



Designation: D 6061 – 01

Standard Practice for Evaluating the Performance of Respirable Aerosol Samplers¹

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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. When a health effects assessment has been based on a specific convention it is appropriate to use that same convention for setting permissible exposure limits in the workplace and ambient environment and for monitoring compliance. 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).

1.2 This practice is complimentary to Test Method **D 4532**, which specifies a particular instrument, the 10-mm cyclone.³ 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.^{3,4} Details on the evaluation have been recently published (5-7) and can be incorporated into revisions of Test Method **D 4532**.

1.3 A central aim of this practice is to provide information required for characterizing the uncertainty of concentration estimates from samples taken by candidate samplers. For this purpose, sampling accuracy data from the performance tests

given here can be combined with information as to analytical and sampling pump uncertainty obtained externally. The practice applies principles of ISO GUM, expanded to cover situations common in occupational hygiene measurement, where the measurand varies markedly in both time and space. A general approach (8) for dealing with this situation relates to the theory of tolerance intervals and may be summarized as follows: Sampling/analytical methods undergo extensive evaluations and are subsequently applied without re-evaluation at each measurement, while taking precautions (for example, through a quality assurance program) that the method remains stable. Measurement uncertainty is then characterized by specifying the evaluation confidence (for example, 95 %) that confidence intervals determined by measurements bracket measurand values at better than a given rate (for example, 95 %). Moreover, the systematic difference between candidate and idealized aerosol samplers can be expressed as a relative bias, which has proven to be a useful concept and is included in the specification of accuracy (3.2.9-3.2.10).

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

1.5 *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 appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:⁵

- D 1356** Terminology Relating to Atmospheric Sampling and Analysis
- D 4532** Test Method for Respirable Dust in Workplace Atmospheres
- D 6062M** Performance Specifications for Samplers of Health-Related Aerosol Fractions
- D 6552** Practice for Controlling and Characterizing Errors in Weighing Collected Aerosols

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

⁴ 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.

⁵ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 International Standards:

ISO TR 7708 Technical Report on Air Quality—Particle Size Fraction Definitions for Health-Related Sampling, Brussels, 1993⁶

ISO GUM Guide to the Expression of Uncertainty in Measurement, Brussels, 1993⁶

CEN EN 481 Standard on Workplace Atmospheres. Size Fraction Definitions for the Measurement of Airborne Particles in the Workplace, Brussels, 1993⁷

CEN EN 1232 Standard on Workplace Atmospheres. Requirements and Test Methods for Pumps used for Personal Sampling of Chemical Agents in the Workplace, Brussels, 1993⁷

CEN EN 13205 Workplace Atmospheres- Assessment of Performance of Instruments for Measurement of Airborne Particle Concentrations, 2001⁷

2.3 NIOSH Standards:

NIOSH Manual of Analytical Methods, 4th ed., Eller, P. M., ed.: Dept. of Health and Human Services, 1994⁸

Criteria for a Recommended Standard, Occupational Exposure to Respirable Coal Mine Dust, NIOSH, 1995⁹

3. Terminology

3.1 Definitions:

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

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:

3.2.1 *aerodynamic diameter*, D (μm)—the diameter of a sphere of density, 10^3 kg/m³, with the same stopping time as a particle of interest.

3.2.2 *respirable sampling convention*, E_R —defined explicitly at aerodynamic diameter D (μm) as a fraction of total airborne aerosol in terms of the cumulative normal function (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 $D_R = 4.25$ μm and $\sigma_R = \ln[1.5]$.

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*

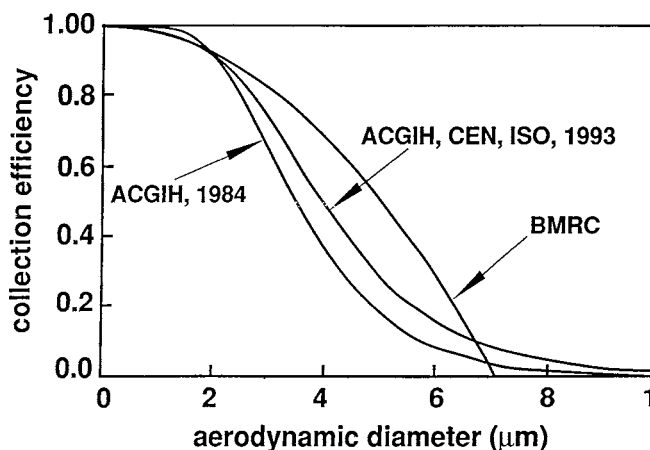


FIG. 1 Respirable Aerosol Collection Efficiencies

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* $C^{-1} dC/dD$ (μm^{-1})—of a given airborne aerosol, the mass concentration of aerosol per unit aerodynamic diameter range per total concentration C .

3.2.3.1 *lognormal size distribution*—an idealized distribution characterized by two parameters: the *geometric standard deviation* (GSD) and *mass median diameter* (MMD). The distribution is given explicitly as follows:

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

where C is the total mass concentration.

3.2.4 *conventional 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:

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

3.2.4.1 *Discussion*—Note that samples are often taken over an extended time period (for example, 8 h), so that dC/dD of Eq. 3 represents a time-averaged, rather than instantaneous, size-distribution.

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_p , where $p = 1, \dots, P$ (for example, 4)—parameters that specify the function $E_s(D, Q)$.

3.2.7 *mean sampled concentration* c_s —the concentration that sampler s would give, averaged over sampling pump and analytical fluctuations, in sampling aerosol of size-distribution $C^{-1} dC/dD$ is given as follows:

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

3.2.8 *mean concentration* c —the population mean of c_s .

3.2.9 *uncertainty components*:

⁶ Available from International Organization for Standardization, Caisse Postale 56, CH-1211, Geneva 20, Switzerland.

⁷ Available from CEN Central Secretariat: rue de Stassart 36, B-1050 Brussels, Belgium.

⁸ Available from Superintendent of Documents, U.S. Government Printing Office, Stock No. 917-011-00000-1, Washington DC 20402.

⁹ Available from NIOSH Publications, 4676 Columbia Parkway, Cincinnati, OH 45226.

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

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

3.2.9.3 *inter-sampler relative standard deviation* RSD_{inter} —the inter-sampler standard deviation (varying sampler s) relative to the respirable concentration c_R and taken as primarily associated with physical variations in sampler dimensions.

3.2.10 *mean relative bias* Δ —of measurement c relative to the conventional respirable concentration c_R , defined as follows:

$$\Delta \equiv (c - c_R)/c_R \quad (5)$$

3.2.11 *symmetric-range accuracy* A —the fractional range, symmetric about the conventional concentration c_R , within which 95 % of sampler measurements are to be found (**8,10-13** and the **NIOSH Manual of Analytical Methods**).

3.2.12 *flow rate* Q (L/min)—the average flow rate of air sampled by a given sampler over the duration of the sampling period.

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

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

3.3 Symbols and Abbreviations:

A —symmetric-range accuracy as defined in terms of bias and precision (see 3.2.11).

$\hat{A}$ —estimated accuracy A .

NOTE 1—Hats as in A refer to estimates, both in sampler application and sampler evaluation.

$95\%A$ —95 % confidence limit on the symmetric-range accuracy A .

$c(\text{mg}/\text{m}^3)$ —expected value of the sampler-averaged concentration estimates c_s .

$c_s(\text{mg}/\text{m}^3)$ —expected value (averaged over sampling pump and analytical variations) of the concentration estimate from sampler s .

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

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

D (μm)—aerosol aerodynamic diameter.

D_0 —sampling efficiency model parameter.

$D_R(\mu\text{m})$ —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 lognormal aerosol size distribution.

MMD —mass median diameter of a lognormal aerosol size distribution.

MSE_c —mean square element for sampler in application (see 10.4).

MSE —mean square element for evaluation data (see A1.5).
 n —number of replicate measurements.

P —number of sampling efficiency parameters.

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

$RSD_{\text{analytical}}$ —relative standard deviation component characterizing analytical random variation.

RSD_{eval} —relative standard deviation component characterizing uncertainty from the evaluation experiment itself (Annex A1).

RSD_{inter} —relative standard deviation component characterizing random inter-sampler variation.

RSD_{pump} —relative standard deviation component characterizing the effect of random sampling pump variation.

s —sampler number.

S —number of samplers evaluated.

t —sampling time (for example, 8h).

U —expanded uncertainty.

u_c —combined uncertainty.

v (m/s)—wind speed.

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

$\epsilon_{\text{eval } s}$ —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_R —respirable sampling convention parameter equal to $\ln[1.5]$.

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

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

4. Summary of Practice

4.1 The sampling efficiency from $D = 0$ to $10\ \mu\text{m}$ and its variability are measured in calm air ($<0.5\ \text{m/s}$) for several candidate samplers operated at a variety of flow rates. This information is then used to compute concentration estimates expected in sampling representative lognormal aerosol size distributions. Random variations (10.2) as well as systematic deviation (10.1) are specified relative to a conventional sampler. Overall performance in calm air can then be assessed by computing a confidence limit $95\%A$ on the symmetric-range accuracy (3.2.11), accounting for uncertainty in the evaluation experiment, given estimated bias and imprecision at each lognormal aerosol size distribution of interest. The symmetric-range accuracy confidence limit $95\%A$ provides conservative confidence intervals bracketing the conventional concentration at given confidence in the method evaluation and lognormal distribution.