Continuous Personal Dust Monitor Accuracy Testing
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Introduction

New Continuous Personal Dust Monitors (CPDM) submitted to NIOSH for approval to sample coal mine dust must accurately measure respirable coal mine dust in mine environments. There are two steps in the process which may be done in any order. The manufacturer is required to submit the results of a comparative underground coal mine dust sampling study, where the candidate CPDM is compared to an approved coal mine dust sampling device (currently the Coal Mine Dust Personal Sampling Unit (CMDPSU)). This testing shall follow the guidelines outlined below and shall demonstrate through weighted regression analysis that the mean coefficient of variation with bias correction is equal to or less than 12.8%. The other step involves laboratory testing to determine the electronic and environmental stability.

This testing must be conducted by a private, commercial, academic or other laboratory approved by NIOSH.

Methods

1.0 Comparative Underground Coal Mine Dust Sampling

The manufacturer shall submit evidence that the unit can perform satisfactorily in the underground mine environment. This may be demonstrated according to durability requirements set forth in § 74.7 (g). Coal mine dust sampling will be performed with the same instruments tested in § 74.7 (g) to compare the results of a candidate instrument to the performance of an approved CMDPSU.

1.1 Criteria for mine selection

A stratified random sampling design should be used to select mechanized mining units (MMUs) that are representative of all U.S. underground coal mines. The selected sample of MMUs should be partitioned into mutually exclusive strata that reflect the various coal seams and mining methods found in U. S. underground coal mines. Because of the mine selection process, any mine dust size distribution or coal type effects are accounted for, on average, in the data analyses. A proportionate allocation strategy with different sampling rates among the strata should be used to ensure that the composition of the sampled MMUs is representative of the composition of the population. Sample size should be adequate to insure a statistically robust sample size but in no case be less than about 20% of the current mine workplaces. An example of this technique may be found in Page et al[1].

1.2 Testing procedures

To minimize spatial variability found in mine sampling environments, instrument sampling inlets should be located inside of a Lipmann type sampling container[2,3] with a single low velocity inlet. This procedure ensures that all samplers are exposed to the same atmospheric conditions. The Lipmann container will, at a minimum, include a NIOSH/MSHA approved CMDPSU, the instrument under evaluation and a size distribution measurement instrument -- intended to provide particle size distributions of sampled aerosol and capable of use in face areas of underground coal mines.

Sampling will be conducted in underground coal mines in representative areas where miners normally work. These areas will include a statistically representative mix of longwall, continuous miner, roof bolter, haulage, and outby work sites. Samples will be collected for 8 hours over a range of equivalent concentrations of 10% to 200% of the occupational exposure limit of coal mine dust. Manufacturer recommended flow rates for all instruments will be used and verified through pre- and post-calibration.

1.3 Analysis

Weighted regression analysis is to be used to stabilize the variance for data analysis by estimating the relationship between the variance of the dependent variable and the independent variable. The CPDM testing shall demonstrate through weighted regression analysis that the mean coefficient of variation with bias correction is equal to or less than 12.8%. Appendix A describes the mathematical representation and weight variable estimation. It should be noted that, since the overall purpose is to predict contaminant concentration from an imprecise measurement in the candidate instrument, there is no need to specifically consider random measurement error in the predictor variable. Weighted regression should be performed using SigmaPlot v.9.0[4] or equivalent statistical software.

2.0 Laboratory Testing

The laboratory test procedures will be used to determine the electronic and environmental stability under conditions that may only be rarely encountered in field sampling. Instruments used for this testing shall also be the same as those tested in § 74.7 (g).

2.1 Zero Stability

Demonstration of the zero mass measurement stability over 8 hours will be conducted and the instrument noise will be reported as the limit of detection and limit of quantification. The stability will be equivalent to or better than that of the CMDPSU.

2.2 Electronic Stability

Temperature stability of the electronics of the instrument will also be measured by subjecting the instrument to temperatures that fluctuate from -10 to +40^{o} C. The continuous zero mass stability during the fluctuation conditions should remain equivalent to the ambient zero mass measurements in section 2.1.

2.3 Environmental operating conditions

Sampling in underground coal mines presents extreme environmental conditions. Laboratory testing must include the demonstration of candidate instrument dust measurement performance in the presence of relative humidity of approximately 95% and direct mist type water sprays. The CPDM will be expected to perform on a statistically equivalent basis as the CMPDSU.

Report

The manufacturer shall submit a complete test report in written and electronic format including all raw data, without omission of outlying data, valid data selection procedures, and analysis of the data according to the criteria listed above.

Appendix A

Mathematical representation

Comparison of the CPDM to the CMDPSU will be made using regression analysis. Sampling data typically indicates an error term increasing with the independent variable, or multiplicative error, in addition to the required constant additive error term[5]. As a result, the total sum of squares will largely be influenced by the large dependent variable values and lead to an analysis bias. There are several different remedial data transformations to eliminate, or at least minimize, the non-constant variance problem.

The general equation used by Eagleson and Muller[6] to represent only multiplicative errors can be written as:

Eq. A-1 $Y = g(X)*(\varepsilon_I)$.

In the present analysis,

Y = a CMDPSU response variable,

g(X) = a function of the CPDM predictor variable (X),

ε_I = a normally distributed random multiplicative error term, mean = 1 and variance resulting from spatial variation of the concentration within the sampling chamber, coupled with sampling and analytical error of the CMDPSU.

The only requirement is that g(x) be a smooth function. Eq. A-1 can also be expressed in terms of the usual error term ε with mean = 0, with inclusion of an additive error term, as

Eq. A-2 $Y = g(X)*(1+\varepsilon) + {}_0\varepsilon_0 = g(X) + g(X)*(\varepsilon) + {}_0\varepsilon_0$,

where,

${}_0\varepsilon_0$ = a normally distributed random additive error term with mean = 0 and constant variance $({}_0\sigma)^2$, resulting from weighing imprecision as the true concentration approaches zero.

A decision for g(X) representing the true underlying model for the data must be made. The model should agree with similar published data, previous experience, and be based on sound statistical arguments. Intuitively, one would expect, in the absence of measurement bias, a linear and monotonic relationship (and ideally with zero intercept, unity slope) between different instruments designed and developed to measure the same true but unknown quantity. In this case, that quantity is the airborne respirable coal mine dust concentration.

Weight variable estimation

Weighted regression can directly stabilize the variance if the variance function can be estimated. There are numerous weighting factors that can be used in regression analysis, the more common of which are $(1/X)$ and $(1/X^2)$.[7,8] The data of this investigation will be used to internally estimate the variance relationship of the CMDPSU with the independent CPDM variable. Typical $1/X^2$ weighting assumes that dependent variable variance increases proportionally with X^2 over the entire range of independent variables. However, at low concentration values there is the limiting error term $({}_0\varepsilon_0)$ due to weighing imprecision. The constant variance $({}_0\sigma)^2$ of this error term is known quite accurately for the CMDPSU samples. The proper weight variable is the reciprocal of the true total variance σ_T^2, given by:

Eq. A-3 $$\sigma_T^2 \approx ({}_0\sigma)^2 + (a*RSD)^2*X^2,$$

where the relative standard deviation (RSD) can be considered to be the variation of the dependent variable about the regression line.

The process for estimating the proper weight variable is iterative, using the following procedure for the CMDPSU data:

Step 1: An initial regression of Eq. A-2 using $1/X^2$ weighting is performed to establish initial weight variables, where $g(X) = Y_0 + a*X$.

Step 2: Using the definition of variance, the values $(Y_i - Y_{ip})^2$, representing the variance between the measured Y_i and predicted Y_{ip} from the initial regression of step 1, are calculated.

Step 3: The plot of $(Y_i - Y_{ip})^2$ vs X_i is fit with the function of Eq. A-3. The second weight estimation is then approximated point-by-point as $1/\sigma_T^2$.

Step 4: Perform a weighted regression with the new weight variable.

Steps 2-4 are then repeated with each new estimate of weight variable and $(Y_i - Y_{ip})^2$ until convergence to a solution.

References

[1] Page-SJ, Volkwein-JC, Vinson-RP, Joy-GJ, Mischler-SE, Tuchman-DP, McWilliams-LJ, *J Environ Monit,* 2008 Jan; 10(1):96-101 http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid2734.htm

[2] Blachman-MW, and Lippmann-M, *Am Ind Hyg Assoc J*, 1974, 35, 311-326.

[3] Volkwein-JC, Vinson-RP, Page-SJ, McWilliams-LJ, Joy-GJ, Mischler-SE, Tuchman-DP, Reference: Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2006-145, Report of Investigations 9669, 2006 Sep; :1-55 http://www.cdc.gov/niosh/mining/pubs/pdfs/ri9669.pdf

[4] Systat Software, Inc. SigmaPlot v.9.0, Richmond, CA, 2005.

[5] NIOSH, *The Precision of Coal Mine Dust Sampling*. US Department of Health and Human Services, Public Health Services, Centers for Disease Control, National Institute for Occupational Safety and Health, NTIS Pub. No. PB-85-220721, 1984.

[6] Eagleson-GK, and Muller-HG, *J Royal Stat Soc*, 1997, 59, 173-189.

[7] Neter-J, Wasserman-W and Kutner-MH, in *Applied Linear Statistical Models*, Richard D. Irwin, Inc. 3rd edn., 1990, ch.11, p. 420.

[8] SPSS, Inc. SPSS v.14.0, Chicago, IL., 2004.