Mine Ventilation, De Souza (ed.)
© 2002 Swets & Zeitlinger, Lisse, ISBN 90 5809 387 5

Evaluation of the respirable dust dosimeter for real-time assessment of airborne respirable coal mine dust exposures

R.V. Ramani, J.M. Mutmansky & H. He
Penn State University, University Park, PA, USA

V.A. Marple, B.A. Olson & P.C. Luna
University of Minnesota, Minneapolis, MN, USA

J.C. Volkwein
National Institute for Occupational Safety and Health, Pittsburgh, PA, USA

ABSTRACT: An encouraging development in the search for an instrument that will provide a real-time measurement of the airborne respirable dust exposure of a coal miner is the Volkwein Respirable Dust Dosimeter (RDD). The performance of the Respirable Dust Dosimeter (RDD) was evaluated against that of the Personal Gravimetric Sampler (GRD) under identical conditions in both underground mines and the laboratory. In all, 114 RDDs (48 in underground mines and 66 in laboratory) were used side-by-side with GRDs in carefully designed experiments to generate comparative data. Data from experiments indicate that the respirable dust dosimeter can be used to assess the cumulative respirable dust exposure of an underground coal miner on a real-time basis. In this paper, the details of the design, results, and conclusions of the underground and the laboratory experiments are presented.

1 INTRODUCTION

One of the longstanding needs in the assessment of airborne respirable dust (ARD) in underground coal mines has been the availability of an instrument that can measure in real time the cumulative ARD exposure of an individual miner. Prior studies have indicated that a respirable dust detector tube, developed by NIOSH, has the potential to fulfill the need (Volkwein et al., 1997, 2000). The results of an in-mine and laboratory investigation undertaken to evaluate the performance of a respirable dust dosimeter (RDD) as compared to that of a personal gravimetric sampler (GRD) under identical conditions are presented in this paper. The RDD consists of a detector tube that contains a respirable dust classifier and a pressure-drop filter media, and a low-flow pump with an integral pressure transducer, designated here as LRPT (Figure 1). The display of the RDD is the pressure across the filter media which increases as the mass of dust on the filter increases (Dobrosky, Tuckman, and Vinson, 1997). The photo also shows the T-connection for a higher resolution pressure transducer (HRPT) as well as connection to the pump with LRPT. The comparative instrument (GRD) incorporates a cyclone as the respirable dust classifier (Figure 1). The mass of dust on the filter, together with the flow rate of the pump and the time of sampling, provides the time-weighted concentration of the airborne respirable dust (ARD) in the environment. The performance evaluation consisted of (1) collecting side-by-side airborne respirable dust data with the GRD (i.e., mass of dust on the filter) and the RDD (i.e., the pressure increase across the filter media), and (2) performing comparative analysis. For the purpose of data collection, specially designed experiments were conducted in underground coal mines and in the laboratory.

The research summarized in this paper was conducted under contract to NIOSH and a report detailing the experimental designs, and all the relevant data and results of the study has been submitted to NIOSH (Ramani et al., 2001).

2 IN-MINE EXPERIMENTS

The in-mine evaluation consisted of data collection in two mines (Mine A and Mine B), each in a different coal region. In one mine, sampling was conducted in a room and pillar section, and in the other, in a longwall face. At each mine, ARD was sampled during each shift at two different locations and for a total of four shifts. At each location, three (3) RDDs and six (6) GRDs were used. One RDD was matched with two (2) GRDs such that over a shift of sampling, two one-to-one comparative RDD and GRD data (half-shift and full-shift) were obtained. The average of the three RDD and GRD data provided yet another two comparative data (half-shift and full-shift). Essentially 48 one-to-one comparative data and 16 average comparative data were obtained from each mine. In all, the performance of 48 dosimeters were evaluated in the in-mine experiments.

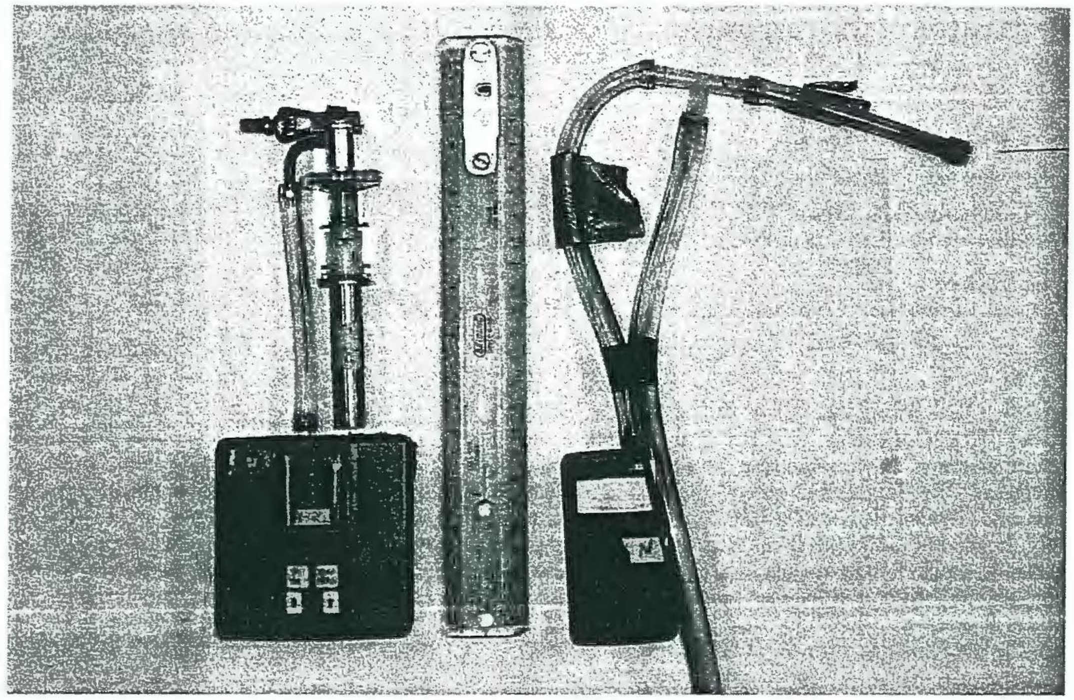

Figure 1. Personal Gravimetric Sampler (Left,Cyclone, Filter, and Pump) and Respirable Dust Dosimeter (Right, Dosimeter Tube and Pump).

3 LABORATORY EXPERIMENTS

The laboratory evaluation consisted of two sets of experiments. In the first set of experiments, the objective was to compare the average pressure increase across six (6) dosimeters with the mass on three (3) personal gravimetric samplers under identical dust loading conditions. The experiments were conducted with three different coal dusts (Pochahontas, Pittsburgh, and Keystone). With each coal dust, measurements were made at 12 different mass loadings resulting in 12 pairs of comparative data.

The second set of experiments consisted of studying one-to-one responses of a RDD and a GRD. These experiments were performed with the Pittsburgh coal. Three experiments were performed. the concentration in each experiment was different from the others. In each experiment, one (1) dosimeter was matched with 12 gravimetric samplers, with the result that 12 pairs of comparative data were available (i.e., one comparative data pair per mass loading). A second dosimeter was incorporated in each experiment to study the dosimeter-to-dosimeter variation. Several other instruments were incorporated in the laboratory investigations. These included pressure transducers with higher resolution (HRPT) than those in the RDDs (LRPT), a Tapered Element Oscillating Microbalance (TEOM) to monitor the cumulative dust mass loading and a Micro Orifice Uniform Deposit Impactor (MOUDI) to determine the size distribution of the airborne dust in the chamber. In all, the performance of 66 dosimeters were evaluated in the laboratory experiments.

4 DATA ANALYSIS PROCEDURES

Analyses performed on the data obtained from the in-mine experiments included the following:

1 The pressure increase observed in each RDD was compared with the mass of dust on the filter of the corresponding GRD.
2 The average pressure increase observed in a group of three RDDs was compared with the average mass of the dusts on the filters of the three corresponding GRDs.
3 From the three RDD and the three GRD readings at a station, the values for the Standard Error of the Mean (SEM) and the Relative Standard Deviation (RSD) for the RDD and GRD, were calculated. From these SEM and RSD values, the global average values for SEM and RSD were calculated for the RDD and GRD. The RSDs of the RDD and GRD were calculated from Mine A, Mine B, and Mine A plus Mine B combined data. RSD is a measure of the uncertainty associated

with any particular measurement of the instrument, and is the standard deviation (S) of the observed values normalized by the mean ($\bar{x}$) of the observed values $\left(\mathrm{RSD}=\frac{S}{\bar{x}}\right)$. The higher the RSD, the greater the variability associated with a particular measurement.

4 Scatter plots of the pairs of RDD and GRD values (both one-to-one and average RDD and average GRD) were drawn. Linear and non-linear regression equations were fitted to the pairs of RDD and GRD data. In addition to calculating the coefficient of determination (R^2) for the equation, the 95% prediction and confidence intervals were determined for the fitted equations.

Similar analyses were performed on the data from laboratory experiments. However, for the calculation of the SEM and RSD values, there were six data points for RDD and three data points for the GRD. Scatter plots and regression equations were fitted for the average RDD and average GRD readings for each coal from the first set of experiments. For the data from the second set of experiments, in addition to the regression analysis of the one-to-one RDD and GRD readings, regression analysis of the readings from the two dosimeters under identical conditions was performed.

5 RESULTS OF THE UNDERGROUND EXPERIMENTS

Due to experimental problems such as disconnected hoses, failed battery, etc., only 39 data pairs were available for the one-to-one comparison for Mine A, and 45 data pairs for Mine B. The range of mass loading in Mine A was small; the mass of dust collected in the GRD filters was between 0.05mg to 0.5mg. In general, linear regression gave a better fit for all the data. As an example, the scatter plots and linear regression analysis of the one-to-one and average data from Mine B experiments are shown in Figures 2 and 3. The regression results of the Mine A, Mine B and Mine A plus Mine B combined data are summarized in Table 1. Since the error in filter weighing is 0.05 mg, it may explain the poor R^2 value (0.59) for Mine A one-to-one linear equation. Because of the greater mass loadings for Mine B, more confidence can be placed in those results. The

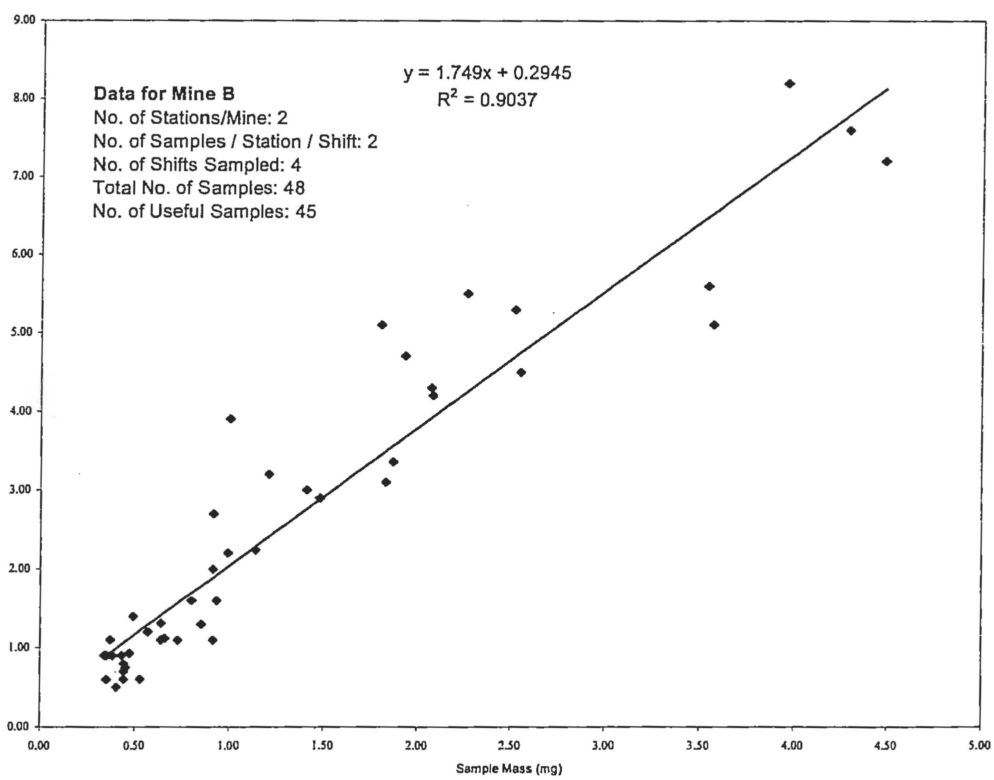

Figure 2. Scatter Plot of the Sample GRD Masses, RDD Pressure Increases, and the Associated Least-Square Linear Regression Equation for Mine B Data.

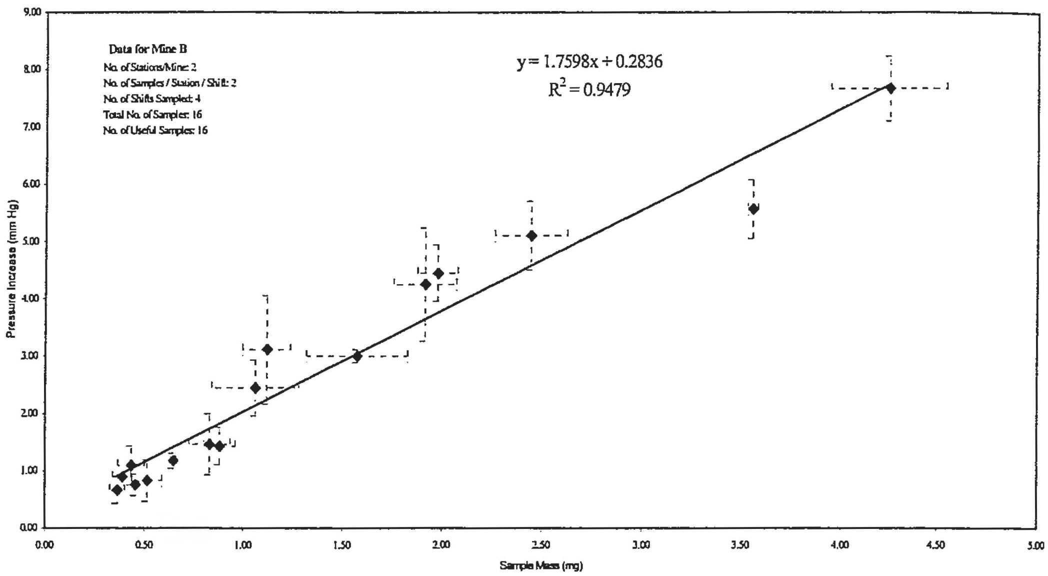

Figure 3. Scatter Plot of the Averages of the Sample Masses and Pressure Increases, and the Associated 95% Error Bars, and the Least Square Linear Regression Equation for Mine B Data.

Table 1. List of the Linear and Non-linear Equations from Mine A and Mine B Data.

Data From	Analysis	Number of Data Pairs	Linear Equation		Non-Linear Equation	
Mine A	One-to-One	39	$y = 1.90x + 0.30$	$R^2 = 0.59$	$y = 1.70x^{0.57}$	$R^2 = 0.57$
	Average	14	$y_1 = 2.23x_1 + 0.22$	$R^2 = 0.91$	$y_1 = 1.92x_1^{0.64}$	$R^2 = 0.89$
Mine B	One-to-One	45	$y = 1.75x + 0.29$	$R^2 = 0.90$	$y = 1.96x^{0.99}$	$R^2 = 0.90$
	Average	16	$y_1 = 1.76x_1 + 0.28$	$R^2 = 0.95$	$y_1 = 1.98x_1^{0.99}$	$R^2 = 0.95$
Mine A and Mine B	One-to-One	84	$y = 1.74x + 0.33$	$R^2 = 0.93$	$y = 2.09x^{0.76}$	$R^2 = 0.86$
	Average	30	$y_1 = 1.74x_1 + 0.32$	$R^2 = 0.96$	$y_1 = 2.14x_1^{0.77}$	$R^2 = 0.93$

Table 2. Ranges of the Relative Standard Deviations of the Personal Gravimetric Sampler (GRD) and the Respirable Dust Dosimeter (RDD) from Mine A, Mine B and Mine A Plus Mine B Combined Data.

Instrument	Mine A Data			Mine B Data			Mine A Plus Mine B Data		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Personal Gravimetric Sampler, (GRD)	0.021	0.299	0.100	0.006	0.184	0.100	0.006	0.299	0.100
Respirable Dust Dosimter (RDD)	0.0670	0.433	0.214	0.033	0.386	0.214	0.033	0.433	0.214

high R^2 values for all the regression equations indicate that there is only a small variance in the original data that is not explained by the fitted relationship. Evidently, there is a strong relationship between the RDD pressure increase and the mass of dust on the GRD filter. Further, this relationship is linear in the range of loading experienced in both mines. The calculated RSD values for the RDD and GRD are summarized in Table 2. Evidently, the RDD is associated with greater uncertainty (average RSD = 0.21) than the personal gravimetric sampler (average RSD = 0.10).

On the basis of the underground experiments, it is concluded that the RDD pressure increase is a good surrogate for the mass of respirable dust collected on a GRD filter. The higher RSD associated with the dosimeter in comparison to the RSD of the personal gravimetric sampler should be taken into account in establishing the confidence and prediction intervals for the estimated gravimetric mass.

6 RESULTS OF LABORATORY EXPERIMENTS

The scatter plots and regression results based on the data from the first set of experiments (average RDD and GRD data) are shown in Figure 4, and those from the second set of experiments (one-to-one RRD and GRD data) are shown in Figure 5. The regression results for all the experiments are summarized in Table 3. It is apparent from both sets of experiments that the relationship between the pressure increase across the RDD filter and the mass of respirable dust collected on the GRD filter is strongly linear.

The relative standard deviations (RSD) of the RDD and GRD, calculated from the first set of experiments, are presented in Table 4. The RSD values with the Pittsburgh coal dust experiments are higher than those with the other coals. GRD has a lower RSD than the RDD for all the coals. Further, the RSD values obtained with the laboratory experiments are, on the average, almost 50% lower than those obtained with the in-mine experiments. It is clear that greater uncertainty is associated with RDD measurements than with GRD measurements. Further, underground experiments are associated with greater uncertainty than the laboratory experiments. The implication of the low R^2 (0.48) in Table 3 for the linear equation representing the combined data from all the coals and the high R^2 values (≥ 0.75) for the equations for the individual coals is important. It appears that for different coals, there are differences in the dosimeter pressure increase for the same gravimetric mass and vice-versa. The high RSD values with Pittsburgh coal dust is also indicative of the last statement. Whether these differences arise due to differences in the particle size distributions of the dusts, or due to differences in the concentrations of the dust in the chamber could not be determined. Also, from the second set of experiments, it is noticed that there are only small differences in the two dosimeter pressure readings (LRPT 1 and LRPT 2) under identical conditions. As can be seen in Figure 6, both the dosimeters track the mass of dust on the filter equally well, and their pressure readings are highly correlated (R^2=0.93 to 0.98). Because of the effect of coal type, the importance of developing a mine-specific calibration curve for use with RDD cannot be over-emphasized. In the manufacture of the dosimeters, additional efforts may be needed to further decrease the dosimeter to dosimeter variation in pressure measurements.

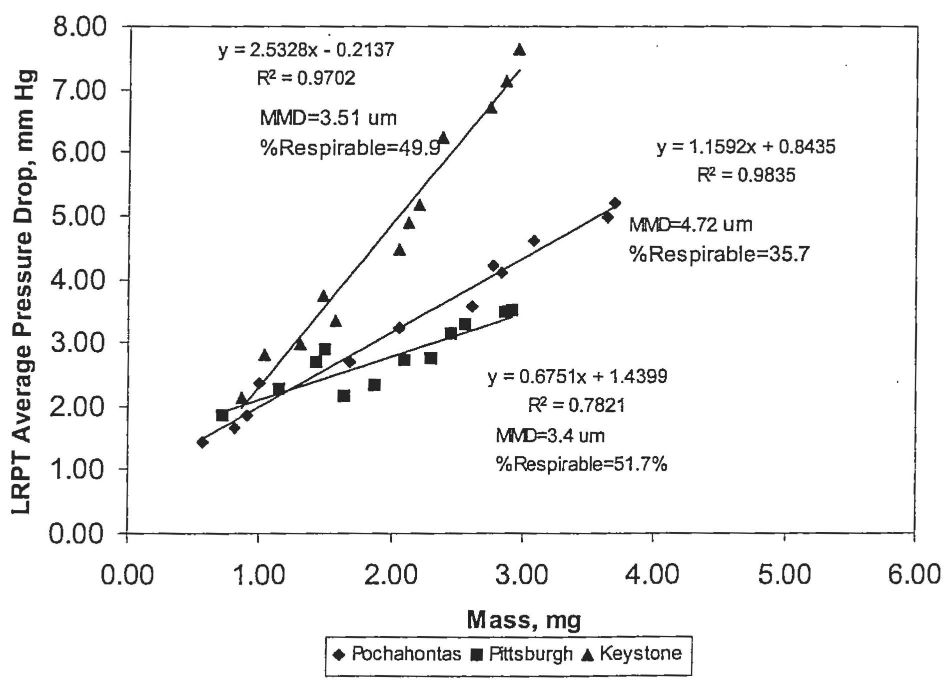

Figure 4. Average LRPT and Average Collected Mass Coal-to-Coal Comparison.

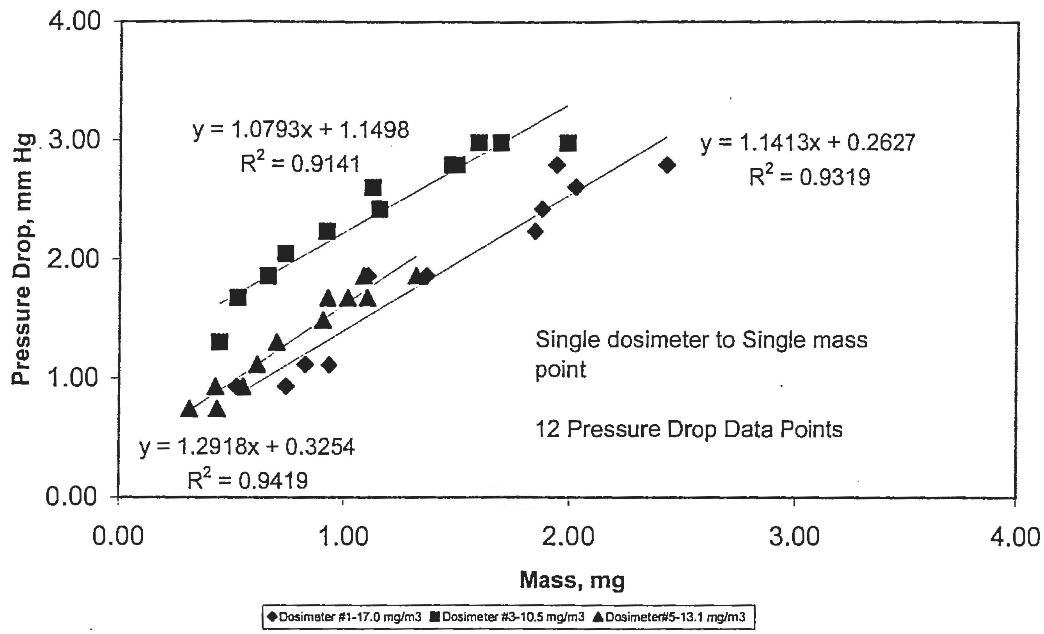

Figure 5. LRPT #1 Pressure Drop to Dust Mass Correlation for Varied Concentrations and Dosimeters.

Table 3. List of the Respirable Dust Dosimeter (LRPT) and the Personal Gravimetric Sampler (GRD) Linear Equations from Laboratory Experiments.

Experiment	Coal Dust		No. of Data Pairs	Regression Equation	R^2
	Pocahontas		12	y=1.16x+0.84	0.98
1st Set	Pittsburgh		12	y=0.68x+1.44	0.78
	Keystone		12	y=2.53x-0.21	0.97
	Combined Data		36	y=1.32x+0.97	0.48
	Test 1	LRPT 1	11	y=1.14x+0.26	0.93
2nd Set	17.0mg/m^3	LRPT 2	11	y=1.16x+0.27	0.92
	Test 2	LRPT 1	12	y=1.08x+1.15	0.91
	10.0 mg/m^3	LRPT 2	12	y=0.96x+0.85	0.95
	Test 3	LRPT 1	12	y=1.29x+0.33	0.94
	13.1 mg/m^3	LRPT 2	12	y=1.29x+0.14	0.94

Table 4. Ranges of the Relative Standard Deviations (RSD) of the Respirable Dust Dosimeter (TDD) and the Personal Gravimetric Sampler (GRD) from Laboratory Experiments.

Coal Dust Type	Respirable Dust Detector			Personal Gravimetric Sampler		
	Min	Max	Ave	Min	Max	Ave
Pocahontas	0.081	0.178	0.125	0.009	0.081	0.046
Pittsburgh	0.150	0.358	0.220	0.013	0.161	0.082
Keystone	0.019	0.157	0.078	0.005	0.102	0.040

There are several other observations from the laboratory experiments. The low resolution pressure transducer (LRPT) associated with the RDD tracks the changes in the pressure equally well as the high resolution pressure transducer (HRPT). Further, the TEOM indicated mass was highly correlated with the mass on the GRD filter, and the LRPT and HRPT pressures. However, for the same TEOM indicated mass, the mass collected on the GRD filter is different for each of the coals even through the relationship between the two is strongly linear.

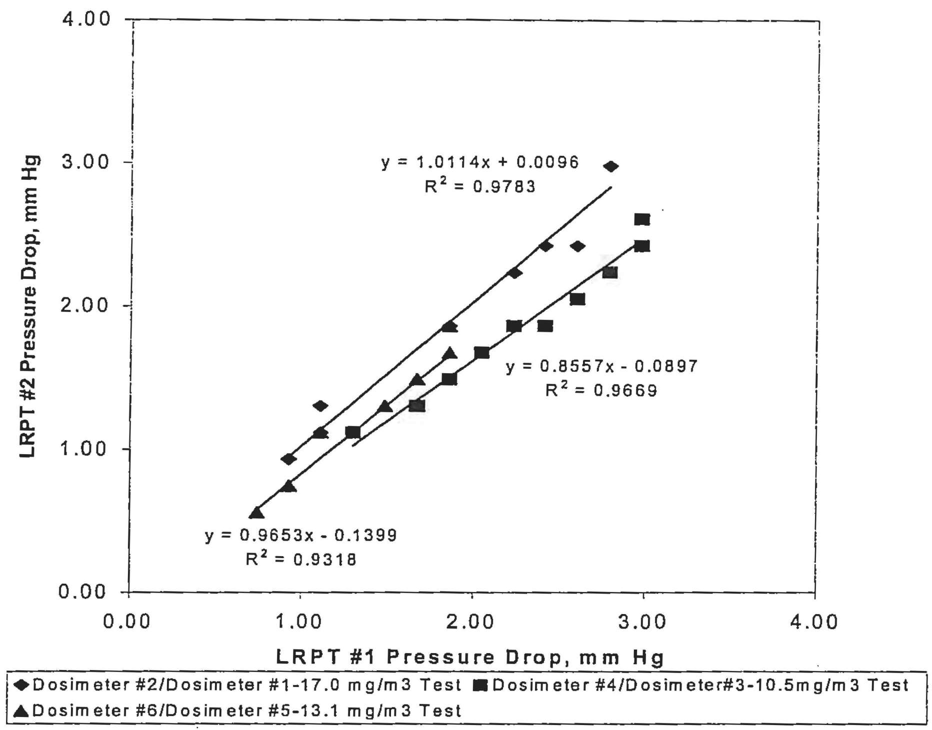

Figure 6. Comparison of the Performance of the Two Dosimeters (LRPT #1 and LRPT #2) Under Identical Conditions.

7 CONCLUSIONS

The data from the in-mine and laboratory experiments support the hypothesis that the pressure increases across the RDD filters is a good surrogate for the mass of respirable dust on the GRD filter. Further, in the range of mass loading studied in the mine and the laboratory, the relationship between the two measures is strongly linear. Therefore, it is concluded that it should be possible to determine, on a real-time basis, the equivalent GRD cumulative respirable dust exposure (mg) or the time-weighted ARD concentration (mg/m^3) from the observed RDD pressure increase and an appropriate calibration curve.

Under identical conditions in both the mines and the laboratory, the RDD exhibits greater variability than the GRD in the measured data. In both cases, the average relative standard deviation (RSD) of the RDD was about twice that of the GRD. In the laboratory experiments, the average RSD for the RDD varied from 0.08 to 0.22 and that for GRD from 0.04 to 0.08. The RSD values in the mine experiments were higher for both the RDD (0.21) and the GRD (0.10). Part of the unexplained variance in the regression equations can be arising due to the variability in the individual measurements.

While the RDD and GRD measurements for Mine A and Mine B and the three coals in the laboratory all exhibit strong linear relationships, there are differences in both the slope and the intercept of the individual relationships. These differences can be arising from the differences in such factors as the coals, size distributions of the airborne dust, concentration levels, dust loading rates, and the variabilities in the RDD and GRD measurements. This finding has implications for the development of mine-specific calibration curves to convert a RDD pressure increase measurement to an estimate of the cumulative mass on the GRD filter or of the equivalent time-weighted ARD concentration. The RDD is a low-weight compact instrument which can be easily carried by a miner. With the development of a user-friendly single-button, operating feature, as well as of a simple procedure develop mine-specific calibration curves, the RDD has great potential to help prevent, in a timely manner, exposure to high levels of ARD, and to enhance the health and safety of miners.

REFERENCES

Dobrosky, H., Jr., Tuckman, D. P., & Vinson, R. Control and Prevention, PRL-NIOSH, Pittsburgh, PA, 125 pp. P. 1997. Differential Pressure as a Means of Estimating Respirable

Dust Mass on Collection Filters. *Appl. Environ. Hyg.* 12(12):1047-1051.

Ramani, R. V., Marple, V. A., Mutmansky, J. M.,Olson, B., He, H., & Luna, P. 2001. Independent Laboratory Evaluation of a Pressure Differential Based Respirable Dust Detector. Final Report on Contract No: 200-1998-8003. Submitted to Centers for Disease Control and Prevention, PRL-NIOSH, Pittsburgh, PA, 125 pp.

Volkwein, J. C., Page, S. J., Baron, P. A., & Deye, G. J. 1997. Particulate Penetration of Porous Foam as a Low Flow Rate Dust Size Classifier (Poster Presentation). *16th Annual Conference of AAAR.* Denver, CO.

Volkwein, J. C., A. L. Schoeneman & Page, S. J. 2000. Laboratory Evaluation of Pressure Differential Based Respirable Dust Detector Tube. *Applied Occupational and Environmental Hygiene* 14(1): 158-164.

ROUTING AND TRANSMITTAL SLIP	Date 7/5/02	
TO: (Name, office symbol, room number, building, Agency/Post)	Initials	Date
1. GEORGE BOCKOSH, OD		
2. ROB TUCHMAN, OD		
3.		
4.		
5.		

X	Action		File		Note and Return
	Approval		For Clearance		Per Conversation
	As Requested		For Correction		Prepare Reply
	Circulate		For Your Information		See Me
	Comment		Investigation		Initial
	Coordination		Justify		

RE: PUBLICATION DISTRIBUTION

ATTACHED ARE 3 COPIES OF THE FOLLOWING PUBLICATION:

DATABASE RECORD NO: 1636

TITLE OF PAPER: Evaluation of the respirable dust dosimeter for real-time assessment of airborne respirable coal mine dust exposures

PUBLISHED IN: Proceedings - Mine Ventilation

AUTHORS: RV Ramani, JM Mutmansky, H He, VA Marple, BA Olson, PC Luna, JC Volkwein

REPORTED IN MONTHLY REPORT: 6 (month) 02 (year)

FILLED IN PUBL. AVAILABILITY DATE IN PUBL. DATABASE: 6 / 12 / 02 (mo / day / year)

SUBMITTED ORIGINAL TO DIANE FELICE FOR POSTING IN CISS: 7 / 5 / 02 (mo / day / year)

DO NOT use this form as a RECORD of approvals, concurrences, disposals, clearances, and similar actions

FROM: (Name, org. symbol, Agency/Post)	Room No. — Bldg. 03
Jill Raufus, Health Branch	Phone No. 412-386-6868 Fax No. 412-386-4917

5041-102

OPTIONAL FORM 41 (Rev. 7-76)
Prescribed by GSA
FPMR (41 CFR) 101-11.206