



Designation: D 6061 – 96

Standard Practice for Evaluating the Performance of Respirable Aerosol Samplers¹

This standard is issued under the fixed designation D 6061; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the evaluation of the performance of personal samplers of non-fibrous respirable aerosol. The samplers are assessed relative to a specific respirable sampling convention. The convention is one of several that identify specific particle size fractions for assessing health effects of airborne particles and in the setting of and testing for compliance with permissible exposure limits in the workplace and ambient environment. The conventions, which define inhalable, thoracic, and respirable aerosol sampler ideals, have now been adopted by the International Standards Organization (Technical Report ISO TR 7708), the Comité Européen de Normalisation (CEN Standard EN 481), and the American Conference of Governmental Industrial Hygienists (ACGIH, Ref (1)),² developed (2) in part from health-effects studies reviewed in Ref (3) and in part as a compromise between definitions proposed in Refs (3,4). This practice is specific to respirable aerosol sampler evaluation because of simplifying characteristics particular to this fraction.

1.2 This practice is complimentary to Test Method D 4532, which specifies a particular instrument, the 10-mm cyclone.^{3,4} The sampler evaluation procedures presented in this practice have been applied in the testing of the 10-mm cyclone as well as the Higgins-Dewell cyclone.^{4,5} Details on the evaluation have been recently published (5-7) and can be incorporated into revisions of Test Method D 4532.

1.3 Units of the International System of Units (SI) are used throughout this practice and should be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appro-*

priate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D 1356 Terminology Relating to Atmospheric Sampling and Analysis⁶

D 4532 Test Method for Respirable Dust in Workplace Atmospheres⁶

D 6062M Performance Specifications for Samplers of Health-Related Aerosol Fractions⁶

2.2 International Standards:

ISO TR 7708 Technical Report on Air Quality—Particle Size Fraction Definitions for Health-Related Sampling, Brussels, 1993⁷

CEN EN 481 Standard on Workplace Atmospheres. Size Fraction Definitions for the Measurement of Airborne Particles in the Workplace, Brussels, 1993⁸

CEN prEN 1232 Pre-Standard on Workplace Atmospheres. Requirements and Test Methods for Pumps used for Personal Sampling of Chemical Agents in the Workplace, Brussels, 1993⁸

2.3 NIOSH Standards:

NIOSH Manual of Analytical Methods, 4th ed., Eller, P. M., ed.: Dept. of Health and Human Services, 1994⁹

Criteria for a Recommended Standard, Occupational Exposure to Respirable Coal Mine Dust, NIOSH, 1995¹⁰

3. Terminology

3.1 Definitions:

3.1.1 For definitions of terms used in this practice, refer to Terminology D 1356.

3.1.2 Aerosol fraction sampling conventions have been presented in Performance Specifications D 6062M. The relevant definitions are repeated here for convenience.

3.2 Definitions of Terms Specific to This Standard:

¹ This practice is under the jurisdiction of ASTM Committee D-22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.04 on Analysis of Workplace Atmospheres.

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² The boldface numbers in parentheses refer to a list of references at the end of this practice.

³ The sole source of supply of the 10-mm cyclone known to the committee at this time is Mine Safety Appliances Co., Instrument Div., P.O. Box 427, Pittsburgh, PA 15230.

⁴ If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

⁵ The sole source of supply of the Higgins-Dewell cyclone known to the committee at this time is BGI Inc., 58 Guinan Street, Waltham, MA 02154.

⁶ Annual Book of ASTM Standards, Vol 11.03.

⁷ Available from International Organization for Standardization, Caisse Postale 56, CH-1211, Geneva 20, Switzerland.

⁸ Available from CEN Central Secretariat: rue de Stassart 36, B-1050 Brussels, Belgium.

⁹ Available from Superintendent of Documents, U.S. Government Printing Office, Stock No. 917-011-00000-1, Washington DC 20402.

¹⁰ Available from NIOSH Publications, 4676 Columbia Parkway, Cincinnati, OH 45226.

3.2.1 *aerodynamic diameter*, D (μm)—the diameter of a sphere of density, 10^3 kg/m^3 , with the same stopping time as a particle of interest.

3.2.2 *respirable sampling convention*, E_R —at aerodynamic diameter D , defined explicitly as a fraction of total airborne aerosol in terms of the cumulative normal function (8) Φ as follows:

$$E_R = 0.50 (1 + \exp[-0.06 D]) \Phi [\ln[D_R/D]/\sigma_R] \quad (1)$$

where the indicated constants are $D_R = 4.25 \text{ } \mu\text{m}$ and $\sigma_R = \ln[1.5]$. The function Φ may be approximated using the algorithm presented in Appendix X1.

3.2.2.1 *Discussion*—The respirable sampling convention, together with earlier definitions, is shown in Fig. 1. This convention has been adopted by the International Standards Organization (Technical Report ISO TR 7708), the Comité Européen de Normalisation (CEN Standard EN 481), and the American Conference of Governmental and Industrial Hygienists (ACGIH, Ref (1)). The definition of respirable aerosol is the basis for the recommended exposure level (REL) of respirable coal mine dust as promulgated by NIOSH (*Criteria for a Recommended Standard, Occupational Exposure to Respirable Coal Mine Dust*) and also forms the basis of the NIOSH sampling method for particulates not otherwise regulated, respirable (*NIOSH Manual of Analytical Methods*).

3.2.3 *size-distribution* dC/dD ($\text{mg/m}^3/\mu\text{m}$)—of a given airborne aerosol, the mass concentration of aerosol per unit aerodynamic diameter range.

3.2.3.1 *log-normal size distribution* dC_{ln}/dD —an idealized distribution characterized by two parameters: the *geometric standard deviation* (GSD) and *mass median diameter* (MMD). dC_{ln}/dD is given explicitly as follows:

$$dC_{\text{ln}}/dD = \frac{1}{\sqrt{2\pi}} \frac{C}{D \ln[\text{GSD}]} \exp\left[-\frac{1}{2} \ln[D/\text{MMD}]^2/\ln[\text{GSD}]^2\right] \quad (2)$$

where C is the total mass concentration.

3.2.4 *true respirable concentration* c_R (mg/m^3)—the concentration measured by a conventional (that is, ideal) respirable sampler and given in terms of the size distribution dC/dD as follows:

$$c_R = \int_0^\infty dD E_R dC/dD \quad (3)$$

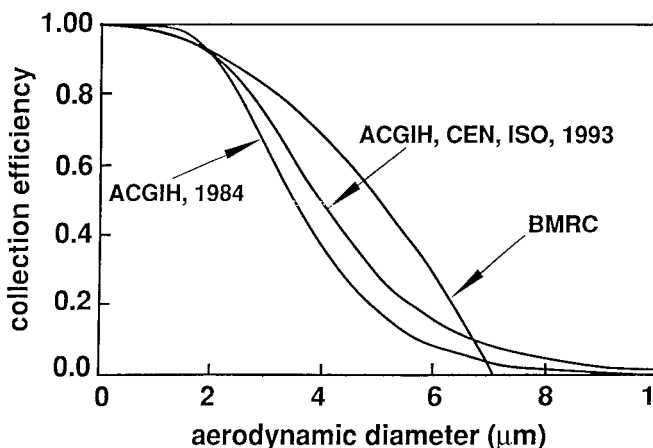


FIG. 1 Respirable Aerosol Collection Efficiencies

3.2.5 *sampler number* $s = 1, \dots, S$ —a number identifying a particular sampler under evaluation.

3.2.6 *sampling efficiency* $E_s(D, Q)$ —the modeled sampling efficiency of sampler s as a function of aerodynamic diameter D and flow rate Q (9.1).

3.2.6.1 *model parameters* θ_j , where $j = 1, \dots, J$ —parameters that specify the function $E_s(D, Q)$.

3.2.7 *sampled concentration* c_s —the concentration that sampler s would give in sampling aerosol of size-distribution dC/dD and is given as follows:

$$c_s = \int_0^\infty dD E_s dC/dD \quad (4)$$

3.2.8 *mean concentration* c —the average of c_s over the samplers tested.

3.2.9 *mean bias* Δ —relative to a conventional sampler, defined as follows:

$$\Delta = (c - c_R) c_R \quad (5)$$

3.2.10 The imprecision or relative standard deviation RSD is defined here in terms of independent analytical, intra-sampler, and inter-sampler components:

3.2.10.1 *analytical relative standard deviation* $RSD_{\text{analytical}}$ —the precision relative to the true respirable concentration c_R associated with analysis, for example, the weighing of filters, analysis of α -quartz, and so forth.

3.2.10.2 *pump-induced relative standard deviation* RSD_{pump} —the intra-sampler imprecision relative to the true respirable concentration c_R associated with both drift and variability in the setting of the pump.

3.2.10.3 *inter-sampler relative standard deviation* RSD_{inter} —the inter-sampler imprecision relative to the true respirable concentration c_R and taken as primarily associated with physical variations in sampler dimensions.

3.2.10.4 The *total imprecision* RSD is then given as follows:

$$RSD = \sqrt{RSD_{\text{analytical}}^2 + RSD_{\text{pump}}^2 + RSD_{\text{inter}}^2} \quad (6)$$

3.2.11 *flow rate* Q (L/min)—the flow rate sampled by a given sampler.

3.2.12 *flow number* F —the number (for example, 4) of sampler flow rates Q tested.

3.2.13 *replication number* n (for example, 4)—the number of replicate measurements for evaluating a given sampler at specific flow rate and aerodynamic diameter.

3.2.14 *parameter number* $p = 1, \dots, P$ (for example, 4)—a number identifying parameters θ_p in modeled sampling efficiency data as in Section 9.

3.2.15 *Accuracy* A , *Busch probabilistic*—the fractional range, symmetric about the true concentration c_R , within which 95 % of sampler measurements are to be found (9-12 and the NIOSH Manual of Analytical Methods).

3.2.15.1 *Discussion*—The function A depends only on the bias Δ and total imprecision RSD in the event that these quantities are independent of c_R . A is defined implicitly as follows:

$$\Phi[\Delta + A/RSD] - \Phi[(\Delta - A)/RSD] = 95 \% \quad (7)$$

where Φ is the cumulative normal function. The function A (Δ , RSD) may be computed numerically and is depicted in Fig. 2. Alternatively, Eq 7 has an approximate solution (13) for A/Δ .

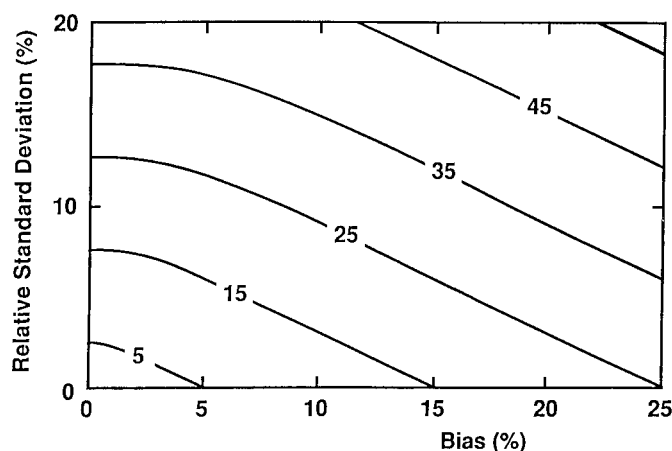


FIG. 2 Contours Showing Accuracy A at 95 % Confidence Level in Terms of Bias and Relative Standard Deviation (RSD)

RSD] given as follows:

$$A[\Delta, RSD] = \Phi^{-1}(0.95) \times RSD + \text{Sqrt}[(\Phi^{-1}(1.95/2) - \Phi^{-1}(0.95))^2 RSD^2 + \Delta^2] \quad (8)$$

This expression is easily evaluated using a calculator, noting that $\Phi^{-1}(0.95) = 1.645$, and $\Phi^{-1}(1.95/2) = 1.960$.

3.3 Symbols and Abbreviations:

A —(Busch probabilistic) accuracy as defined in terms of bias and precision (see 3.2.15).

$\hat{A}$ —estimated accuracy A .

$_{95 \% A}$ —95 % confidence level on the (Busch probabilistic) accuracy A .

C (mg/m^3)—total mass concentration.

$_{s \text{ cov}_{ij}}$ —covariance matrix for sampler s and efficiency parameters θ_i and θ_j .

c_R (mg/m^3)—concentration measured by a conventional (that is, ideal) respirable sampler.

$\hat{c}$ —sampler-averaged concentration estimate.

$\hat{c}_s$ —concentration estimate from sampler s .

D (μm)—aerosol aerodynamic diameter.

D_0 —sampling efficiency model parameter.

D_R (μm)—respirable sampling convention parameter equal to $4.25 \mu\text{m}$ in the case of healthy adults, or $2.5 \mu\text{m}$ for the sick or infirm or children.

E —sampling convention in general.

E_R —respirable sampling convention.

E_s —sampling efficiency of sampler s .

F —number of flow rates evaluated.

GSD —geometric standard deviation of a representative log-normal aerosol size distribution.

MMD —mass median diameter of a representative log-normal aerosol size distribution.

n —number of replicate measurements.

P —number of sampling efficiency parameters.

Q (L/min)—sampler flow rate.

RSD —relative standard deviation (relative to true concentration as estimated by an ideal sampler following the respirable sampling convention).

$RSD_{\text{analytical}}$ —analytical imprecision component.

RSD_{flow} —uncertainty in the pump flow rate.

RSD_{inter} —inter-sampler imprecision.

RSD_{pump} —imprecision induced by imprecision in the sampling pump.

RSD_{inter} —estimated inter-sampler imprecision RSD_{inter} .

$\hat{RSD}_{\text{pump}}$ —estimated pump-induced imprecision RSD_{pump} .

s —sampler number.

S —number of samplers evaluated.

t —sampling time.

v (m/s)—wind speed.

Δ —bias relative to an ideal sampler following the respirable sampling convention.

$\hat{\Delta}$ —estimated bias Δ .

$\epsilon_{\text{eval } s}$ —random variable contribution to evaluation experimental error in a concentration estimate.

ϵ_s —random variable contribution to inter-sampler error in a concentration estimate.

θ —sampling efficiency model parameter.

σ_0 —sampling efficiency model parameter.

σ_{eval} —evaluation experimental standard deviation in a concentration estimate.

σ_{inter} —inter-sampler standard deviation in a concentration estimate.

σ_{eval} —estimate for σ_{eval} .

σ_{inter} —estimate for σ_{inter} .

σ_R —respirable sampling convention parameter equal to $\ln[1.5]$.

σ_{weight} —weighing imprecision in mass collected on a filter.

$\Phi[x]$ —cumulative normal function defined, given argument x .

4. Summary of Practice

4.1 Calm-air Evaluation—The sampling efficiency from $D = 0$ to $10 \mu\text{m}$ and its variability are measured in calm air ($<0.5 \text{ m}/\text{s}$) for several candidate samplers operated at a variety of flow rates. This information is then used to compute concentration estimates expected in sampling representative log-normal aerosol size distributions. Precision and bias (4.1.1 and 4.1.2) are therefrom determined relative to a conventional sampler. Overall performance in calm air can then be assessed by computing a confidence limit on the Busch probabilistic accuracy, accounting for uncertainty in the evaluation experiment, given measured bias and imprecision at each log-normal aerosol size distribution of interest. This test has evolved from work described in Refs (14-21).

4.1.1 Precision—In the sampling of aerosol, several components of precision have been found (5) significant. These include inter-sampler variability, caused by physical variations in the samplers; intra-sampler variability, from inaccuracy in the setting and maintenance of required airflow; and analytical error, for example, in the weighing of filters, or, as another example, in the measurement of α -quartz.

4.1.2 Bias—As no real sampler follows the aerosol fraction conventions exactly, bias always exists between true and conventional (ideal) samplers. This bias depends on the particle size-distribution of the aerosol sampled. The worst-case situation is in the sampling of monodisperse aerosol. However, in most workplaces, aerosol is present in a broad distribution of sizes. The cancellation of positive and negative components of bias at different particle sizes reduces the overall bias in this case.