COMPARISON OF NUMBER AND RESPIRABLE MASS CONCENTRATION DETERMINATIONS

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INTRODUCTION

Regulations pertaining to Safety and Health Standards for Surface Metal and Nonmetal Mines; and for Underground Metal and Nonmetal Mines in the United States are specified in Title 30, CFR, Parts 56 and 57, respectively. In these parts of Title 30, exposure limits for airborne contaminants are based on the Threshold Limit Values (TLV) adopted by the ACGIH (American Conference of Governmental Industrial Hygienists) as set forth and explained in the 1973 Edition of the Conference's publication, entitled "TLVs Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973." Exposure limits established in this edition for various mineral silicate dusts containing less than one percent quartz are based on the number of particles per cubic foot of air.

In the 1976 Edition of the "Threshold Limit Values for Chemical Substances in Workroom Air," limits based on the respirable mass of the dust per cubic meter of air that were supposedly equivalent to previously recommended limits based on the number of particles per cubic foot of air were published in Appendix G. The bases for establishing the equivalent mass concentration values were:

1. An empirical relationship, derived by Jacobson and Tomb,[1] that indicated 5.65 mppcf was approximately equal to 1 mg/m^3 of respirable dust sampled with an Isleworth Gravimetric Dust Sampler, Type 113A.[2]

2. A relationship of 6 mppcf = 1 mg/m^3 developed from a calculation that assumed that the average density for silica containing dust is approximately 2.5 grams per cubic centimeter and that the mass median diameter of particles collected in midget impinger samplers, (counted by the standard light field microscopic technique) and in respirable dust samplers is approximately 1.5 micrometers (μm).

In the 1986-87 Edition of the "Threshold Limit Values for Chemical Substances in Workroom Air" references to count standards were eliminated. Respirable mass standards listed were based on the above conversion or when a respirable hazard had not been documented a total dust standard of 10 mg/m^3 was adopted. Additionally the recommended standard for respirable talc dust was reduced from 3 to 2 mg/m^3. Documentation for the rationale of these changes has not been published.

Recognizing that an assessment based on a respirable mass limit would: be more relevant to the health hazard; provide a method of assessing the quality of an environment which is simpler; be less expensive and be more reproducible than the count method; MSHA investigated the validity of the equivalent respirable mass limits recommended. This investigation was principally performed to provide documentation to support any legal actions that would result from the use of the recommended limits as "equivalent" standards.

The purpose of this paper was to investigate the validity of the equivalent respirable mass concentrations recommended. To accomplish this a review of the rationale published in the 1976 and subsequent TLV Handbooks was made, "Documentation of the Threshold Limit Values" was reviewed and empirical relationships were derived from comparative measurements obtained with a long running midget impinger and a respirable dust sampler.

PROCEDURES

To develop the empirical relationships, comparative measurements with the midget impinger and respirable dust samplers were obtained at operations mining or processing natural graphite, perlite, mica, diatomaceous earth and talc (nonasbestiform). Although soapstone was another mineral of interest, at the time of the study, no soapstone mines were operational.

Samples collected with the midget impinger were analyzed for number concentration using light-field microscopy following the Bureau of Mines[3] standard microprojector technique. The results were reported as millions of particles per cubic foot. Respirable dust samples were weighed and the mass concentration of dust was determined and reported as milligrams of respirable dust per cubic meter of air sampled.

The respirable dust sampler was that typically utilized by MSHA's Metal and Nonmetal Mine enforcement personnel to assess the respirable mass concentration of dust in an environment. Airflow through the respirable dust sampling system was maintained constant at 1.7 liters per minute using either an MSA Model G, Bendix 3900 or Bendix BDX30 pump.

The various instruments used to obtain comparative measurements were assembled into a package. Each package contained two modified midget impinger samplers, two respirable dust samplers and a total dust sampler. The modification to the impinger consisted of replacing the standard

1 by 4.5 inch particle collection flask with a larger container that would permit extending the sampling time of the impinger from 20 minutes to four hours. Normally two packages, located at different sampling sites at a respective mineral processing operation, were used. The sampling time for comparative samples ranged from two to four hours. The number of comparative samples obtained for the respective minerals varied.

The total dust samples were collected with a sampling system similar to that used to collect the respirable dust samples, but without the 10 mm nylon cyclone attached. Total dust samples were also collected at a flow rate of 1.7 liters per minute. In addition to determining the total mass concentration of the aerosol in the environment, a representative number of the total dust samples collected were particle sized with a Model TA II Coulter Counter.

TREATMENT OF DATA

Empirical relationships between number concentration, in mppcf, and respirable mass concentration, in mg/m^3, were derived from the comparative measurements for the respective minerals using the method of least squares. For each mineral, the best fit regression line relating the measurements, standard error of estimate, $S_{y/x}$, and correlation coefficient, r, were calculated. The standard error of estimate provides a quantitative measure of the variability of the data about the regression line and the correlation coefficient provides a measure of the degree of linearity between the respective variables (number and mass concentration).

Equivalent respirable mass concentration values derived from the empirical relationships for each of the minerals were compared to the equivalent mass concentration limits specified in the 1976 TLV Handbook. In addition, respirable mass concentration equivalent values were calculated using the method given in the Handbook and the parameters required for that calculation; i.e., aerosol, density and mass median diameter (M'_g).

Data obtained from the Coulter Counter analysis of the total dust samples were used to characterize the size distributions of the aerosols sampled. Count-versus-size data were converted to mass-versus-size data mathematically for each aerosol. Cumulative mass-versus-size data were plotted on logarithmic-probability graph paper, and the mass median diameter (M'_g) and geometric standard deviation (σ_g) were determined using the graphic technique developed by Hatch and Choate.[4] The count median diameter (M_g) was then determined using the relationship:

$$\text{Log } M_g = \text{Log } M'_g - 6.9078 \text{ Log}^2 \sigma_g.$$

RESULTS AND DISCUSSION

Figures 1 through 5 graphically show the data for the comparative measurements obtained for the respective minerals, the regression lines relating the count and mass concentrations obtained and the standard error of estimate and correlation coefficient for each of the relationships derived. The data compiled on Table I are: the density of the respective aerosols; the recommended limits specified in the 1976 and 1986 TLV Handbooks; four count-to-mass ratios (R) derived from: (1) the recommended count and mass concentration limits specified in the Handbook; (2) the empirically derived regression equations; and, (3) and (4) the procedure given in the TLV Handbook using the M_g and M'_g valves that were determined to be representative of the respective aerosols sampled.

A comparison (Table I) was made of the ratio (R) between the count and mass concentrations (mppcf:mg/m^3) recommended

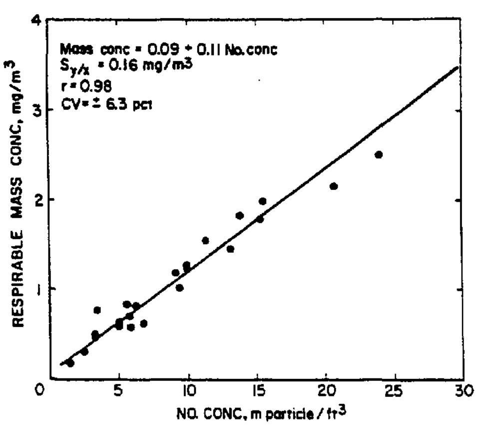

Figure 1. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two graphite processing operations.

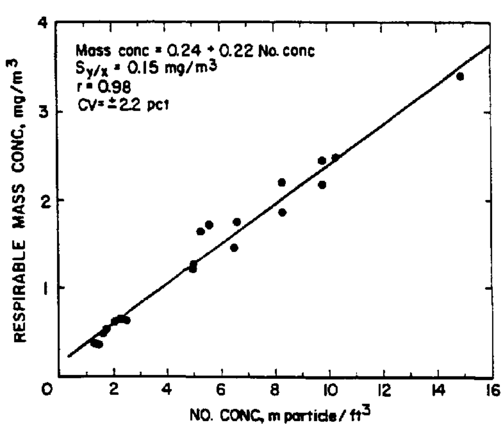

Figure 2. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two perlite processing operations.

in the TLV Handbook for the respective minerals and the ratios established from the empirical relationships and the calculation method using both the M_g' and M_g derived from the total dust samples. The comparison shows that only the empirically derived count to mass concentration ratio established for the mica and talc aerosols approximated the values recommended in the TLV Handbook. None of the ratios established from the calculation method agreed with the values recommended in the TLV Handbook or with the empirically derived values. It is apparent from the data that the M_g' or M_g established from a total dust sample measurement cannot be used to derive a factor for converting number concentration determinations to equivalent mass concentrations.

The method given in the TLV Handbook for calculating a factor based on the M_g' and density of the aerosol makes the implicit assumption that the size distribution of the aerosols is similar; however, as the data show, the M_g' and geometric standard deviation differ significantly for aerosols found in the same type of mineral operations as well as those established for different mineral processing operations. It should also be recognized that when using the calculation method recommended in the TLV Handbook, a 15 percent difference in the diameter used to calculate an equivalency factor can result in a difference in the calculated equivalency factor of greater than 60 percent. This is due to the fact that conversion from a count to a mass concentration is a function of the cube of the particle diameter.

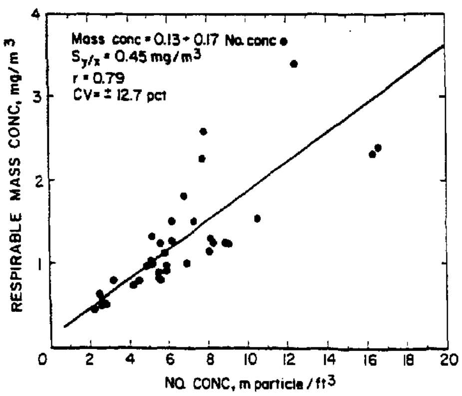

Figure 3. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two talc processing operations.

Review of the documentation, published in the 1976 TLV Handbook to arrive at, or substantiate, the value of "6" as the approximate factor used to obtain respirable mass concentration values equivalent to previously recommended number concentration values, showed that some of the supporting documentation is questionable. First, it is not clear which respirable dust criterion (that defined by the British Medical Research Council [BMRC] or by the ACGIH) was assumed to be followed by the respirable sampler when sampling the respirable fraction of the dust. The empirical relationship of 5.6 mppcf to 1 milligram per cubic meter of air was derived by Jacobson and Tomb,[1] from comparative measurements obtained with the midget impinger and the Isleworth Gravimetric Dust Sampler, Type 113A, an instrument that samples respirable dust according to the BMRC criteria. Mass concentration measurements obtained with a respirable mass sampler sampling respirable dust in accordance with the ACGIH criteria would be significantly lower. For coal mine dust, it has been shown[5] that the ratio between mass concentrations determined with an instrument sampling respirable dust with respect to the BMRC criteria and an instrument sampling with respect to the ACGIH criteria is 1.38.

Another questionable item deals with the statement that "the mass median diameter of particles collected in impinger samplers and counted by the standard light-field technique and

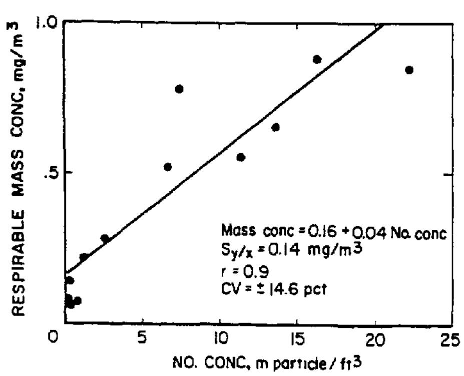

Figure 4. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two diatomaceous earth processing operations.

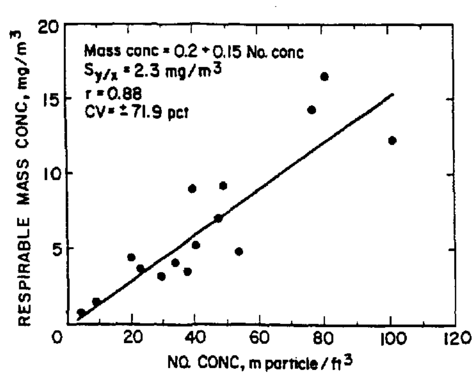

Figure 5. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two mica processing operations.

Table I

Comparison of Values (R) Obtained for Converting Count Concentration Data to Equivalent Mass Concentration Data

Aerosol	Density gm/cm^3	Recommended TLV: Count, mppcf	Recommended TLV: Mass mg/m^3	R (mppcf/mg/m^3): TLV	Emp	Calc. (M_g)	Calc. (M_g')	Aerosol Parameters: M_g	M_g'	σ_g
Graphite I	1.76	15	2.5(1)	6	9.8	-	1.46	0.07	2.76	3.16
Graphite II					8.8	-	0.54	0.02	3.84	4.65
Perlite I	2.30	30	5 (1)	6	4.4	260	0.05	0.45	7.57	2.64
Perlite II			10 (2)		3.2	0.15	0.004	5.36	18.56	1.92
Talc I	2.75	20	3 (1)	6.6	5.5	28	0.32	0.89	3.95	2.01
Talc II			2 (3)	10	5.3	660	0.05	0.31	7.49	2.80
Diatomaceous Earth	2.20	20	1.5(1) 10 (2)	13	21.7	45	0.05	0.82	7.98	2.38
Mica	2.80	20	3	6.6	6.6	116	0.05	0.55	7.50	2.55

M_g = Count Median Diameter.
M_g' = Mass Median Diameter.
σ_g = Geometric Standard Deviation.
EMP = R Derived from Empirical Relationship.
Calc. (M_g) = R Calculated Using Count Median Diameter.
Calc. (M_g') = R Calculated Using Mass Median Diameter.

(1) Respirable Dust Concentration Based on 1976 TLV Handbook.
(2) Total Dust Concentration Based on 1986-87 TLV Handbook.
(3) Respirable Dust Concentration Based on 1986-87 TLV Handbook.

Table II

Particle Size Distribution Parameters Derived from the 1 to 10 Micrometers Fraction of the Aerosols

Aerosol	Aerosol Parameters: M_g	M_g'	σ_g	R (mppcf/mg/m^3): Calc. (M_g)	Calc. (M_g')
Graphite I	0.52	2.79	2.11	506	1.41
Graphite II	0.36	3.52	2.39	658	0.70
Perlite I	1.15	4.67	1.98	15.4	0.24
Perlite II	1.86	6.81	1.93	3.65	0.08
Talc I	1.31	3.42	1.76	8.74	0.49
Talc II	1.17	1.22	1.13	12.3	0.25
Diatomaceous Earth	1.97	5.14	1.76	3.21	0.18
Mica	1.42	4.61	1.87	6.60	0.20

M_g = Count Median Diameter.
M_g' = Mass Median Diameter.
σ_g = Geometric Standard Deviation.
Calc. (M_g) = R Calculated Using Count Median Diameter.
Calc. (M_g') = R Calculated Using Mass Median Diameter.

collected in a respirable sampler is approximately 1.5 μm." From the size distribution data obtained from the analysis of total dust samples in the size interval from 1 to 10 micrometers (Table II), and from comparing size distribution data from the Coulter Counter analysis of comparative total dust samples and impinger samples collected during these studies, it would appear that 1.5 μm would be more representative of the M_g than the M_g'. This is also supported by data obtained by Cooper[6] in the Public Health Service's study of the diatomaceous earth industry. It is also highly unlikely that the M_g' of the particles collected in the impinger sample would be the same as the M_g' of the particles collected in the respirable dust sampler because of the nonuniform selection process of the particle classifier on the respirable dust sampler.

The last questionable item has to do with the diameter used in the calculation method to calculate an equivalent mass concentration. The example specifies using the M_g'. It appears from the presentation and definition of various diameters presented by Reist,[7] that the diameter which should be used is the diameter of average mass; which is defined as representing the diameter of a particle whose mass times the number of particles per unit volume is equal to the total mass per unit volume of the aerosol. Although by definition this would appear to theoretically be the diameter to use, the recommended limits also could not be obtained when this diameter was used in the calculation method.

Based on the review of the documentation in the TLV Handbook and the relationships derived from comparative measurements obtained with the midget impinger and the personal respirable dust sampler, it is concluded that: (1) "6" is not a factor that should be universally used to convert number concentration data obtained from the analysis of midget impinger samples using light-field microscopic techniques to equivalent mass concentration data, (2) because of the variability that occurs in the size distributions of the aerosols sampled (even in the 1 to 10 micrometer size fraction), it is unlikely that a single parameter characterizing an aerosol can be used to calculate an equivalent mass concentration; and (3) comparative measurements should be used to derive the necessary factors for converting count concentration to equivalent mass concentration data.

SUMMARY

The validity of respirable mass concentration limits for mineral dusts recommended in the 1976 and 1986-87 ACGIH Threshold Limit Value Handbook as equivalent to previously recommended number concentration limits was investigated. The investigation consisted of reviewing the documentation in the 1976 TLV Handbook that was used to support the respirable mass concentration limits recommended; deriving empirical relationships from comparative measurement obtained with a midget impinger and respirable personal dust sampler at industrial operations processing graphite (natural), perlite, talc, diatomaceous earth and mica; and comparing equivalent respirable mass concentration measurements obtained from the derived empirical relationships to those recommended in the TLV Handbook.

It was concluded from the investigation conducted that the general relationship, 6 mppcf = 1 mg/m^3, used to convert particle count concentration data to respirable mass concentration data was not valid. This conclusion was based on:

1. Equivalent mass concentrations established from the empirical relationships derived from comparative impinger and respirable samples did not always agree with those recommended in the TLV Handbook.

2. The rationale supporting the 6 mppcf = 1 mg/m^3 relationship was questionable and could not be confirmed using data collected during this investigation.

Because there was a significant difference in the empirical relationships derived between count and respirable mass concentration determinations and attempts to mathematically calculate equivalent mass concentrations were unsuccessful, equivalent respirable mass concentration limits should be empirically derived using comparative measurements obtained in the aerosol of interest.

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