



# Standard Guide for Personal Samplers of Health-Related Aerosol Fractions [Metric]<sup>1</sup>

This standard is issued under the fixed designation D 6062M; 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 guide defines conventions for personal samplers of specific particle-size-dependent fractions of any given non-fibrous airborne aerosol. Such samplers are used for assessing health effects and in the setting of and testing for compliance with permissible exposure limits in the workplace and ambient environment. The conventions have 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) (1).<sup>2</sup> The conventions were developed (2) in part from health-effects studies reviewed (3) by the ACGIH and in part as a compromise between definitions proposed by the ACGIH (3) and by the British Medical Research Council (BMRC) (4). Conventions are given here for inhalable, thoracic, and respirable fractions.

1.2 This guide is complementary to Test Method D 4532, which describes the performance of a particular instrument, the 10-mm cyclone, and operational procedures for use. The procedures, specifically the optimal flow rate, are still valid although the estimated accuracy differs somewhat from use with previous aerosol fraction definitions. Details on this instrument and also the Higgins-Dewell cyclone have recently been published (5-7).

### 1.3 Limitations:

1.3.1 The definitions given here were adopted by the agencies listed in 1.1 in part on the basis of expected health effects of the different size fractions, but in part allowing for available sampling equipment. The original adoption by CEN was, in fact, for the eventual setting of common standards by the EC countries while permitting the use of a variety of instrumentation. Deviations of the sampling conventions from health-related effects are as follows:

1.3.1.1 The inhalable fraction actually depends on the specific air speed and direction, on the breathing rate, and on whether breathing is by nose or mouth. The values given in the inhalable convention are for representative values of breathing rate and represent averages over all wind directions.

1.3.1.2 The respirable and thoracic fractions vary from individual to individual and with the breathing pattern. The conventions are approximations to the average case.

1.3.1.3 Each convention applies strictly to a fraction penetrating to a region, rather than depositing. Therefore, samples collected according to the conventions may only approximate correlations with biological effects. For example, the respirable convention overestimates the fraction of very small particles deposited in the alveolar region of the respiratory system because some of the particles are actually exhaled without being deposited (8). In many workplaces, these very small particles contribute insignificantly to the sampled mass. Furthermore, the large variability between individuals and the details of clearance may be as important as this type of effect.

1.3.1.4 The thoracic convention applies to mouth breathing, for which aerosol collection is greater than during nose breathing.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

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:

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres<sup>3</sup>

D 4532 Test Method for Respirable Dust in Workplace Atmospheres<sup>3</sup>

<sup>1</sup> This guide 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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<sup>2</sup> The boldface numbers in parentheses refer to a list of references at the end of this standard.

<sup>3</sup> Annual Book of ASTM Standards, Vol 11.03.

## 2.2 International Standards:

ISO TR 7708 Technical Report on Air Quality—Particle Size Fraction Definitions for Health-Related Sampling, Brussels, 1993<sup>4</sup>

CEN EN 481 Standard on Workplace Atmospheres. Size Fraction Definitions for the Measurement of Airborne Particles in the Workplace, Brussels, 1993<sup>5</sup>

## 3. Terminology

3.1 Many terms used in this guide are defined in Terminology D 1356.

### 3.2 Definitions of Terms Specific to This Standard:

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

3.2.2 *inhalable convention,  $E_I$* —the target specification for sampling instruments when the inhalable fraction is the fraction of interest. Specifically,  $E_I$  is taken (Technical Report ISO TR 7708, CEN Standard EN 481, and the present ACGIH threshold limit values (1)) as follows:

$$E_I = 0.50 (1 + \exp[-0.06 D]), D < 100 \mu\text{m} \quad (1)$$

defined in terms of aerodynamic diameter,  $D$ .

3.2.2.1 *Discussion*—The inhalable convention  $E_I$  is illustrated in Fig. 1. Note that  $E_I \rightarrow 0.50$  (50 %) at large  $D$ . Eq 1 approximates the inhalable fraction when averaged over all wind directions for windspeeds  $v < 4 \text{ m/s}$ . At higher wind speeds, the following convention has been tentatively suggested as follows (9):

$$E_I = 0.50 (1 + \exp[-0.06 D]) + 10^{-5} v^{2.75} \exp[0.055 D], \quad 4 \text{ m/s} < v < 9 \text{ m/s} \quad (2)$$

3.2.3 *inhalable fraction*—the total airborne particle mass fraction inhaled through the nose and mouth, that is, which enters the respiratory system.

3.2.4 *respirable convention,  $E_R$* —the target sampling curve for instruments approximating the respirable fraction.  $E_R$  is defined (Technical Report ISO TR 7708, CEN Standard EN 481, and the present ACGIH Threshold Limit Values (1)) in terms of the cumulative normal function (10)  $\Phi$  as follows:

$$E_R = E_I \cdot \Phi[\ln[D_R/D]/\sigma_R] \quad (3)$$

where the indicated constants are  $D_R = 4.25 \mu\text{m}$  and  $\sigma_R = \ln[1.5]$ . The cumulative normal function  $\Phi$  is easily approximated using the algorithm given in Appendix X1.

3.2.4.1 *Discussion*—For protecting the sick or infirm or children, a quantity  $D_R = 2.5 \mu\text{m}$  has been suggested (Technical Report ISO TR 7708). This accounts for the fact that in children and in adults with certain chest diseases, the tracheo-bronchial region is more effective at collecting particles of small aerodynamic diameter than it is in healthy adults. The respirable convention  $E_R$  is illustrated in Fig. 1. Note that 50 % of total airborne particles with  $D = 4.0 \mu\text{m}$  are in the respirable fraction.

3.2.5 *respirable fraction*—the mass fraction of total airborne particles penetrating to the alveolar region of the respiratory system.

3.2.6 *sampling convention*—a target specification that approximates to a specific health-related fraction of aerosol of given aerodynamic diameter. A sampling convention is specified in terms of the sampling efficiency  $E$ , the fraction of particles at given aerodynamic diameter collected by an ideal instrument.

3.2.7 *thoracic convention,  $E_T$* —the target sampling curve for instruments approximating the thoracic fraction.  $E_T$  is defined (Technical Report ISO TR 7708, CEN Standard EN 481, and the present ACGIH Threshold Limit Values (1)) in terms of the cumulative normal function (10)  $\Phi$  as:

$$E_T = E_I \cdot \Phi[\ln[D_T/D]/\sigma_T] \quad (4)$$

where the indicated constant parameters are  $D_T = 11.64 \mu\text{m}$  and  $\sigma_T = \ln[1.5]$ .

3.2.7.1 *Discussion*—The thoracic convention  $E_T$  is illustrated in Fig. 1. Note that 50 % of total airborne particles with  $D = 10 \mu\text{m}$  are in the thoracic fraction.

3.2.8 *thoracic fraction*—the mass fraction of total airborne particles penetrating beyond the larynx.

### 3.3 Abbreviations: Symbols and Abbreviations:

3.3.1  $D$  ( $\mu\text{m}$ )—aerosol aerodynamic diameter.

3.3.2  $D_R$  ( $\mu\text{m}$ )—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.

3.3.3  $D_T$  ( $\mu\text{m}$ )—thoracic sampling convention parameter equal to  $11.64 \mu\text{m}$ .

3.3.4  $E$ —sampling convention in general.

3.3.5  $E_I$ —inhalable sampling convention.

3.3.6  $E_R$ —respirable sampling convention.

3.3.7  $E_T$ —thoracic sampling convention.

3.3.8  $v$  (m/s)—wind speed.

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

3.3.10  $\sigma_T$ —thoracic sampling convention parameter equal to  $\ln[1.5]$ .

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

## 4. Significance and Use

4.1 The convention to be used is not always straightforward, but generally depends on what part of the respiratory system is affected by the aerosol particles. For example, if an aerosol (for example, silica) is expected to be hazardous mainly in the alveolar regions of the respiratory system, then the respirable convention applies. On the other hand, if an aerosol is extremely soluble (for example, KCN), then the inhalable convention should be used for monitoring or setting exposure limit standards. The conventions are often applied for approximating mass fractions, but they may also be used in the evaluation of total surface area or the number of particles in the collected material.

4.2 The conventions 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

<sup>4</sup> Available from International Organization for Standardization, Caisse Postale 56, CH-1211, Geneva 20, Switzerland.

<sup>5</sup> Available from CEN Central Secretariat: rue de Stassart 36, B-1050 Brussels, Belgium.

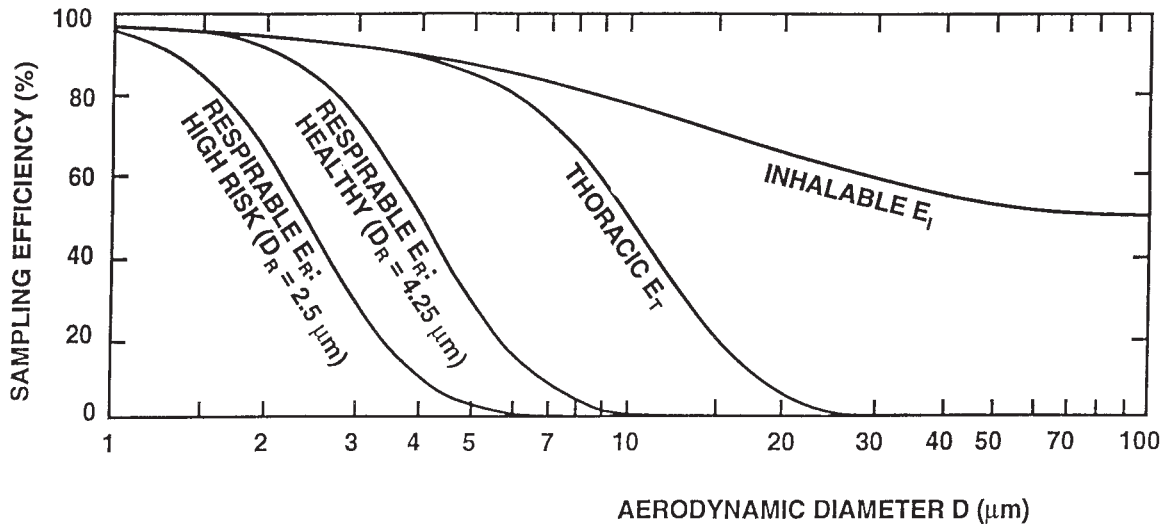


FIG. 1 Inhalable, Thoracic, and Respirable Conventions Relative to Total Airborne Particles

Industrial Hygienists (ACGIH) (1). The definition of respirable aerosol is the basis for recommended exposure levels (REL) of respirable coal mine dust as promulgated by NIOSH (Criteria for a Recommended Standard, Occupational Exposure to Respirable Coal Mine Dust). The respirable aerosol definition also forms the basis of the NIOSH sampling method for respirable particulates not otherwise regulated (*NIOSH Manual of Analytical Methods*).

4.3 The conventions constitute a part of the performance characteristics required of aerosol samplers for collecting aerosol according to the relevant health effects. This guide therefore does not specify particular samplers for measuring the aerosol fractions defined here. Detailed guidelines for evaluating any given sampler relative to the conventions are under preparation. Several advantages over instrument specification can be attributed to the adoption of these performance-associated conventions:

4.3.1 The conventions have a recognized tie to health effects.

4.3.2 Performance criteria permit instrument designers to seek practical sampler improvements.

4.3.3 Performance criteria promote continued experimental testing of the samplers in use with the result that the significant variables (such as wind speed, particle charge, and so forth) affecting sampler operation become understood.

## 5. Precision and Bias

5.1 Precision and bias are detailed in specific test methods (for example, Test Method D 4532). Furthermore, how these quantities are to be measured will be presented in a performance evaluation protocol to appear as a separate standard. Nevertheless, general comments are in order.

5.1.1 *Precision*—In the sampling of aerosol, several components of precision have been found significant (5). 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.

5.1.2 *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.

## 6. Keywords

6.1 aerosol; conventions; deposition; fractions; inhalable; particle; particulates; penetration; respirable; sampling efficiency; size-selective; thoracic

**APPENDIX**
**(Nonmandatory Information)**
**X1. ALGORITHM FOR CUMULATIVE NORMAL FUNCTION**

X1.1 The cumulative normal function  $\Phi[x]$  is easily approximated on a calculator or small computer using the following algorithm **(10)**:

$$\Phi[x] = 1 - Z[x](a_1t + a_2t^2 + a_3t^3) \quad (\text{X1.1})$$

where  $t$  is given in terms of  $x$  as follows:

$$t = 1/(1 + px), \text{ and} \quad (\text{X1.2})$$

where the function  $Z[x]$  is defined as follows:

$$Z[x] \equiv \frac{1}{\sqrt{2\pi}} \exp[-x^2/2], \text{ and} \quad (\text{X1.3})$$

where the constants  $p$ ,  $a_1$ ,  $a_2$ , and  $a_3$  are given as follows:

$$(a_1, a_2, a_3) = (0.4361836, -0.1201676, 0.937298) \quad (\text{X1.4})$$

$$p = 0.33267 \quad (\text{X1.5})$$

**REFERENCES**

- (1) ACGIH: 1994–1995 *Threshold Limit Values*, American Conference of Governmental Industrial Hygienists, 1994.
- (2) Soderholm, S. C., “Proposed International Conventions for Particle Size-Selective Sampling,” *Annals Occupational Hygiene*, Vol 33, 1989, pp. 301–320; Vol 35, pp. 357–358.
- (3) ACGIH, “Particle Size-Selective Sampling in the Workplace,” *Annals of the American Conference of Government Industrial Hygienists*, Vol II, 1984, pp. 21–100.
- (4) British Medical Research Council, “Recommendations of the MRC Panels Relating to Selective Sampling,” *Inhaled Particles and Vapours*, Pergamon Press, Oxford, 1961.
- (5) Bartley, D. L., Chen, C. C., Song, R., and Fischbach, T. J., “Respirable Aerosol Sampler Performance Testing,” *American Industrial Hygiene Assoc. Journal*, Vol 55, 1994, pp. 1036–1046.
- (6) Maynard, A., “Respirable Dust Sampler Characterisation: Efficiency Curve Reproducibility,” *Proceedings of the European Aerosol Conference, Journal of Aerosol Science*, Vol 24, 1993, pp. S457–S458.
- (7) Lidén, G., and Kenny, L. C., “Organization of the Performance of Existing Respirable Dust Samplers,” *Applied Occupational Environmental Hygiene*, Vol 8, 1993, pp. 386–391.
- (8) Heyder, J., Gebhart, J., Rudolph, G., Schiller, C. F., and Stahlhofen, W., “Deposition of Particles in the Human Respiratory Tract in the Size Range 0.005–15  $\mu\text{m}$ ,” *Journal of Aerosol Science*, Vol 17, 1986, pp. 811–825; also, Erratum, *Journal of Aerosol Science*, Vol 18, p. 353.
- (9) Vincent, J. H., Mark, D., Armbruster, L., and Ogden, T. L., “Aerosol Inhalability at Higher Windspeeds,” *Journal of Aerosol Science*, Vol 21, 1990, pp. 577–586.
- (10) Abramowitz, M., and Stegun, I. A., *Handbook of Mathematical Functions*, Dover Publications, Inc., New York, 1965, p. 932.
- (11) NIOSH Criteria for a Recommended Standard, Occupational Exposure to Respirable Coal Mine Dust, 1995.
- (12) NIOSH Manual of Analytical Methods, 4th Ed., P. M., Eller, Ed.: Dept. of Health and Human Services, 1994.

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