al. 2004). The underground mine testing was conducted at 10 mines where full-shift samples were taken. Unfortunately, the report did not provide any information on the temperature and humidity levels inside the mine. According to the CPDM manual, the CPDM units are certified by TFS to operate in extreme environments of –20°C to 40°C and 0–100% relative humidity (RH) (TFS 2009). Also specified in the CPDM manual, the unit operates in compliance with EN61326-1 and FCC Part 15 subpart B in reference to electrical emissions and immunity (TFS 2009).

Based on discussions with mine personnel and our review of information provided about the CPDMs from NIOSH, MSHA, and the manufacturer, we designed a variety of tests to evaluate CPDM performance under a variety of physical and environmental conditions. Exponent identified a laboratory that had the capabilities to conduct these tests. The purpose of the testing was to determine whether the CPDM units are reproducible and correspond to other monitoring devices under a range of environmental conditions that can be present in underground mines.

Exponent identified a laboratory in Fredericksburg, Virginia (E-Labs, Inc.), that was available to provide the necessary equipment and technical expertise in testing electronic equipment. The E-Labs facility has extensive experience performing military specification testing for the government and major industries. Exponent consulted with mine personnel and worked with the laboratory to determine the types of tests to be conducted. Five types of tests were identified and conducted at the E-Labs facility under the supervision of Exponent personnel:

- Settling dust chamber: Three CPDM units and a gravimetric sampler were placed inside a sealed chamber under different dust concentrations with various temperature and humidity conditions.

- Temperature and humidity tests: Three CPDM units were placed inside a sealed chamber under varying temperature and humidity levels.
- Drop tests: Physical test involving dropping a CPDM onto packed dirt.
- Shaker shock tests: Physical test involving placing the CPDM unit under severe gravimetric forces.
- Electromagnetic Interference (EMI) test. Various frequency and power levels were applied in close proximity to a CPDM unit to mimic possible EM fields found in an underground mine.

The following sections present a description of these tests, the study methods, observations, and conclusions regarding the CPDM's performance. E-Labs' report provided the physical parameters for the tests and is attached.

2 Settling Dust Chamber Tests

2.1 Overview

The settling dust test was a modified version of the Military Standard (Mil-Std) 810F, Method 510.4, Procedure 3. This standard provides specifications to measure and record dust that is released inside a sealed container and settles over a period of time. E-Labs modified this specification slightly to accommodate the lower concentrations of dust needed for our tests. A steel chamber (72 ft^3 or 2.04 m^3) was equipped with a dust application mechanism that was capable of releasing small quantities of dust into the sealed chamber at set temperature and humidity levels. Different monitoring instruments, including the CPDM unit and the traditional gravimetric instrument, were placed inside the chamber and recorded dust concentrations during each test. E-Labs' report describes in detail the settling dust test, the dust application mechanism, the amount of dust released into the chamber, and the environmental conditions during each test run. Temperature and humidity data obtained from E-Labs were correlated with the dust concentrations obtained from the monitoring instruments, and the results are summarized here.

2.2 Settling Dust Chamber

E-Labs was capable of controlling the temperature and humidity levels and the amount of dust released or purged inside the chamber during each test. A dust container was equipped with 1–3 internal nozzles and suspended 1 foot from the ceiling in the center of the chamber. To release the dust, E-Labs injected a short burst of air through a tube connected to the nozzles of the container, which would force the release of dust from the container in to the chamber. E-Labs personnel manually controlled the onset of a purge and the duration of the purge for each test. Figures 1 and 2 show the settling dust chamber.

Although underground coal mine dust would have been ideal to simulate coal mine dust exposures, in the time period available to conduct this testing and submit results in MSHA's comment period, it was not feasible to use coal dust material. The laboratory did not have the equipment to pulverize coal and verify that they could obtain a standard respirable size for the

CPDM and gravimetric samplers to evaluate. Hence, a certified surrogate material was needed for the testing. A surrogate would still permit evaluation of the CPDMs performance while measuring dust particle concentrations under environmental conditions that were not tested by NIOSH in their 2006 report. (Other laboratories that we contacted would not allow the use of material that was outside the parameters of their standard tests that use talc, silica, and other materials).

Since the two devices monitor respirable dust (coal mine dust or other materials), a surrogate material was chosen that could provide a known standard size respirable particle for the monitoring devices. This study did not assume that the surrogate material would have identical chemical and physical properties as coal mine dust. Talc was chosen as a reasonable, available surrogate with known size characteristics in order to test the response of the CPDM units under known environmental conditions while monitoring for respirable dust.

Silica dust was tested initially, but talcum dust was eventually used for the settling dust tests. After several initial dust application tests with silica dust, it was determined that a finer dust, such as talc, would be better suited for respirable dust tests and would also make the dust application mechanism more efficient. The average particle size for the VANTALC was 0.8–1.3 µm (talc dust specification sheet is attached). Talc dust was used during all settling dust chamber tests.

Figure 1. Settling dust chamber

2.3 Monitoring Instruments

Three types of instruments were used to determine the amount of airborne dust inside the chamber. Each monitoring device used different technology to determine the dust concentrations in the chamber. These devices are summarized in Table 2. All units were equipped with a cyclone to separate and remove the larger particles. Only smaller, respirable particles, generally less than 4 µm in diameter, were analyzed by the three types of instruments.

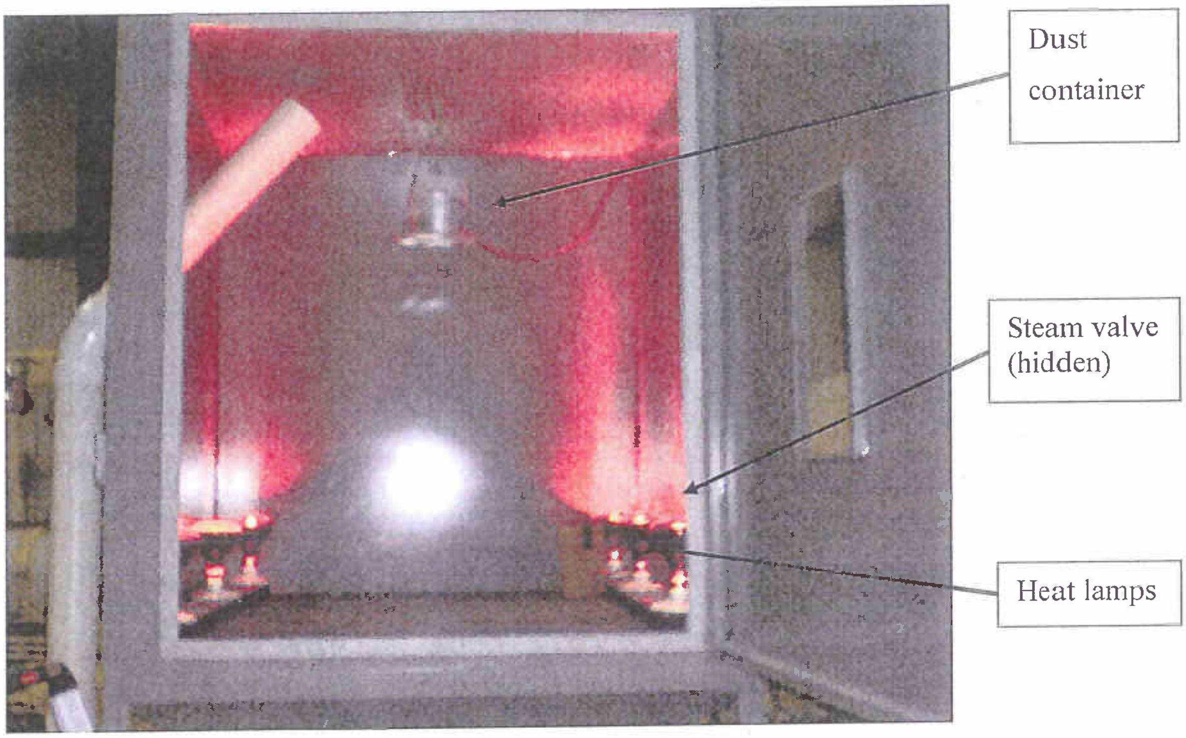


Figure 2. Inside the settling dust chamber

Table 1. Dust monitoring instrumentation

Monitoring devices	Manufacturer	Underlying Technology	Serial No.	Comment
Continuous Personal Dust Monitor (CPDM)	Thermo Fisher Scientific	Tapered Element Oscillating Microbalance	609014 310531 509055	New technology specified in MSHA proposed rule Near-real-time monitoring device Three separate CPDM units used inside the settling dust chamber
Gravimetric sampling and analytical method	Mine Safety Appliances	Gravimetric analysis (weight)		Current methodology under MSHA regulation Comparison for new CPDM unit Delayed response—Laboratory analysis required
SidePAK AM510	TSI	Laser Photometer	10601099	Real-time, direct-reading instrument

2.3.1 Personal Dust Monitor (PDM), Model 3600 (P/N 42-00904)

The PDM, also referred to as a Continuous Personal Dust Monitor (CPDM), unit uses a tapered element oscillating microbalance technology to provide a digital output of dust concentrations. Air is drawn through the device using a pump that is running at a pre-determined flow rate of 2.2 liters per minute (LPM). The unit is equipped with a cyclone that will separate out the larger particles, allowing only the smaller, respirable particles to settle on a filter that is positioned on top of a tapered element. As dust continues to accumulate on the filter, the tapered element will oscillate at a different frequencies, and a dust concentration is determined and electronically recorded by the CPDM unit.

There are two types of failures that were considered during the laboratory testing. First, the CPDM unit reports errors when the internal component of the CPDM has failed. Before the unit can monitor dust concentrations, the CPDM automatically runs a warm-up test, during which the internal components are tested and any errors with those components are reported before the monitoring period begins. The CPDM also has additional software diagnostic tests that can be run using the CPDM software and a laptop. These diagnostics also test functionality of the internal component and any failures of those components are displayed on the laptop using the CPDM software. While monitoring for respirable dust, the CPDM also reports any problems with the functionality of its internal components. These errors are shown on the LED display at the time of the error and on the dust card that is produced at the end of the monitoring period.

In addition to the errors reported by the CPDM, the airborne concentrations reported by the unit were analyzed to determine if any unusual concentrations were reported under particular conditions. For example, a large fluctuation of airborne concentrations in an environment where dust concentrations were constant, would raise questions about the validity of the data reported by the CPDM. In the same manner, if the concentrations reported by several CPDM units operating in the same environment, were different, that would point to a failure of the CPDM in the sense that different CPDM devices are not reliably measuring the same dust concentration. Good reliability does not ensure validity because all of the units could be systematically off in the same direction, but reliability is a needed initial performance measure in consideration of instrument validity. The lack of reliability with the monitoring device indicates a potentially serious problem when we consider the potential widespread use of the CPDMs.

The CPDM has an LED screen that provides a read-out of dust concentration, although these readings are not real-time readings. The units can only provide dust concentrations averaged over a particular period of time. The LED screen initially shown on the CPDM shows two dust concentrations: 1) the cumulative dust concentration in the past 30 minutes (30 Min Conc on the LED) and 2) the average dust concentration since the beginning of the monitoring period, also called the end of shift (EOS) concentration (Cum1 Conc on the LED). Therefore any change in the dust concentration will not be seen immediately on the LED screen.

The dust concentration is reported by the CPDM in units of milligrams of dust per cubic meter of air (mg/m^3). All instruments used in these tests report dust concentrations in these units, so that the results from each device are comparable.

2.3.2 Gravimetric Analysis Method (Gravimetric Sampler)

The gravimetric method, the method currently required by MSHA, collects dust on a pre-weighed filter to determine the airborne dust concentration. Respirable dust samples were collected on a 37-mm-diameter pre-weighed polyvinyl chloride (PVC) membrane filter with a 5-µm pore size. The sampling train included the steel lapel holder, the filter cassette, 10-mm cyclone assembly, tubing, and sampling pump. Air was drawn through the filter using a battery-operated pump at a known flow rate, and the respirable dust was collected on the filter. The flow rate (liters per minute [LPM]) for the sampling pump was recorded before and after each test run, and the average of the two readings was used for the sample collection rate. The total volume of air (in liters) drawn through the filter was determined by multiplying the average flow rate by the total duration of the test (in minutes). After the test was completed, the filter was sealed and sent under proper chain of custody to a laboratory. There, it is analyzed using the National Institute of Occupational Safety and Health (NIOSH) Method 500/600 (Gravimetric Method). The airborne concentration of settling dust was determined by the laboratory by measuring the amount of dust collected on the filters (mg) divided by the volume of air pulled through the filter (liters or cubic meters [m^3]). The dust concentration reported by gravimetric method is reported by the laboratory in units of milligrams per cubic meters of dust (mg/m^3), and the laboratory report is provided.

2.3.3 SidePak Personal Aerosol Monitor, Model AM510 (P/N 1980456)

A third monitoring device was used that provided real-time dust concentrations. The TSI SidePak™ AM510 Personal Aerosol Monitor is a handheld instrument equipped with a cyclone, and it measures particles smaller than 4 µm. While using the cyclone, the flow rate was modified to be 1.7 LPM, verified using a DryCal primary standard. The device measures particle concentrations by use of a laser photometer and reports and records dust concentrations in mg/m^3. The instrument was factory calibrated prior to this evaluation, as recommended by the manufacturer.

This device is not currently approved by MSHA for use in mines. The results from the SidePak were not compared to those from the gravimetric and CPDM devices, which are approved by MSHA. The SidePak was intended to be used as a monitoring tool for the settling chamber tests, because it is capable of providing real-time measurements.

2.4 Test Preparation and Calibration

Before each test in the settling dust chamber, a series of calibration procedures was conducted on each monitoring device.

Prior to any test (chamber test, shock test, drop tests), the CPDM units were cleaned in accordance with procedures specified in the CPDM 3600 manual for daily cleaning (TFS 2009). This includes:

- Cleaning the grit pot and nozzle
- Cleaning the mass transducer
- Cleaning the air inlet on the cap lamp
- Replacing the TEOM filter.

Two sets of diagnostic tests were run before every test. First, the CPDM software diagnostic tests were run prior to each test. These diagnostics tested the internal components of the units while the pump was turned off and while it was on. Also prior to every test, each CPDM ran through the 35-min warmup period prior to monitoring. (The CPDM will not monitor if the unit fails the warmup diagnostics tests.) The CPDM units were charged completely overnight, and they kept at least 80% of their charge during the tests, as noted by the charger unit.

The cyclone used for the gravimetric analysis was cleaned before each run by using a burst of compressed air to remove any large deposits of dust. The cyclones were also cleaned daily with the mild soap and water. The cyclone for the SidePak direct-reading instrument was cleaned in the same manner as the one used for the gravimetric sampling.

The CPDM and SidePak were programmed using a laptop and the software provided with each unit. The start time and duration of the sample run were downloaded to the unit, and the unit automatically started the test run. The gravimetric sampler needed to be started manually, because it is not electronically programmable.

2.5 CPDM Preliminary Tests: Office Environment

Prior to conducting the tests at E-Labs, Exponent conducted a series of tests in an office environment using the CPDM units that would be tested at the laboratory. The purpose of these tests was to determine whether the CPDM units provided similar concentrations under temperature and humidity levels typically found in a ventilated, office environment. The units were tested side by side and programmed to monitor for different sampling periods. Seven tests were conducted in this environment, with the duration of the test ranging from 2 hours to 12 hours. Table 2 shows the test parameters and results; the latter are graphed on Figure 3. CPDM1, CPDM2, and CPDM3 were used in the laboratory during the settling dust tests. CPDM4 was used for the physical tests, including the drop and shock tests. CPDM1 was used for the EMI tests.

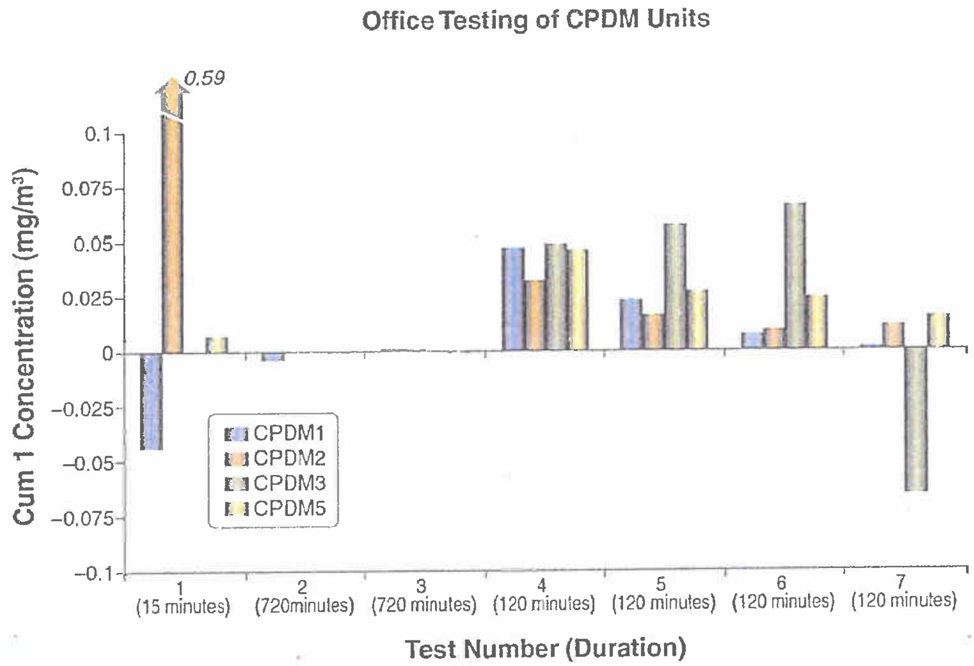


Figure 3. CPDM testing in office environment

Table 2. CPDM testing in office environment

Test No.	Duration (min)	CPDM1	CPDM2	CPDM3*	CPDM4
1	15	-0.044	0.59	N/A	0.007
2	720	-0.004	0.0	N/A	-0.001 +
3	720	0.001	0.001	N/A	-0.001
4	120	0.047	0.032	0.049	0.046 +
5	120	0.023	0.016	0.057	0.027
6	120	0.007	0.009	0.066	0.024
7	120	0.001	0.011	-0.066	0.015 +

* CPDM3 was not used for the first three tests

+ CPDM4 failed software diagnostics tests prior to Tests 2 and 4 and after Test 7. The unit passed the warm-up diagnostics and monitored for the stated sampling duration with any errors reported by the CPDM on the LED display or dust card.

Daily cleaning, as defined above, was conducted before Tests 1, 2, and 4. The 35-minute warm-up period was conducted prior to each run. All units passed the warm-up testing and proceeded with the programmed shift. The software diagnostic tests were performed before Tests 2 and 4 and after Test 7. CPDM4 was the only unit that had failures with the software diagnostics. Before Test 2 and 4 and after Test 7, with the pumps turned off, the diagnostics test reported a "Flow Rate Volts Raw" error for CPDM4. According to the manual, this error points to a defective board. Because of this error, it was determined that this could only be used for a limited number of tests at the laboratory (e.g. the drop and shock tests). This error was not consistently repeated during additional diagnostic tests at the laboratory. CPDM2 showed a high airborne concentration (0.59 mg/m^3) compared to other units during Test1 (15 min.). This unit reported no errors on the LED display or dust card and subsequent tests of CPDM2 did not show any unusual concentrations.

No errors were reported by the CPDM on the LED display or dust card during the monitoring period of these seven tests. Even despite the "Flow Rate Volts Raw" failure with CPDM4, the unit passed the warm-up test and ran without any reported errors.

2.6 Outline of Settling Dust Tests

Settling dust tests were conducted in the settling dust chamber. Each test was one hour in duration. The environmental conditions and test parameters are listed in Table 3.

Table 3. Summary of settling dust tests

Test #	Description	Duration (min)	Temperature (C)	Temperature (F)	Relative Humidity (%)
1	Baseline, high dust emissions	60	26	79	45
2	High T and RH, high dust emissions	60	35	95	88
3	High T, high dust emissions	60	35	95	77
4	No dust emissions	60	N/A	N/A	N/A
5	Low T and RH, low dust emissions	60	23	73	75
6	Low T, high RH, low dust emissions	60	22	72	87
7	Low T, high RH, low dust emissions	60	25	72	90

T = temperature; RH = relative humidity, N/A Not applicable

2.7 Observations: Settling Dust Tests

2.7.1 Dust Concentrations Inside the Chamber

For the first three one-hour settling dust tests (Tests 1–3), an initial application of talc dust was made for a duration of 50 seconds, followed by four applications of shorter durations (10–35 seconds), approximately 10–15 minutes apart. The additional applications were made to keep the dust concentrations relatively constant during the one-hour tests. With this process, high dust concentrations were observed. It was determined that the large dust container (as shown in Figure 2) was unable to release a small amount of measureable dust that would simulate a lower concentration closer to the regulatory limit. To help correct this problem, E-Labs personnel modified the dust application mechanism by using a smaller dust application container and applying a different application method. Using the smaller container, it was determined that an initial purge of 5 seconds, followed by three (3) subsequent purges of 10 seconds each, would be needed to sustain a lower concentration. This dust application method was used for Tests 4–7, and lower dust concentrations were observed.

2.7.2 Diagnostic Failures of CPDM Units

Two types of diagnostic tests - the software diagnostics and the warm-up tests - were performed prior to every test. For all settling dust tests, with the exception of one test, both the software diagnostics and the warm-up tests passed. For Test #1, the software diagnostics failed for CPDM1 with a "Flow line press raw" failure with the pumps turned on (passed with the pumps turned off). This error could mean that there was a problem with the filter or a defective sensor. The TEOM filter was changed and the software diagnostics was run again. The unit failed the software diagnostics a second time with the pumps on, with two errors: "Flow line press raw" and "Flow rate volts raw" failures. This second failure pointed to a pump problem. Despite the software failures, CPDM1 passed the warm-up tests and completed Test 1 without any errors. These errors were never repeated with this unit in the subsequent tests over the next several days.

2.8 Summary of Results

Table 4 summarizes the results of the tests conducted inside the settling dust chamber. These concentrations at the various temperatures (°F) and relative humidity levels (%) are also shown in Figure 4.

Tests 1–3 were run using the larger dust container and, consequently had higher dust concentrations inside the chamber. Tests 5–7 used a smaller container and a better dust application mechanism, resulting in overall lower dust concentrations. The dust application mechanism failed and a problem with one of the heat bulbs occurred during Test #4 so this test was excluded from our evaluation.

Table 4. Results of settling dust tests

Test #	Duration (min)	Temp (F)	RH (%)	Gravimetric Method* (mg/m^3)	CPDM1 (mg/m^3)	CPDM2 (mg/m3)	CPDM3 (mg/m3)
1	60	79	45	4.968	5.009	5.786	5.784
2	60	95	88	3.174	9.678	7.868	8.19
3	60	95	77	12.834	12.153	11.649	9.498
5	60	73	75	2.898	3.108	3.447	3.548
6	60	72	87	1.38	1.832	2.338	1.706
7	60	76	90	2.76	3.777	3.597	3.095

* MRE Equivalent concentration provided. Factor of 1.38 used.

Control gravimetric filter <0.05 mg

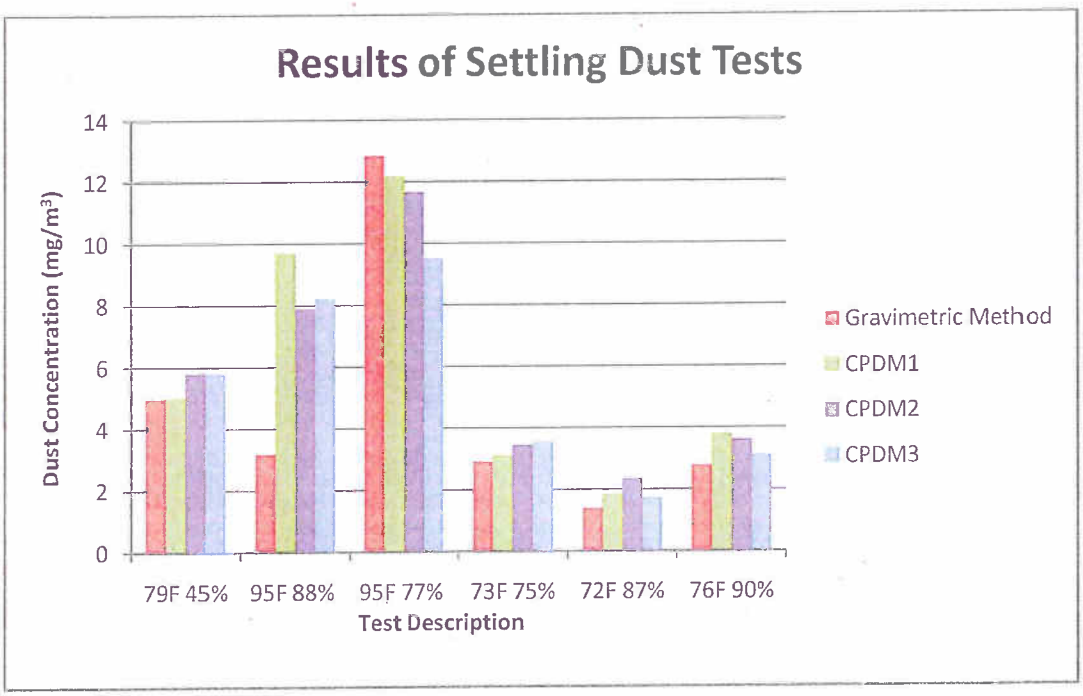


Figure 4. Summary of settling dust tests

In all settling dust tests, no errors were reported on the CPDM LED display or dust card during the monitoring period.

2.8.1 Comparison of CPDM to Gravimetric Sampler

As shown in Table 3 and Figure 4, there are differences between the concentrations reported by the CPDM and concentrations reported by the gravimetric sampler. The gravimetric sampler reported lower concentrations than the CPDM in five of the six tests. In Tests 3, the gravimetric sampler reported a higher concentration than the CPDM units.

As shown in Figure 4, there is no consistent correlation between the CPDM and gravimetric results with temperature, or humidity levels. Additionally, the variations among the CPDM units under temperature and humidity levels demonstrate differences between the individual CPDM units and the gravimetric sampler which are nearly as high as the new exposure limit in the proposed rule. This raises questions about the use of the CPDM for compliance purposes under various temperature and humidity conditions.

The magnitude of the difference between the results reported by the CPDM units and those reported by the gravimetric sampling device varied, depending on which CPDM unit was used for comparison. Table 5 summarizes the differences between the minimum and maximum CPDM concentration and the gravimetric method. For Test 3 (95°F and 77% RH), one CPDM unit (CPDM1) reported concentrations 0.68 mg/m^3 less than the gravimetric sampler, while another CPDM unit (CPDM3) reported concentrations 3.3 mg/m^3 less than the gravimetric sampler. In Test 6 (72°F and 87% RH), the concentration reported by CPDM3 was 0.33 mg/m^3 greater than the gravimetric sampler. However, if CPDM2 was used, the concentration was 0.96 mg/m^3 greater than the gravimetric sampler.

Table 5. Difference between CPDM units and gravimetric method

Test #	Temp (F)	RH (%)	Minimum Difference: CPDM vs. Gravimetric (mg/m^3)	Maximum Difference: PDM vs. Gravimetric (mg/m^3)
1	79	45	0.041	0.818
2	95	88	4.694	6.504
3	95	77	-3.336	-0.681
5	73	75	0.210	0.650
6	72	87	0.326	0.958
7	76	90	0.335	1.017

2.8.2 Comparison of CPDM Units

Three CPDM units were used for each of the settling dust tests. These were the same CPDM units that were tested in the office environment described previously. These three CPDM units showed little to no variation in airborne concentrations when operating under temperature and humidity levels associated with an office environment.

Considerable variation, however, was shown among the three units during the settling dust tests at higher temperature and humidity levels, as shown in Figure 4. Table 6 shows the difference between the maximum and minimum concentration reported between the CPDM units.

The tests with the highest combined temperature and humidity levels, Tests 2 and 3, produced the greatest differences between the CPDM units, 2.7 and 1.8 mg/m^3, respectively. Test 2 also showed the greatest difference between the CPDM units and the gravimetric sampler. Even at lower humidity levels, as shown in Test 1 (79°F, 45% RH), a variation of 0.78 mg/m^3 was observed among the three units.

Table 6. Differences among CPDM units

Test #	Temp (F)	RH (%)	CPDM1 (mg/m^3)	CPDM2 (mg/m^3)	CPDM3 (mg/m^3)	Maximum Difference between CPDM units (mg/m^3)
1	79	45	5.009	5.786	5.784	0.777
2	95	88	9.678	7.868	8.19	2.655
3	95	77	12.153	11.649	9.498	1.81
4	95	72	0.715	0.733	0.761	0.046
5	73	75	3.108	3.447	3.548	0.44
6	72	87	1.832	2.338	1.706	0.632
7	76	90	3.777	3.597	3.095	0.682

Tests 5–7 used a different dust application mechanism resulting in lower airborne concentrations. However, variations among the CPDM units were observed, ranging from 0.44 to 0.68 mg/m^3. Although these differences are smaller than what occurred at the higher concentrations, the impact could be significant, particularly in light of a proposed regulation of 1.0 mg/m^3.

The individual CPDM units at times provide the highest concentration result and at times the lowest result without any apparent correlation to the temperature or humidity levels. For example, during Tests 2 and 3, CPDM1 reported higher concentrations compared to the other two units but during Test 5, CPDM1 reported the lowest concentrations among the CPDM units. If this small sample set shows such variability, questions are raised concerning the range of variation from a larger sample set.

Additional testing is needed to further investigate the differences between the CPDM units and the gravimetric sampler at various temperatures, humidity levels, and airborne dust concentrations.

3 Temperature and Humidity Tests

The three CPDM units used for the settling dust test were also placed under additional temperature and humidity chamber tests without the application of dust. Figure 5 shows the chamber used for this testing. This was a sealed chamber, and very low concentrations were seen at the onset of the tests. The units were programmed to monitor for six hours while the temperature and humidity levels were modified as shown in Figure 6.

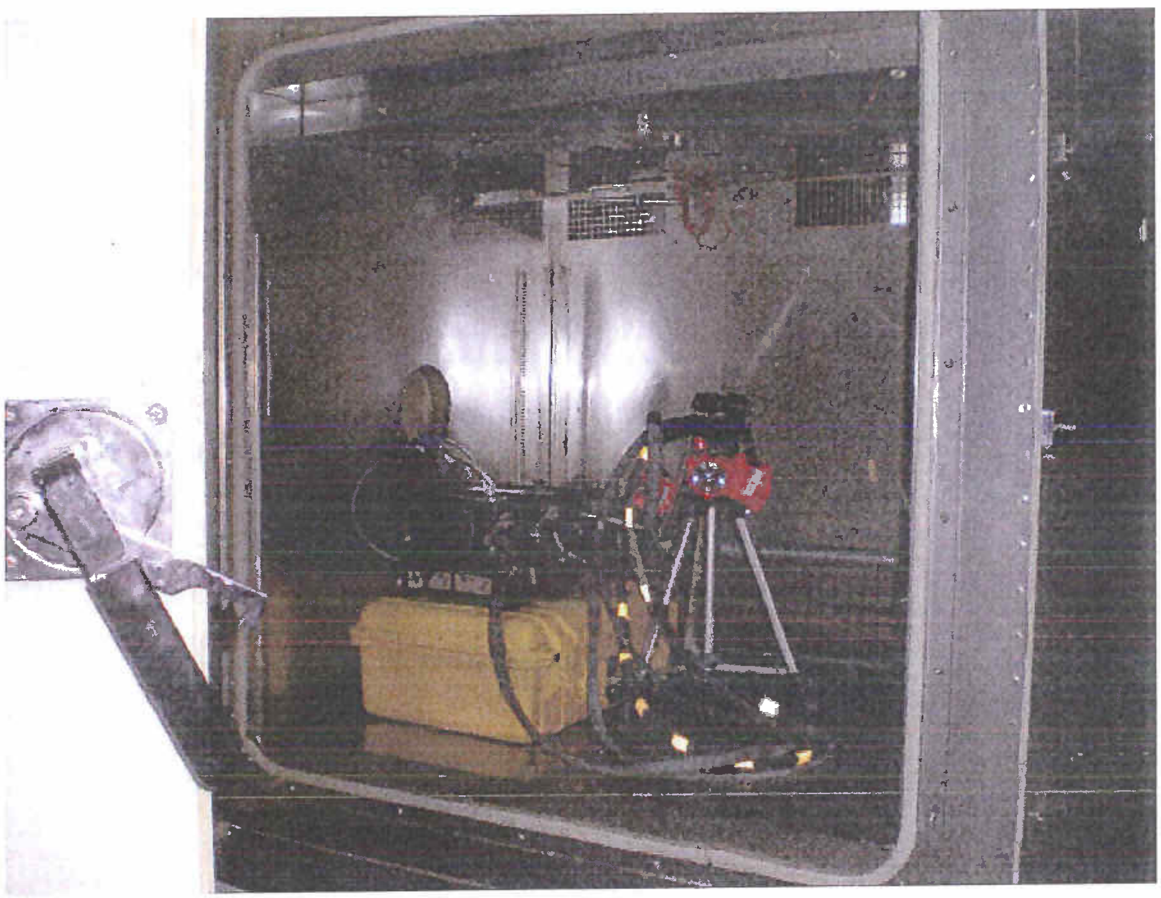


Figure 5. Inside temperature and humidity chamber

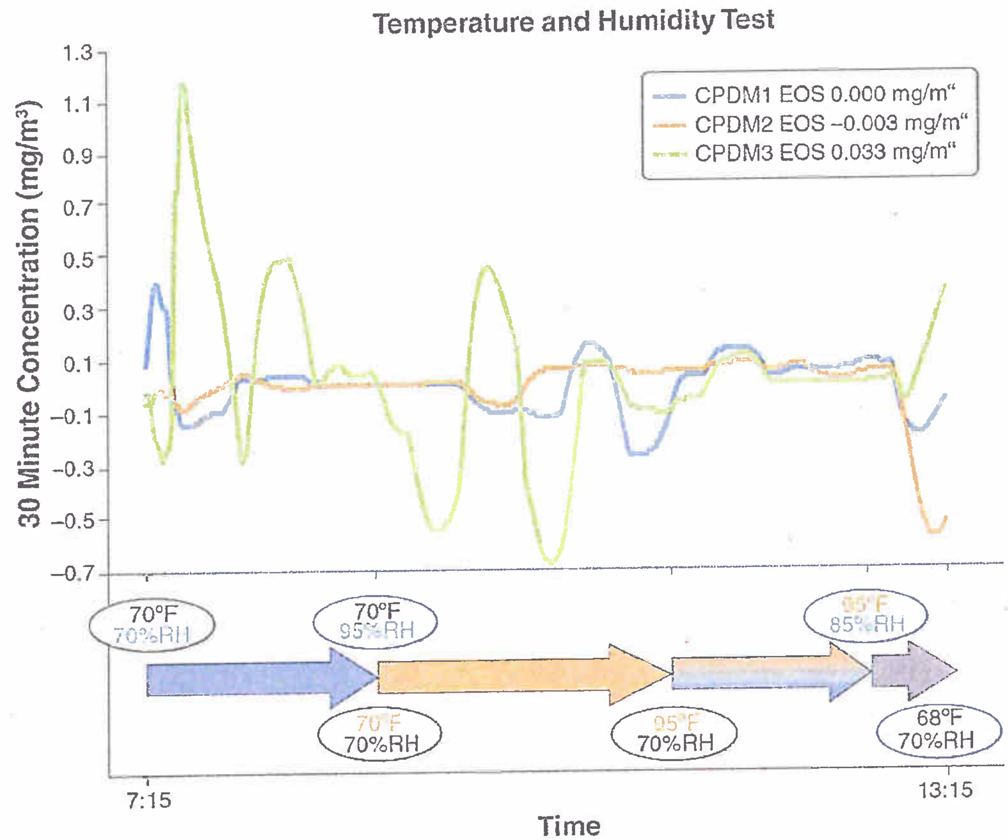


Figure 6. Results of temperature and humidity tests

Over a six hour period, there were three phases for the temperature and humidity testing: 1) increase humidity level (70% to 95%) at a constant temperature (70F); 2) increase temperature (70F – 95F) at constant humidity level (70%) and 3) increase humidity (70% to 85%) at high temperature (95F) to obtain a maximum temperature and humidity level. As shown in Figure 6, the concentrations of the three units changed during three phases of the testing. The reported concentrations among the three units varied once again, at times up to 0.6 mg/m^3. One unit, CPDM1, showed the greatest amount of variation, throughout the first two phases of the tests. CPDM2 showed more variation when the temperature was raised to 95F at a constant humidity level (70%).

The end of shift (EOS) concentrations for the three units revealed an order of magnitude difference even though the units were under identical environmental conditions throughout the test. The EOS concentration for CPDM1 was 0.000 mg/m^3; CPM2 -0.003 mg/m^3 and CPDM3 0.033 mg/m^3.

4 Drop Tests of CPDM Unit

E-Labs personnel performed a drop test of one CPDM (Serial number 310532). This test was in conducted accordance with Military Method MIL-STD-810F, Method 516.5, Procedure IV. The unit was dropped from a height of approximately four to five feet onto packed dirt (see Figures 7 and 8). The unit was dropped on four different sides:

1. Bottom of the unit (opposite end of the LED display)
2. Front site
3. Back side (with the belt loops)
4. Side of the CPDM (opposite the grit pot and nozzle).

This series of four drops was repeated for a total of eight drop tests. The drops were spaced 1–2 min apart from one another to allow the instrument to respond to the drops. The cap lamp and intake of the CPDM were not dropped and were kept several feet away from the impact area, as shown in Figure 8 (back side drop).

Figure 7. Drop test setup

Figure 8. Drop test of CPDM unit (back side)

Prior to the drop tests, the CPDM unit was cleaned following the CPDM manual instructions for daily cleaning. The unit also passed the software diagnostic tests with the pumps turned off and on.

The unit was manually programmed to operate before, during, and after the drop tests for approximately 1½ hours. Figure 9 shows the dust card produced during this time, with the times of the drop tests displayed.

No errors were shown on the CPDM LED display during the two series of drop tests. As shown in Figure 9, no errors were reported on the Dust Card. Spikes in the airborne concentration are evident, particularly with the cumulative concentration data; however, the change in dust concentrations did not have a significant effect on the final concentration.

Dust Data Card: (Serial Number 0310532)

Wearer ID

Contractor Code
0

Company Name
***

Sampling Time (minutes)
83

MMU DA/SA
0

Part 90 Miner Employee Number
(N/A)

Results
MRE Equivalent: Yes
Shift Limit: 2.00 mg/m³
EOS Final Concentration: 0.007 mg/m³

Mine ID Number
0

Mine Name
***

Date Sampled
Thursday, April 14, 2011 13:29:02

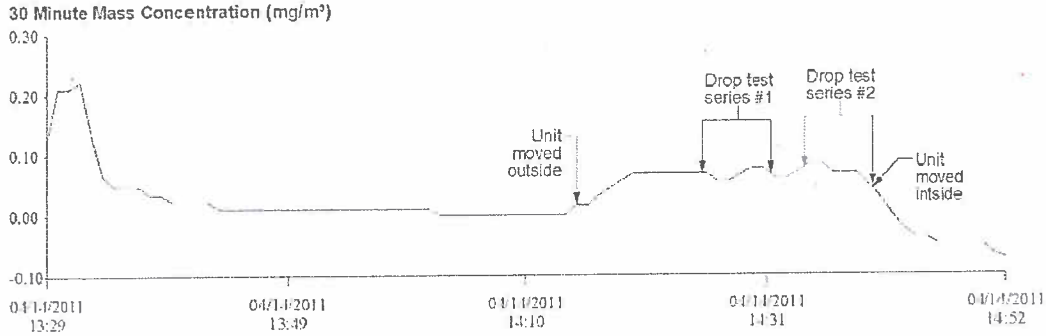
Type of Sample
Unknown

Occ Code
0

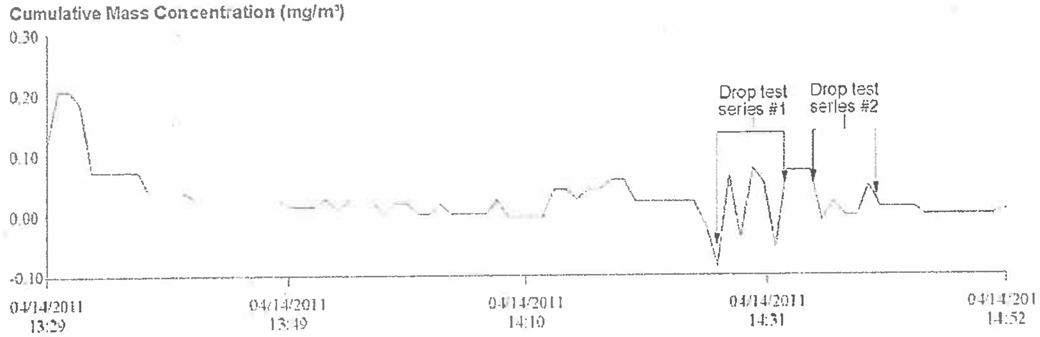
Certification Officer
0

Errors
(No errors)

30 Minute Mass Concentration (mg/m³)



Cumulative Mass Concentration (mg/m³)



Notes:

Figure 9. Dust card—drop tests

5 Shock Tests of CPDM Unit

A series of shaker shock tests were performed on one CPDM unit (serial number 310532). These tests are based on Mil-STD-810F, Method 516.5, Procedure 1. During these tests, the CPDM unit was secured to a table that was placed under a series of pulses at 30 g-forces (30 times the acceleration due to gravity [g]) for 11 milliseconds. A total of six pulses were made along each axis: horizontal (x and y) and vertical (z), for a total of 18 pulses (see Figures 10-12). Figure 10 shows the table used for the horizontal (x and y axis) shock tests with the CPDM in place for the x-axis tests. Figure 11 shows the CPDM mounted on the table for the vertical shock tests. Prior to the shock tests, the CPDM unit was cleaned following the CPDM manual instructions for daily cleaning. The unit also passed the software diagnostic tests with the pumps turned off and on.

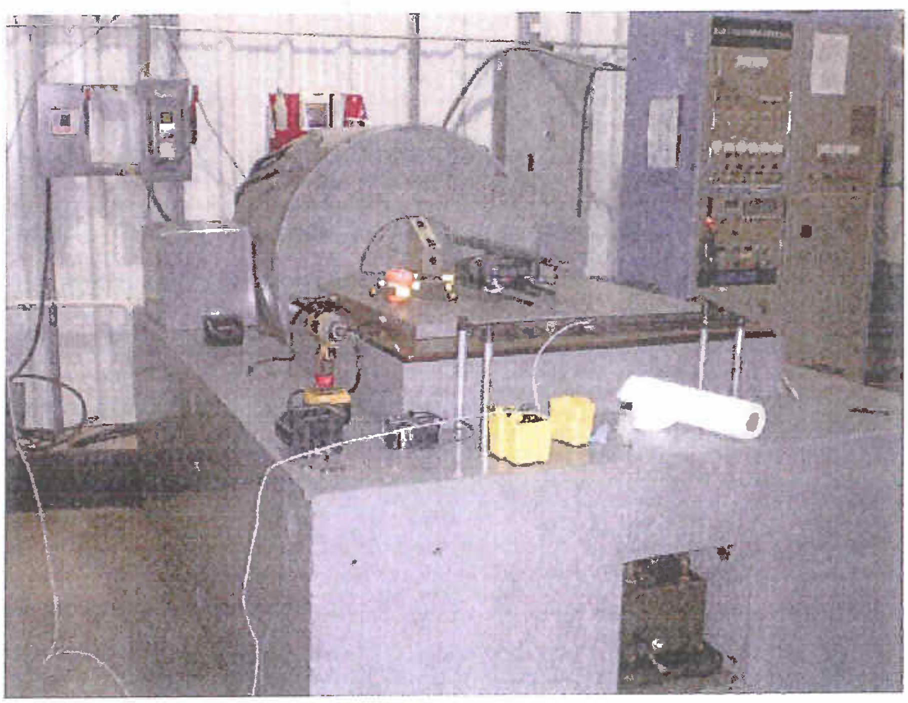


Figure 10. Shaker shock table

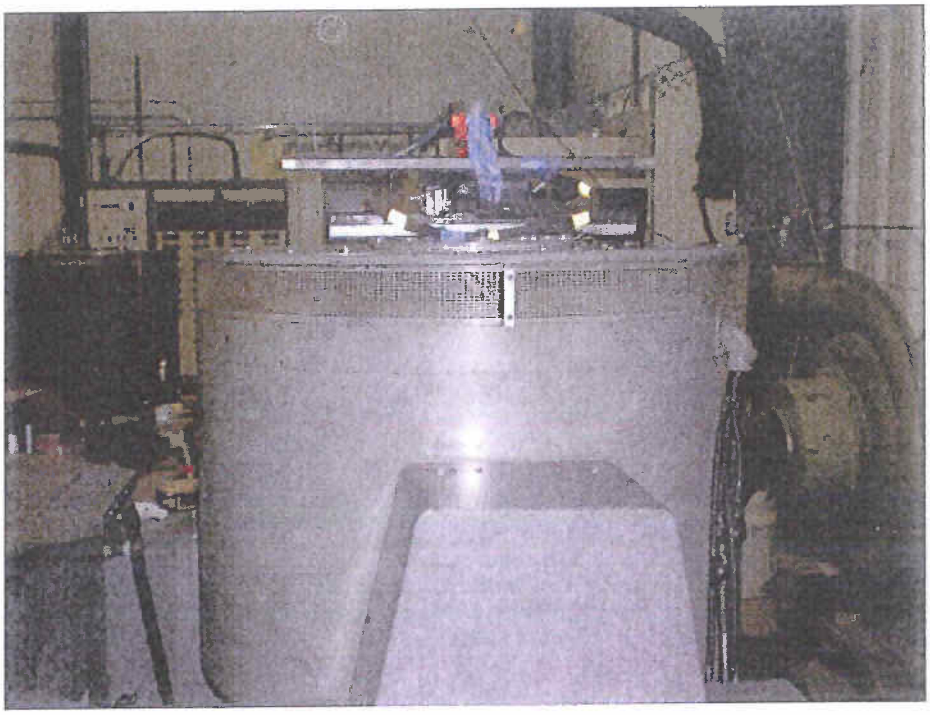


Figure 11. Vertical (z-axis) shock test table

The unit was operating before, during, and after it the shock tests, for a total monitoring duration of 1 hour. Figure 12 shows the dust card produced during the one-hour monitoring series. The time of the three separate shock tests are shown on this figure.

No errors were recorded on the CPDM LED display during the series of tests, and no abnormal airborne dust concentrations were observed during the series of tests.

Dust Data Card: (Serial Number 0310532)

Wearer ID

Mine ID Number
0

Contractor Code
0

Mine Name
***

Company Name
***

Date Sampled
Thursday, April 14, 2011 15:30:43

Sampling Time (minutes)
60

Type of Sample
Unknown

MMU DA/SA
0

Occ Code
0

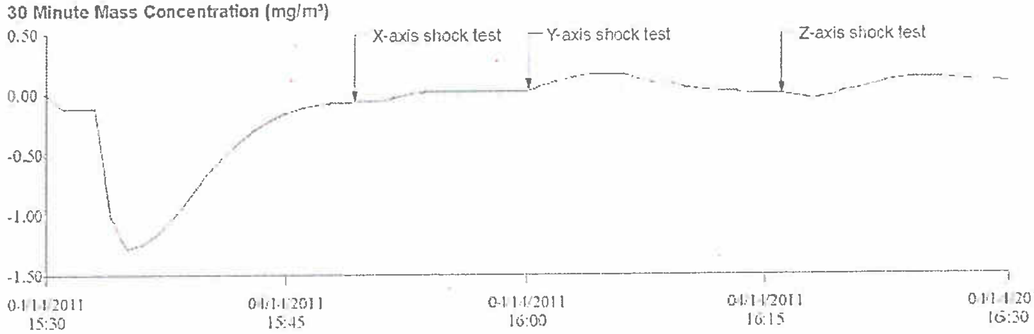
Part 90 Miner Employee Number
(N/A)

Certification Officer
0

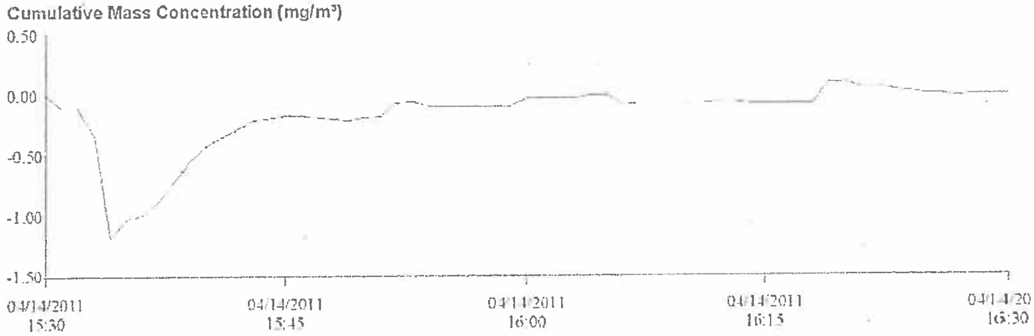
Results
MRE Equivalent: Yes
Shift Limit: 2.00 mg/m³
EOS Final Concentration -0.006 mg/m³

Errors
(No errors)

30 Minute Mass Concentration (mg/m³)



Cumulative Mass Concentration (mg/m³)



Notes:

Figure 12. Dust card—shaker shock tests

6 Electromagnetic Interference Tests

A series of electromagnetic interference (EMI) tests were performed on one CPDM unit (serial number 0509005). These tests are based on MIL-STD-461F, Section 5.20, Radiated Susceptibility. A band of radiofrequency signals ranging from 200 MHz and 1 GHz were directed at a CPDM unit at power levels of 5 W and 10 W. The parameters of the EMI tests were based on our discussions with mine personnel and on available equipment at the laboratory during our visit. Not all frequencies and power levels that may occur in an underground mine were tested. The lower power level for these EMI tests (5 W) is the maximum output at which hand-held walkie talkie devices are allowed to operate. Tests at higher power levels were conducted to mimic the electromagnetic environment that may occur inside a mine due to other mining equipment. The mining environment should to be monitored to develop a full understanding of the electromagnetic signals that exist inside a mine. These levels of power frequency and radiofrequency fields should then be tested on multiple CPDM units for a full evaluation of this issue.

During the EMI tests, the CPDM unit was placed on a table with a transmitting antenna placed 0.5 to 1 m away from the CPDM. A signal generator and power amplifier were connected to the antenna, and radiofrequency signals were directed at the CPDM unit. A broadband spectrum meter was placed directly above the CPDM unit to record the actual frequency and power level that the CPDM was receiving.

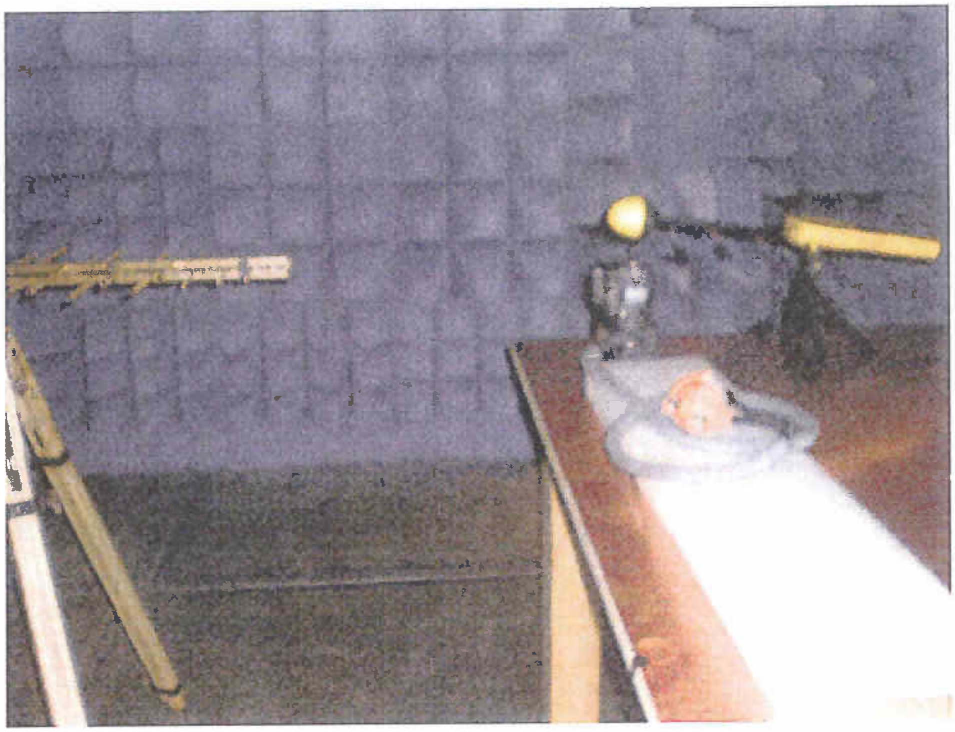


Figure 13. EMI testing

Prior to beginning the EMI tests, the CPDM unit was cleaned following the CPDM manual instructions for daily cleaning. The unit also passed the software diagnostic tests with the pumps turned off and on. The CPDM was programmed to run for 8 hours. The unit was placed on the table in the EMI room for several hours while the EMI system was set up as shown in the above figure.

The first series of tests involved a frequency sweep of 200 MHz to 1 GHz, in 100-kHz increments, maintaining a power level of 5 W. The CPDM was initially placed at a distance of 1 m from the antenna for the first 15 minutes, but the signal generator and amplifier were unable to maintain a power level of 5 W at this distance. The antenna was moved to a distance of 0.5 m for the remainder of the EMI tests.

Figure 14 shows the dust card produced during the first series of tests. No errors were recorded on the CPDM LED display during this first set of tests, but some unusual airborne concentrations were observed, as shown on the dust card. At 5 W, the 30-min concentration started to increase when a signal of approximately 353 MHz was emitted. Over a period of 15 min, the 30-min concentration increased from 0.1 mg/m^3 to 0.8 mg/m^3, while the frequency changed from 353 MHz to 580 MHz. The concentration suddenly dropped off as the frequency sweep continued between 580 MHz and 1GHz. No errors were reported by the CPDM on the LED display or the dust card during this first series of tests at 5 W.

A second frequency sweep was started once the CPDM concentration stabilized. During this second series of tests, the CPDM received signals of 10 W along the same frequency band of 200 MHz to 1 GHz. The CPDM ran without reporting any errors until 11:55, when the CPDM pump shut off. This error occurred while a signal of 451.9 MHz at 10 Watts was being received by the CPDM. An error signal, "Flow out of range," was shown on the CPDM LED display and the error was reported on the dust card with the time stamp of 11:55. The unit was removed from the EMI room; the sample run was stopped using the CPDM software, and the data were downloaded. The software diagnostics were performed twice on the unit after the failure, and it passed all tests.

Dust Data Card: (Serial Number 0509005)

Wearer ID

Contractor Code
0

Company Name
***

Sampling Time (minutes)
301

MMU DA/SA
0

Part 90 Miner Employee Number
(N/A)

Results
MRE Equivalent: Yes
Shift Limit: 2.00 mg/m³
EOS Final Concentration: -0.100 mg/m³

Mine ID Number
0

Mine Name
***

Date Sampled
Tuesday, April 19, 2011 07:00:00

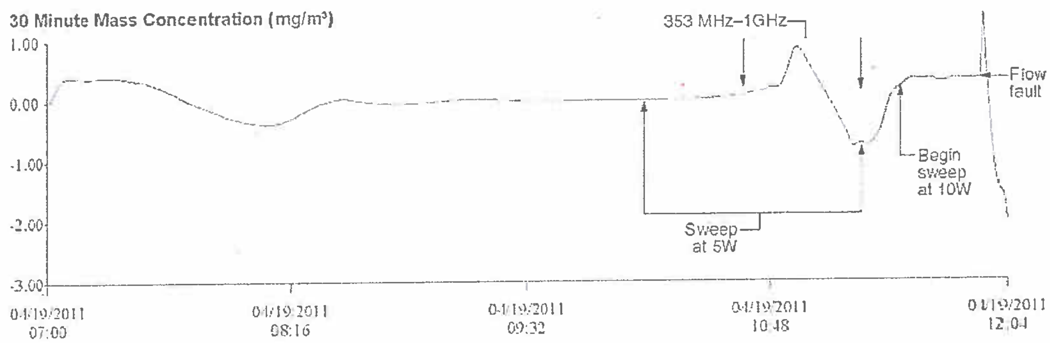
Type of Sample
Unknown

Occ Code
0

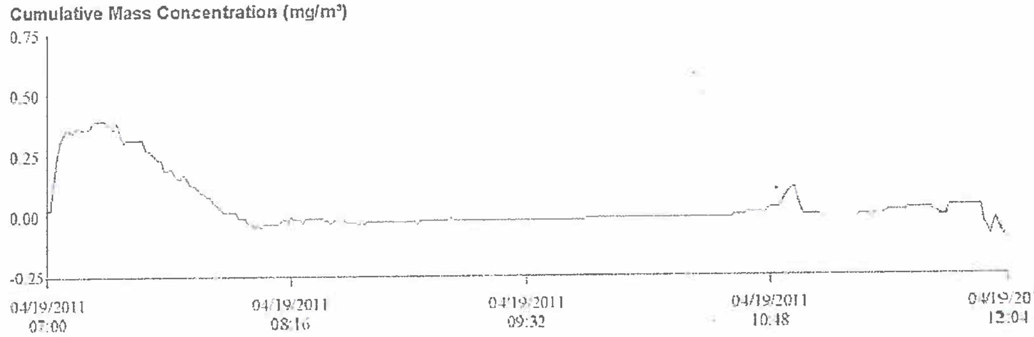
Certification Officer
0

Errors
04/19/2011 11:55:07 - Flow out of range

30 Minute Mass Concentration (mg/m³)



Cumulative Mass Concentration (mg/m³)



Notes:

Figure 14. Dust card—EMI testing: 5 W and 10 W

The unit was reprogrammed to begin a second monitoring period. The CPDM unit passed the warm-up period and the series of frequency sweeps at 10 W continued beginning at 580 MHz. The dust card for this second monitoring period is shown in Figure 15. The CPDM unit continued to run without any reported errors on the LED display for the remaining portion of the frequency sweep, from 580 MHz to 1 GHz, although tonal changes were observed during the remaining sweep. The airborne concentration also increased to a peak of 1.2 mg/m^3 at 631 MHz before dropping suddenly, similar to the drop that occurred at 580 MHz during the 5-W test. The unit did not report any errors on the LED display during the remainder of the sweep at 10 W.

After the sweep at 10 W, additional tests, called threshold tests, were made to identify the frequency and power level above which the pump on the CPDM unit would to cease to operate. More narrowed increments were used between 451 MHz and 580 MHz. The following table summarizes the power levels at which the pump motor would change tone. When signals with power levels above those noted in Table 7 were applied to the CPDM unit, the pump would stop altogether. Once the power level was reduced, the pump would begin to operate again. The on/off nature of the pump was tested for the frequencies shown below. No errors were reported by the CPDM on the LED display during this time, nor were any errors reported by the CPDM on the dust card as shown in Figure 15.

Table 7. EMI threshold tests of CPDM

Frequency (Hz)	Level at Which CPDM Motor Changes Tone (Watts)
531.3	9.4
531.1	9.0
511.0	6.0
491.9	6.5
471.0	7.0
451.0	9.2
431.0	10.0 (no change)
411.0	10.0 (no change)

Dust Data Card: (Serial Number 0509005)

Wearer ID

Contractor Code
0

Company Name
***

Sampling Time (minutes)
84

MMU DA/SA
0

Part 90 Miner Employee Number
(N/A)

Results
MRE Equivalent: Yes
Shift Limit: 2.00 mg/m³
EOS Final Concentration: 0.021 mg/m³

Mine ID Number
0

Mine Name
***

Date Sampled
Tuesday, April 19, 2011 12:48:00

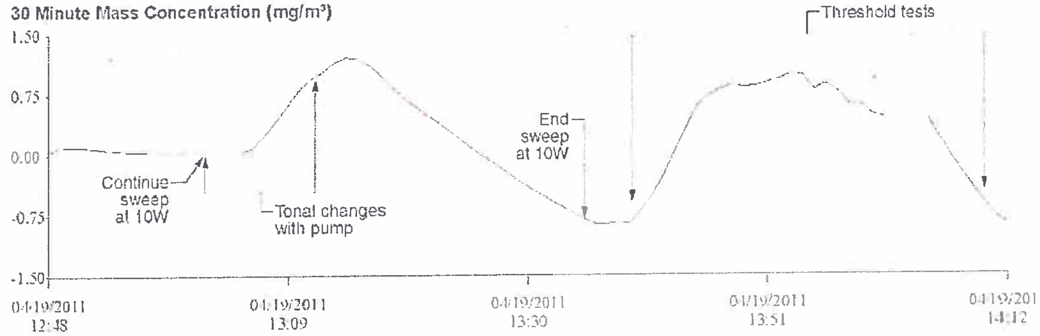
Type of Sample
Unknown

Occ Code
0

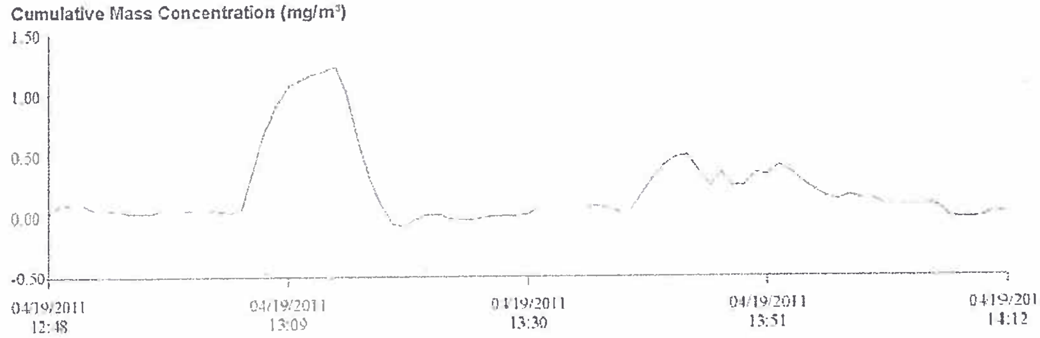
Certification Officer
0

Errors
(No errors)

30 Minute Mass Concentration (mg/m³)



Cumulative Mass Concentration (mg/m³)



Notes:

Figure 15. Dust card—EMI testing: 10 W

7 Conclusions

Based on the results of the laboratory testing discussed in this report and on our experience working with the CPDM, we have concluded that, although the CPDM offers promise as an advancement for monitoring underground coal-mine dust levels, it is not reliable for continuous monitoring in underground mining environments. As such, it should not be used for compliance citation purposes.

Chamber tests at elevated temperature and humidity levels have shown considerable differences among the CPDM units, at times varying by more than the 1mg/m^3, the regulatory limit under the proposed rule. Differences between the CPDM and the traditional gravimetric method, ranging from less than 1 mg/m^3 to several times the proposed limit, were also observed under these strenuous environmental conditions. These differences, reported here under limited laboratory testing, could frequently occur because of the significant increase in CPDM sampling required by the proposed rule.

Although a CPDM did not report any errors on the LED display or dust card during a series of drop tests and shock tests, the CPDM unit did experience problems during the electromagnetic interference tests. Variations in concentrations in a controlled room were seen, and the pump of the CPDM unit slowed down and eventually stopped when signals between 6.0 W and 10 W were received by the CPDM. The CPDM did not report any errors when the pumped stopped. The failure of the CPDM motor and the lack of reporting by the CPDM unit when EMI is applied, is concerning. If a miner wearing this device were to enter an area, even momentarily, where these signals are present, the CPDM could fault without reporting an error. Only a portion of the electromagnetic spectrum that could occur in an underground mining environment could be tested at this time. It is suggested that the mining environment be monitored to develop a full understanding of the electromagnetic signals that exist inside a mine, and that further testing of the CPDM in this environment be conducted.

The CPDM unit is clearly valuable if used as a tool to provide data to mine operators in their efforts to reduce miner exposures to respirable coal dust. The results of the laboratory testing underscore, however, that there is insufficient industry and laboratory experience with the CPDM to determine the full range of potential error conditions, reasons for variability in reported concentrations, practical problems during use, or what these conditions will mean for data validity. The significant increase in the number of samples required by the proposed rule will only serve to highlight these factors which effect data accuracy. Hence, we conclude that these legitimate concerns need to be resolved before extensively using the CPDM for compliance purposes.

8 References

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Volkwein JC, Vinson RP, McWilliams LJ, Tuchman DP, Mischler SE. 2004. Performance of a new personal respirable dust monitor for mine use. Pittsburgh, PA: DHHS (NIOSH) Publication No. 2004– 151, RI 9663.

Attachment A

E-Labs Environmental Test Report No. 2341-B (2011)

Talcum Powder Specification Sheet

Forensic Analytical Laboratory Report (2011)