A review and critique of the MSHA proposed regulation (October 19, 2010) for evaluation and control of respirable coal mine dust exposures.

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Executive Summary

In October 2010 the Mine Safety and Health Administration (MSHA) published a proposed rule to revise the existing standards governing exposure to and control of respirable coal mine dust. The proposed changes constitute a complete revamping of the respirable coal mine dust (RCMD) exposure limits and monitoring approach, including a new sampling device, extensive changes to how RCMD is monitored and controlled and how compliance is determined. In this report, each of the major changes will be described and evaluated.

The proposed MSHA changes we evaluated resulted in our opinion that:

- This new Continuous Personal Dust Monitor (CPDM) has not been demonstrated to be reliable or accurate when used in the general coal mine environment.
- The use of area sampling is not a valid approach for determining miner RCMD exposures.
- The proposed Sampling and Analytical Error (SAE) used in calculating the proposed Excessive Value concentrations is based on unverified assumptions and will result in unjustified non-compliance determinations.
- The SAE for the new personal coal mine dust sampling device was estimated from studies by NIOSH conducted in selected mines that do not appear to be representative of conditions that exist in all mines.
- The underlying assumption that errors inherent in the sampling and analytical system are normally distributed and, therefore, estimated without verification, is unsupported by observations or specific studies.
- The reported relationship between the CPDM results and the MRE values, 1.05, is questionable and likely lower.

- The proposed use of a daily exposure limit exposures appears to have been calculated assuming a daily sampling and analytical error (SAE). In addition, the MSHA proposal states that a Weekly Permissible Accumulated Exposure (WPAE) will be evaluated without addressing any associated errors, e.g. SAE.
- Proper control of RCMD to below regulatory limits will not assure mine operators that they will not be cited for false over exposures due to the proposed sampling strategy and its use of continuous sampling on all shifts.

In conclusion, we find the MSHA proposal is seriously flawed and often without a proper scientific or technologic basis. While the technology described appears to be a major step forward in the understanding of RCMD exposures and, therefore, the occurrence of related pulmonary disease, the published scheme for measurement and control of respirable coal mine dust exposures fails to recognize and properly account for a variety of errors. These unaccounted for errors can severely impact a mine operator's ability to comply with the projected changes in coal mine dust regulations resulting in spurious citations and wasted resources.

Background

In a recent published proposed regulation MSHA is seeking to completely revamp their Respirable Coal Mine Dust (RCMD) sampling program.[1] In this proposed regulation, MSHA is outlines a number of new approaches to their RCMD compliance program. MSHA is proposing a reduced allowable exposure limit to be phased in over a two year period, reducing the allowable RCMD exposure for coal miners from 2.0 mg/m^3 to 1.0 mg/m^3. MSHA also is proposing to further reduce the limit based on extended work shifts. The third major change MSHA proposes is to phase in a new, direct readout continuous personal dust sampling system, for full time exposure monitoring.

The following define some of the MSHA proposed changes in the exposure monitoring program for compliance. We note that the proposed sampling device, a direct reading, data accumulating dosimeter, is a potentially significant improvement over the existing methodology which is more than 40 years old. The new sampling device appears to require extensive testing and modifications or corrections, based on user result reports.

Discussion of Proposed Changes in the Respirable Coal Mine Dust Sampling Program

- **A new personal sampling system within a two year period.**

A new respirable coal mine dust personal sampling system will be required for all coal mines within a two year period.[1] This system replaces a respirable coal mine dust sampling (Coal Mine Dust Personal Sample Unit, CMDPSU) and analysis system that have been in place for more than 30 years. The proposed new respirable coal mine dust sampling system employs a technology is that is described in detail by Pataschnick, et al.[2]

This new device is described in detail by Page, et al.[3] This new system uses a dust measuring system that allows for continuous monitoring and recording of respirable dust levels. This system has undergone testing and has been described by NIOSH as "accurate, " according to a NIOSH definition, proposed to be adopted by MSHA (± 25% of the true value with 95% confidence) respirable dust exposure measurements.[4-7] However, reports at public hearings of field testing by Alliance Coal (and other mine operators) demonstrate far higher variability and differences from current sampler results during a study of almost 1000 paired samples.

While testing has ongoing for a number of years, the wide spread application of this new technology still leaves many questions. How robust are these new and relatively expensive dust monitoring systems? NIOSH claims that the monitoring systems are electromechanically robust and they experienced few failures during almost 11,000 hours of testing. However, their data do reveal that the NIOSH investigators experienced numerous system failures during their experimentation. This indicates that while this new system may function adequately when engineering expertise is readily available (the NIOSH experimenters were individuals with engineering expertise), this same "reliability" may not exist when these systems are placed in operating coal mines. The operating experience data provided by the Alliance Coal study described in the public hearing transcript indicates that the new sampling devices are not as robust and the NIOSH engineers claim. In the Alliance Coal study, 35% if the 40 devices used had to be returned to the factory for repair. Again, these data do not support the NIOSH claims that the instrument is reliable, nor the MSHA claim that they are feasible for universal deployment in the mines

- **MSHA is proposing the continued use area sample monitoring with personal sampler equipment.**

It is clear from the industrial hygiene and scientific literature that ***area*** air samples do not represent personal exposures and, therefore, do not provide information for either estimating RCMD exposures or determining the efficacy of control measures. The use of area samples as the basis for health risk assessment or compliance determinations assumes that a miner is exposed to the measured RCMD of that area. This, however, does not make much sense for a standard based on personal exposures intended to prevent risk of health effects. and, when miners are wearing a sampler, their personal exposure is being monitored, unlike when a sampler is placed in a location that miners may or may not travel through. The miner's exposure to RCMD in the area traveled will already be recorded by a personal sampler worn by that miner. It is unclear how collecting area samples will augment the MSHA RCMD protection / compliance strategy. The use of area sample for the control of individual miner exposures implies that the time a miner may spend in a monitored area has a significant impact on his/her exposure and that the miner exposure can be assumed to be approximated by these measurements. This belief has not been supported or validated in the industrial hygiene/scientific literature.[8]

- **The proposed Sampling and Analytical Error used in calculation of Excessive Value concentrations is based on unverified assumptions.**

The tests for compliance are based on the assumption that the random errors have a normal (Gaussian) distribution. While that is not an unusual assumption, since it is sometimes a reasonable approximation (i.e., a bell-shape curve), it is a fact that the errors do NOT come from an actual normal distribution. The question is how "good" is the approximation? Even a small discrepancy in the approximation (e.g., the tail of the distribution) can result in unintended errors in the probability of compliance or noncompliance, as will be illustrated later. The normality assumption for errors associated with the estimate of the SAE has not been shown to be justified. The result is that the SAE is not supported by the science and statistical analysis conducted by MSHA.

- **The reported relationship between the CPDM results and the MRE values, 1.05, is highly questionable. The data from Page, et al., actually demonstrate a slope (MRE conversion factor) of 1.01.**

To illustrate why the proposed value is problematic consider the assumptions and analyses leading to the Mining Research Establishment (MRE) conversion factor of 1.05 for the CDPM. To further understand the nature of this relationship as described by Page, et al. the following analysis shows at how the conversion factor was derived in detail.

To illustrate why the MSHA 1.05 MRE conversion value is problematic consider the assumptions and analyses leading to the conversion factor for the CDPM. First, these two methods use completely different particulate collection methodologies. The method by the British Research Mining Council (BRMC) used to collect respirable coal mine dust exposure estimates in the study that serves as the "gold standard" was a horizontal elutriator. This device employs gravitational settling as the principal particle separation technique. Both the CMDPSU and CDPM both use cyclones, albeit, variations of these devices, to separate the "respirable" particulate, defined differently than the MRE, from the non-respirable. Previous studies of the relationship between the CMDPSU and the BRMC method established a relationship suggesting that the BRMC sampling device collected approximately 1.38 times as much particulate mass as the CMDPSU.

The data, assumptions and analyses of the proposed MSHA MRE/CMDPSU relationship are published in "Equivalency of a personal dust monitor to the current United States coal mine respirable dust sampler" by Page et al. (2008). Table B-1, Appendix II, from that document was used to construct Table 1 of these comments. The columns **MSHA District, Field Office, PDM, Void, CMDPSU, Void, and Notes** (including the footnotes) are directly from that table, with the first column, **Order**, indicating the row position in Table B-1. Section 3.1 of that manuscript described a negative "bias correction factor" of 6.6% and a "thermal zero drift bias correction" of 25.5 mg (0.024 mg/m^3 for an 8-hour sample) that were applied for "all subsequent data analysis." The 6.6% bias was apparently estimated from additional analysis (it was "estimated from previous empirical work") of the data in Volkwein et al. (2006). However, while this data apparently shows a tendency for a negative bias, applying a single correction for all values is not justified. Page et al. (2007) shows that the zero drift bias is an average of 25.5 mg, ranging from 7.5 to 56.6 mg (the 95% CI for the mean was 23.6 - 27.4). The column headed **PDM Corrected** in Table 1 was thus obtained from the **PDM** column by multiplying by 1.066 and subtracting 0.024. The weights **(Wt)** for the weighted linear regression are calculated based on equation (2) from Page et al., using the inverse of $(0.011)^2 + 0.0155x\ (\text{PDM corrected})^2$ (another complex model that required an iterative solution).[3] The last two columns show the fraction of the total weights and the cumulative sum of the fractions.

To check on the calculations, a weighted linear regression was computed using only the 129 paired samples in Table 1 that have PDM and CMDPSU values. The regression gave a slope of 1.01 and an intercept of 0.018, which agree with Page et al.[3] The authors then went on for about half a page of discussion that concluded that the analysis should not include an intercept, which should be forced equal to zero.

There are several issues that can be discussed regarding the assumptions, calculations and conclusions leading up to the conversion factor of 1.05 that resulted from the regression with zero intercept. First, consider the weights used to calculate the weighted regression.(See Appendix II) The lowest 11 (8.5% of the 129 values) PDM values (corrected PDM values of 0.0826 and less) were given over 50% of the weights. The lowest 41 (32% of the 129 values) PDM values (corrected PDM values of 0.3203 and less) were given over 90% of the weights. **The heavy weighting of the lowest PDM values essentially assures the nonzero intercept.** The analyses that are presented are overwhelmingly determined by PDM values that are, in large part, below the practical range of concern in many mining operations.

The weighted regression analyses given by Page et al. (2008) have furthermore used a methodology that should be questioned. It was argued earlier in their Analysis section that there is no need to specifically consider random measurement error in the predictor variable (the PDM measurement) and that it can be demonstrated that the random error in the PDM can be classified as one of the embodiments of the Berkson case. That is not obvious and was not justified. If there is an underlying linear relationship for the "true" CDPM value (i.e., the mean, not the mean plus the error term), then there is no question that the regression analysis used by the authors gives a biased estimate of the slope (tending to underestimate it). The models that they fit assume that the abscissa (X or horizontal axis) corrected PDM values are known without error or that the error term in the model is independent of the PDM value

(Berkson case). Furthermore, it can be argued that the model selected (forcing the zero intercept) overestimated the slope, which is exaggerated by the weighting scheme.

While there is an MSHA assumption that CPDM and CMDPSU provide similar monitoring results, the side by side field testing by Alliance Coal show significant differences (Figures 1 and 2).

The precision is determined from "CV total corresponding to the CPDM" which was estimated as 7.8 percent based on in-mine studies and as cited from Volkwein et al. (2006). In a subsequent publication, Page et al. estimate the 1.05 multiplier for the CPDM values to "convert" this concentration to an equivalent 8-hour exposure as measured by the Mining Research Establishment (MRE) instrument. It is fundamental in statistics that when a random variable is multiplied by a constant (1.05 here), the variance of the product is the square of the constant times the variance of the random variable. Thus, the standard deviation of the CPDM reading multiplied by 1.05 should be estimated by 0.078 multiplied by 1.05. That fundamental statistical fact is ignored and is a clear oversight on the part of the authors. The numerous studies and documents cited in the proposed regulations show a broad understanding of statistical concepts, theory and analyses (e.g., citing Berkson case and the Central Limit Theorem, the use of transformations, etc.), so it is peculiar that something so basic is overlooked.

Additionally, the data used by Page, et al. were collected from 129 mines and represent a single days sample from each of those mines. In figure 1 below, the Page, et al, data after applying the MRE multiplier show little variation when compared with the PDM data. However, when this same comparison is made in Figure 2 with multiple samples collected from a single mine, a mine where exposures typically average less than the proposed standard of 1.0 mg/m^3, much more variation can be observed.

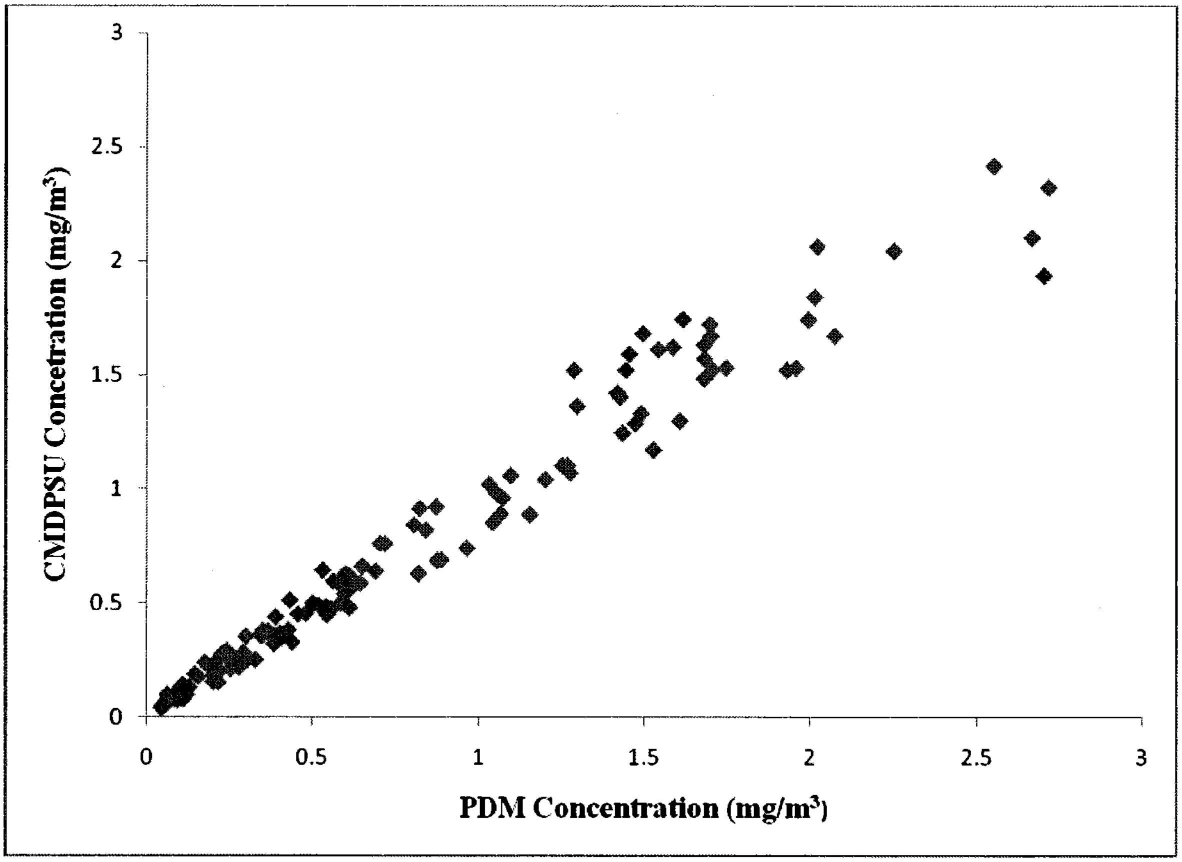

Figure 1. Data from Page, et al. representing 129 paired samples collected from 129 separate mining operations. CMDPSU data have already been multiplied by 1.38 to approximate MRE data. (See Appendix II)

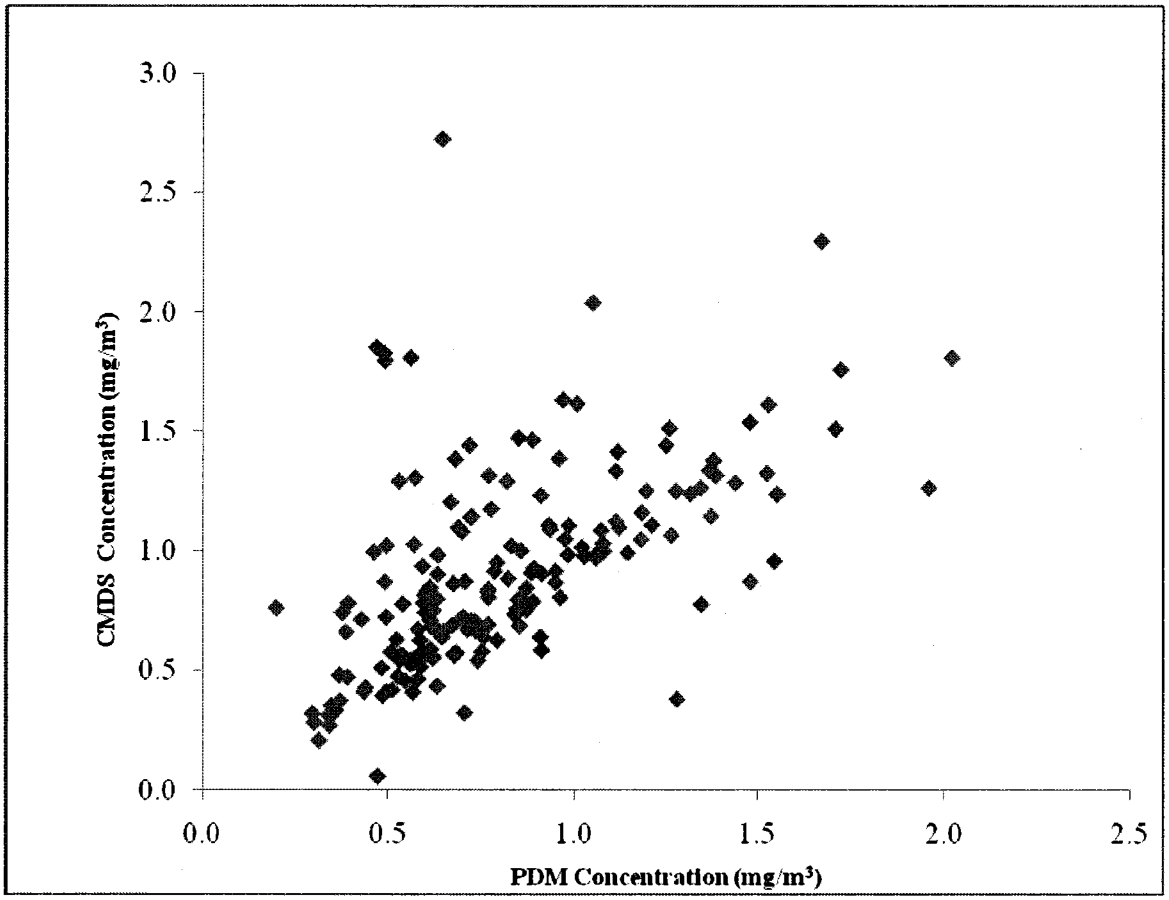

Figure 2. 170 Paired samples from the Dotiki Mine, Alliance Coal. CMDPSU data have already been multiplied by 1.38 to approximate MRE data

- **MSHA proposes using a statistical approach to determine compliance with the proposed respirable coal mine dust standard that emphasizes the upper 95% confidence limit for compliance determinations.**

This is however only one-half of the issue. For mine operators to determine compliance with the proposed dust standard, the average RCMD concentration would have to be less than the existing standard, around 0.5-0.7 mg/m^3. This approach effectively establishes a "de facto" RCMD standard in this target range.

As a result, hypothetically, for a single designated operation, with miners working 8 hour shifts, 52 weeks per year, in an environment that is always just below the standard, there would be an average of over 54 citations per year. That is based on only the single-day citations. Of course, the number of citations would vary depending on shift lengths.

Under this proposed approach the daily average personal exposure of miners will be estimated using the continuous personal dust monitor (CPDM) and accumulated until the work week has ended or they have accumulated an estimated week's worth of exposure to RCMD. MSHA has indicated what single day exposure values will be considered non-complaint exposures, by defining what are called excessive concentration values (ECVs). ECV values are based on the assumption of the upper 95% confidence sampling and analytical error established under controlled studies. Additionally, MSHA has defined a weekly accumulated exposure (WAE) and a weekly permissible accumulated exposure (WPAE). **The establishment of a single day ECV for use in a multi-day compliance approach ignores the contribution of previous or successive day exposures which may reduce the WAE to an acceptable value.** Additionally, the daily and WPAE concepts assume that these time frames, an 8 or 40 hour exposure, is relevant to the development of disease. This has not been demonstrated in the scientific/medical literature.

■ **The proposed use of daily exposure limits that have been calculated using coefficients of variation (CV_ts) purported to related "entirely to variability due measurement error." However, the MSHA proposed rules discussion of the Weekly Personal Accumulated Exposure (WPAE) curiously makes no mention of measurement or any other associated errors.**

The use of the single day SAE will underestimate the accumulated errors incurred during a multi-sampling protocol. If the sampling covers 4 days, the accumulated errors will now result in a coefficient of variation for the entire period that is approximately 1/2 that experienced for a single day. In other words, if we assume that the original estimates of the CV provided by Paige are correct after multiplying by 1.05, the total CV for a 40 hour shift completed in 4 days (10 hr. work days) would approximate 3.9%. A CV of this magnitude would indicate that the error bars around an accumulated exposure of 80 mg-hr./m^3, the accumulated exposure presented by MSHA as the target exposure, $\pm$ 5.3. A citable exposure would then have to be greater than 85.3 mg-hr/m^3, not 80 mg-hr/m^3 as noted in the proposed regulation. This approach does assume that what MSHA has presented is correct and scientifically defensible, something we take issue with.

To illustrate how the probabilities can be impacted by departing from the conclusions put forth in the proposed regulations, first suppose that the assumptions and assertions are correct and hypothetically the **underlying airborne dust levels are a constant 2 mg/m^3.** Under such conditions, the probability that at least one out of five eight-hour samples is greater than the ECV value in Table 70-2 in the Proposed Regulations is 0.217. The chance that either the maximum of the five exceeds the ECV value or the average of the five exceeds 2.0 (which is equivalent to the WAE exceeding the WPAE of 40X2.0 = 80 mg-hr/m^3) is approximately 0.53. For ease of calculation, the total has been estimated using Monte Carlo techniques, since the covariance matrix of the multivariate normal of the five independent samples and the average (or sum) of the five is singular. If the constant 1.05 is used to correct the underlying standard deviation, , the probability that at least one out of five eight-hour samples is greater than the ECV value in Table 70-2 in the Proposed Regulations is 0.251. The chance that either the maximum of the five exceeds the ECV value or the average of the five exceeds 2.0 (which is equivalent to the WAE exceeding the WPAE of 40X2.0 = 80 mg-hr/m^3) is approximately 0.54. Similar differences can be illustrated for other values of the "applicable" standard. Suppose the underlying dust levels are a constant 1.95 mg/m^3. If the assumptions in the Proposal are assumed, the probability that at least one out of five eight-hour samples is greater than the ECV value in Table 70-2 in the Proposed Regulations is 0.100; and the chance that either the maximum of the five exceeds the ECV value or the average of the five exceeds 2.0 (which is equivalent to the WAE exceeding the WPAE of 40X2.0 = 80 mg-hr/m^3) is approximately 0.26. If the 1.05 constant is accounted for, the probability that at least one out of five eight-hour samples is greater than the ECV value in Table 70-2 in the Proposed Regulations is 0.124; and the chance that either the maximum of the five exceeds the ECV value or the average of the five exceeds 2.0 (which is equivalent to the WAE exceeding the WPAE of 40X2.0 = 80 mg-hr/m^3) is approximately 0.28. It is thus apparent that if the airborne levels are at or slightly below the applicable standard taking the constant into account can have a notable impact.

The illustration in the previous paragraph was for only a single worker for a single week. If a 50 week year is considered for a single worker with the assumptions in the proposal, and the underlying dust levels are a constant 1.95 mg/m^3, it is virtually certain that at least one week will have either the maximum of the five exceeding the ECV value or the average of the five exceeding 2.0. In fact, on average each year would have about 13 weeks with such a finding. Taking the 1.05 constant into account, the virtual certainty increases and on average each year would have about 14 weeks with such a finding. These computations have been presented to both illustrate the effect of the constant term as well as to show that even if a workplace is constantly slightly below the applicable standard, many findings of noncompliance will result under the proposed regulations. Also, these examples have only taken a single worker into account. If a DO is considered, there would be at least 3 workers monitored every week. Thus the number of noncompliance findings would average at least 40 every year in these examples.

References

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3. Page, SJ, Volkwein, JC, Vinson, RP, Joy, JR, Mischler, SE , Tuchman, DP and McWilliams, LJ. Equivalency of a personal dust monitor to the current United States coal mine respirable dust sampler. J Environ Monit Jan; 10(1):96-101 2008.

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Appendix I

While there appear to be clear advantages to using CDPM for monitoring dust levels, it is also apparent that the proposed regulations have not adequately accounted for the precision of the technique in actual use.

The proposal asserts that for a dust concentration equal to S, the standard deviation for a CMDPSU measurement is equal to

$$[(0.14)^2 + 2S^2\,(0.05)^2]^{1/2}$$

and the standard deviation for a CPDM measurement, including the 1.05 multiplier, is equal to

$$S(0.078)$$

Also, the means of the two measurements should be equal. Thus, if X represents the CMPDSU measurement, with mean μ_x, and Y represent the CPDM measurement, with mean μ_y, then

$$\mu_x = \mu_y = \mu$$

The expected value of the average of X and Y is equal to μ.

$$E(X+Y)/2 = \mu.$$

$$\text{Variance}[(X+Y)/2] = [\text{Variance}(X) + \text{Variance}(Y)]/4$$

And

$$E(X-Y)^2 = \text{Variance}(X) + \text{Variance}(Y)$$

Thus, the coefficient of variation of the sample mean (X+Y)/2 is given by

$$[\text{Variance}(X) + \text{Variance}(Y)]^{1/2}/(2\mu)$$

and can be estimated by

$\{[(X-Y)^2]^{1/2}\}/[X+Y]$

To illustrate empirical coefficients that should occur if the assumptions in the proposed regulations are correct, a Monte Carlo investigation using the above assumptions is given in Chart 1. First a "true mean" was randomly selected between 0.5 and 1.5 mg/m^3, and then CDPM and CMDPSU samples were selected with the above parameters. Chart 1 contains 250 such samples, with sample means between 0.5 and 1.5.

There are over 900 empirical paired personal samples from actual mining operators available from Alliance. Chart 2 contains 250 of the paired samples, with sample means between 0.5 and 1.5, selected randomly from the 900 Alliance samples.

While the two charts are not comparable on a one-to-one basis, if the field precision and accuracy are close to the claims of the proposal, they should show similar patterns. There are clear, substantial differences between Charts 1 and 2. Basically, if the accuracies of the two methods are even close, the clear differences between the Charts illustrate that the theoretical precision in the proposed regulations is far less than the precision shown by empirical data from real mining operations. Of course, difference in the accuracies would also contribute to the clear increase in values in Chart 2 over Chart 1, but it is believed that a significant contribution is from the claimed precisions.

Chart 1. Monte Carlo Coeffients of Variation from a Random Sample of 250 Paired Personal Samples of CPDM and CMPDSU with Averages Between 0.5 and 1.5 mg per cubic meter

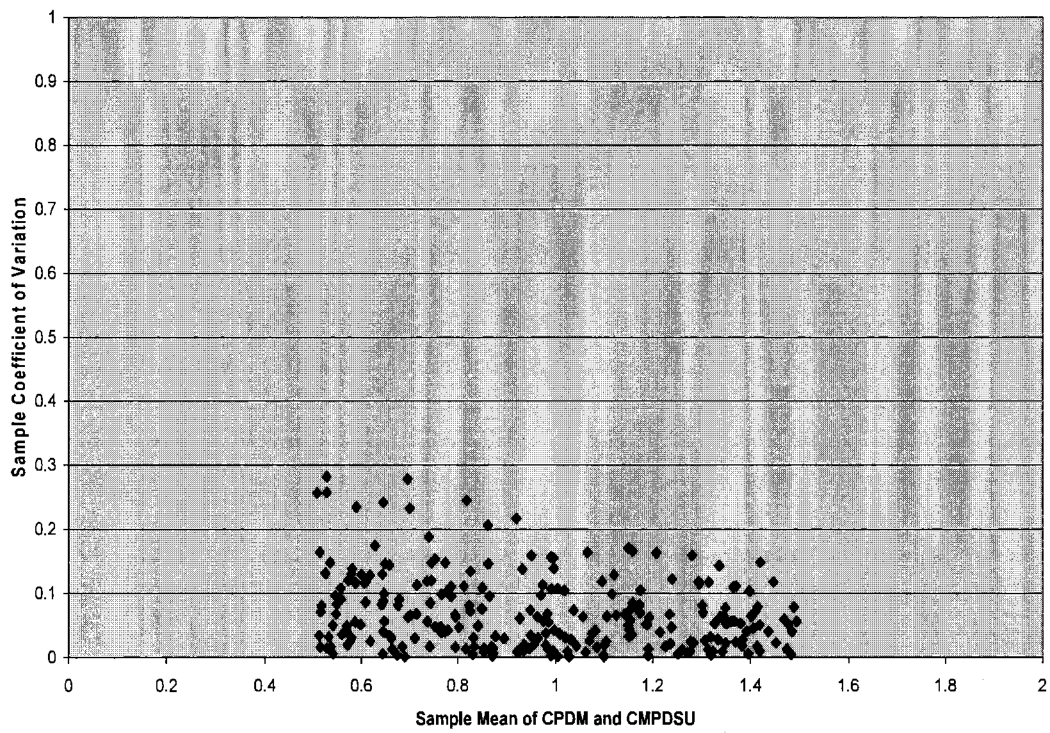
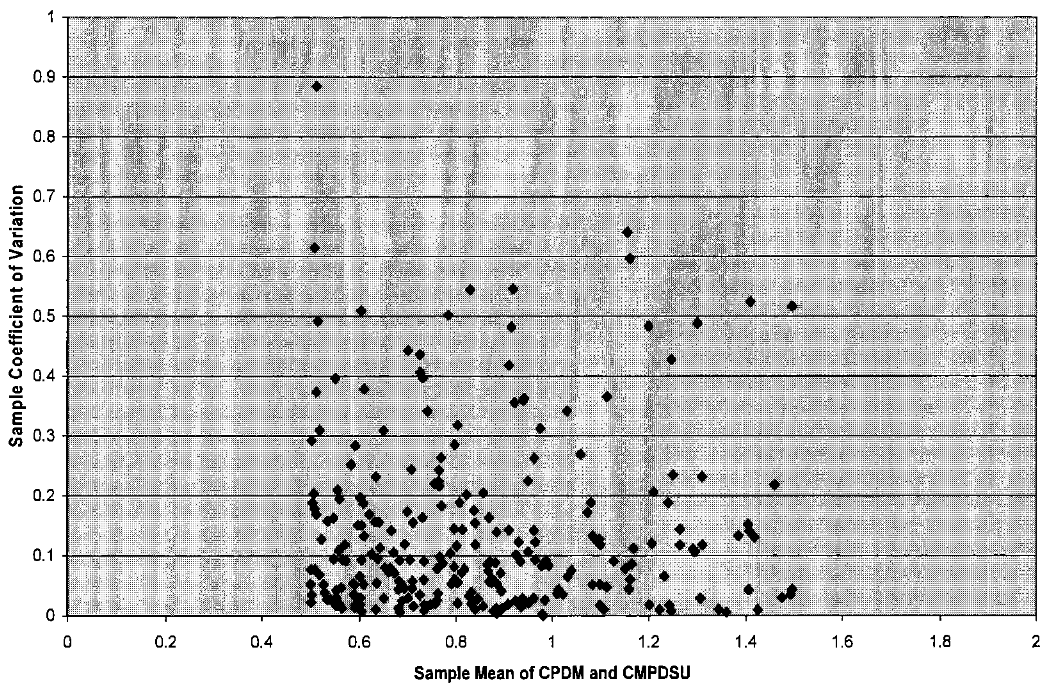


Chart 2. Empirical Coeffients of Variation from a Random Sample of 250 Paired Personal Samples of CPDM and CMPDSU with Averages Between 0.5 and 1.5 mg per cubic meter .



Appendix II

TABLE 1, DERIVED FROM TABLE B-1 OF PAGE ET AL. (2008)

Order	MSHA District	Field Office	PDM	CMDPSU	PDM corrected	Wt.	Fraction of tot. wts.	Cum sum: frac. wts
1	6	Whitesburg-KY	0.041	0.047	0.02	2575.2	0.06252	0.06252
2	4	Pineville-WV	0.05	0.055	0.029	1164.8	0.05913	0.12165
3	7	Barbourville-KY	0.05	0.048	0.029	1164.8	0.05913	0.18079
4	6	Whitesburg-KY	0.073	0.063	0.054	345.3	0.04787	0.22866
5	6	Elkhorn City-KY	0.076	0.097	0.057	307.6	0.04634	0.275
6	5	Norton-VA	0.08	0.078	0.061	266.3	0.04432	0.31931
7	6	Elkhorn City-KY	0.08	0.114	0.061	266.3	0.04432	0.36363
8	6	Pikeville-KY	0.08	0.088	0.061	266.3	0.04432	0.40794
9	4	Logan-WV	0.095	0.088	0.077	167.5	0.03719	0.44513
10	5	Norton-VA	0.1	0.124	0.083	146.6	0.03502	0.48016
11	5	Norton-VA	0.1	0.065	0.083	146.6	0.03502	0.51518
12	2	Indiana-PA	0.115	0.109	0.099	102.9	0.02923	0.54441
13	6	Martin-KY	0.119	0.098	0.103	94.53	0.02787	0.57228
14	2	Kittanning-PA	0.126	0.104	0.11	82.17	0.02565	0.59793
15	9	Delta-CO	0.129	0.129	0.114	77.61	0.02476	0.62269
17	2	Ruff Creek-PA	0.134	0.132	0.119	70.8	0.02336	0.64606
18	5	Norton-VA	0.14	0.112	0.125	63.75	0.02181	0.66787
19	2	Kittanning-PA	0.143	0.113	0.128	60.62	0.02108	0.68895
20	9	Craig-CO	0.155	0.22	0.141	50.14	0.01846	0.70741
21	9	Castle Dale-UT	0.158	0.205	0.144	47.94	0.01787	0.72528
22	4	Princeton-WVA	0.18	0.16	0.168	35.48	0.01424	0.73952

Order	MSHA District	Field Office	PDM	CMDPSU	PDM corrected	Wt.	Fraction of tot. wts.	Cum sum: frac. wts
25	4	Logan-WV	0.204	0.224	0.193	26.72	0.01133	0.77718
26	2	Ruff Creek-PA	0.213	0.257	0.203	24.25	0.01045	0.78763
27	8	Benton-IL	0.22	0.282	0.211	22.56	0.00983	0.79746
28	7	Jacksboro-TN	0.222	0.195	0.213	22.11	0.00966	0.80712
29	2	Kittanning-PA	0.24	0.18	0.232	18.6	0.00832	0.81544
30	8	Hillsboro-IL	0.24	0.276	0.232	18.6	0.00832	0.82377
31	9	Castle Dale-UT	0.248	0.301	0.24	17.31	0.00781	0.83158
32	11	Hueytown-AL	0.253	0.331	0.246	16.57	0.00752	0.83909
33	2	Ruff Creek-PA	0.254	0.22	0.247	16.42	0.00746	0.84655
34	10	Beaver Dam-KY	0.254	0.308	0.247	16.42	0.00746	0.85401
35	9	Craig-CO	0.265	0.246	0.258	14.97	0.00687	0.86088
36	4	Logan-WV	0.265	0.262	0.258	14.97	0.00687	0.86774
37	4	Madison-WV	0.272	0.244	0.266	14.14	0.00652	0.87427
38	4	Pineville-WV	0.28	0.233	0.274	13.27	0.00616	0.88043
39	6	Whitesburg-KY	0.284	0.295	0.279	12.87	0.00599	0.88642
40	2	Johnstown-PA	0.292	0.246	0.287	12.12	0.00567	0.89209
41	3	Morgantown-WV	0.323	0.387	0.32	9.75	0.00464	0.89673
42	8	Benton-IL	0.33	0.441	0.328	9.31	0.00445	0.90118
43	11	Hueytown-AL	0.348	0.408	0.347	8.31	0.004	0.90518
44	3	Morgantown-WV	0.355	0.303	0.354	7.96	0.00384	0.90902
45	5	Norton-VA	0.36	0.415	0.36	7.73	0.00373	0.91275
46	6	Pikeville-KY	0.36	0.352	0.36	7.73	0.00373	0.91648
47	8	Hillsboro-IL	0.36	0.346	0.36	7.73	0.00373	0.92022
48	8	Vincennes-IN	0.36	0.39	0.36	7.73	0.00373	0.92395

Order	MSHA District	Field Office	PDM	CMDPSU	PDM corrected	Wt.	Fraction of tot. wts.	Cum sum: frac. wts
50	4	Logan-WV	0.376	0.368	0.377	7.04	0.00342	0.93092
51	4	Madison-WV	0.379	0.369	0.38	6.92	0.00337	0.93429
52	7	Hindman-KY	0.38	0.354	0.381	6.89	0.00335	0.93764
53	3	St.Clairsville-OH	0.383	0.429	0.384	6.77	0.0033	0.94093
54	7	Harlan-KY	0.44	0.392	0.445	5.05	0.00249	0.94342
55	10	Madisonville-KY	0.449	0.546	0.455	4.84	0.00239	0.94581
57	7	Hazard-KY	0.452	0.459	0.458	4.77	0.00236	0.94817
58	6	Martin-KY	0.455	0.482	0.461	4.7	0.00233	0.95049
59	4	Madison-WV	0.475	0.558	0.482	4.3	0.00213	0.95262
60	5	Vansant-VA	0.48	0.612	0.488	4.2	0.00209	0.95471
61	7	Hindman-KY	0.485	0.543	0.493	4.11	0.00204	0.95675
62	6	Phelps-KY	0.49	0.52	0.498	4.03	0.002	0.95875
63	5	Vansant-VA	0.5	0.503	0.509	3.86	0.00192	0.96067
64	8	Benton-IL	0.5	0.587	0.509	3.86	0.00192	0.96259
65	4	Logan-WV	0.513	0.434	0.523	3.66	0.00182	0.96441
66	3	Morgantown-WV	0.54	0.599	0.552	3.29	0.00164	0.96606
67	9	Delta-CO	0.563	0.614	0.576	3.01	0.00151	0.96756
68	4	Madison-WV	0.57	0.595	0.584	2.94	0.00147	0.96903
69	2	Ruff Creek-PA	0.579	0.588	0.593	2.84	0.00142	0.97046
70	7	Barbourville-KY	0.588	0.644	0.603	2.75	0.00138	0.97184
71	10	Beaver Dam-KY	0.596	0.565	0.611	2.68	0.00134	0.97318
72	6	Pikeville-KY	0.61	0.601	0.626	2.55	0.00128	0.97446
73	5	Norton-VA	0.62	0.612	0.637	2.47	0.00124	0.9757

Order	MSHA District	Field Office	PDM	CMDPSU	PDM corrected	Wt.	Fraction of tot. wts.	Cum sum: frac. wts
75	8	Hillsboro-IL	0.63	0.819	0.648	2.38	0.0012	0.97811
76	4	Pineville-WV	0.64	0.689	0.658	2.31	0.00116	0.97927
77	2	Johnstown-PA	0.644	0.533	0.663	2.28	0.00115	0.98042
78	6	Phelps-KY	0.66	0.65	0.68	2.17	0.00109	0.98151
79	11	Hueytown-AL	0.686	0.875	0.707	2	0.00101	0.98252
80	3	Bridgeport-WV	0.689	0.888	0.71	1.98	0.001	0.98352
81	9	Delta-CO	0.741	0.965	0.766	1.7	0.00086	0.98438
82	5	Norton-VA	0.76	0.717	0.786	1.62	0.00082	0.9852
83	6	Phelps-KY	0.76	0.703	0.786	1.62	0.00082	0.98602
84	8	Vincennes-IN	0.82	0.841	0.85	1.38	0.0007	0.98672
85	9	Craig-CO	0.842	0.805	0.874	1.31	0.00066	0.98738
86	10	Beaver Dam-KY	0.852	1.046	0.884	1.28	0.00065	0.98803
87	9	Price-UT	0.888	1.156	0.923	1.17	0.0006	0.98863
88	4	Mt.Carbon-WV	0.89	1.07	0.925	1.17	0.00059	0.98922
89	6	Whitesburg-KY	0.914	0.822	0.95	1.11	0.00056	0.98978
90	3	Morgantown-WV	0.921	0.872	0.958	1.09	0.00055	0.99034
91	4	Mt. Hope-WV	0.96	1.076	0.999	1	0.00051	0.99085
92	9	Price-UT	0.979	1.059	1.02	0.96	0.00049	0.99134
93	6	Pikeville-KY	1.02	1.035	1.063	0.88	0.00045	0.99179
94	7	Barbourville-KY	1.041	1.203	1.086	0.85	0.00043	0.99222
95	7	Jacksboro-TN	1.058	1.1	1.104	0.82	0.00042	0.99263
96	7	Harlan-KY	1.07	1.28	1.117	0.8	0.00041	0.99304
97	7	Jacksboro-TN	1.103	1.255	1.152	0.75	0.00038	0.99343

Order	MSHA District	Field Office	PDM	CMDPSU	PDM corrected	Wt.	Fraction of tot. wts.	Cum sum: frac. wts
99	10	Madisonville-KY	1.171	1.528	1.224	0.67	0.00034	0.99415
100	10	Madisonville-KY	1.244	1.435	1.302	0.59	0.0003	0.99445
101	4	Logan-WV	1.285	1.473	1.346	0.55	0.00028	0.99473
102	4	Madison-WV	1.297	1.607	1.359	0.54	0.00028	0.99501
103	7	Harlan-KY	1.33	1.491	1.394	0.51	0.00026	0.99527
104	6	Whitesburg-KY	1.362	1.301	1.428	0.49	0.00025	0.99552
105	6	Martin-KY	1.401	1.428	1.469	0.46	0.00024	0.99576
106	3	Morgantown-WV	1.419	1.42	1.489	0.45	0.00023	0.99599
107	4	Madison-WV	1.482	1.68	1.556	0.41	0.00021	0.9962
108	5	Norton-VA	1.52	1.291	1.596	0.39	0.0002	0.9964
109	6	Phelps-KY	1.52	1.445	1.596	0.39	0.0002	0.9966
110	8	Vincennes-IN	1.52	1.93	1.596	0.39	0.0002	0.9968
111	4	Logan-WV	1.522	1.705	1.598	0.39	0.0002	0.997
112	3	Oakland-MD	1.529	1.956	1.606	0.39	0.0002	0.9972
113	5	Vansant-VA	1.53	1.746	1.607	0.39	0.0002	0.9974
114	6	Elkhorn City-KY	1.57	1.681	1.65	0.37	0.00019	0.99759
115	6	Pikeville-KY	1.59	1.455	1.671	0.36	0.00018	0.99777
116	4	Mt. Hope-WV	1.61	1.543	1.692	0.35	0.00018	0.99795
117	7	Harlan-KY	1.62	1.586	1.703	0.34	0.00018	0.99812
118	5	Norton-VA	1.63	1.68	1.714	0.34	0.00017	0.9983
120	7	Jacksboro-TN	1.669	1.7	1.755	0.32	0.00017	0.99846
121	7	Hazard-KY	1.67	2.074	1.756	0.32	0.00017	0.99863
122	7	Harlan-KY	1.68	1.496	1.767	0.32	0.00016	0.99879

Order	MSHA District	Field Office	PDM	CMDPSU	PDM corrected	Wt.	Fraction of tot. wts.	Cum sum: frac. wts
124	4	Mt. Hope-WV	1.74	1.993	1.831	0.3	0.00015	0.9991
125	7	Barbourville-KY	1.742	1.616	1.833	0.3	0.00015	0.99925
126	7	Harlan-KY	1.84	2.012	1.937	0.27	0.00014	0.99939
127	7	Hindman-KY	1.934	2.702	2.038	0.24	0.00012	0.99951
129	6	Martin-KY	2.042	2.25	2.153	0.22	0.00011	0.99962
130	4	Mt. Carbon-WV	2.06	2.02	2.172	0.21	0.00011	0.99973
131	6	Pikeville-KY	2.1	2.666	2.215	0.2	0.0001	0.99984
132	4	Pineville-WV	2.32	2.715	2.449	0.17	0.00009	0.99992
133	4	Logan-WV	2.415	2.55	2.55	0.15	0.00008	1