Air quality - particle size fraction definitions for health-related sampling

ISO 7708

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Contents

0. Introduction

The fraction of airborne particles which is inhaled into a human body depends on properties of the particles, on the speed and direction of air movement near the body, on breathing rate, and whether breathing is through the nose or mouth. Inhaled particles can then deposit somewhere in the respiratory tract, or can be exhaled. The site of deposition, or probability of exhalation, depends on properties of the particle, respiratory tract, breathing pattern, and other factors.

Liquid particles or soluble components of solid particles can be absorbed by the tissues wherever they deposit. Particles can cause damage close to the deposition site if they are corrosive, radioactive, or capable of initiating some other type of damage. Insoluble particles can be transported to another part of the respiratory tract or body, where they can be absorbed or cause a biological effect.

There is a wide variation from one person to another in probability of particle inhalation, deposition, reaction to deposition, and clearance. Nevertheless, it is possible to define conventions for size-selective sampling of airborne particles when the purpose of sampling is health-related. These are relationships between aerodynamic diameter and the fractions to be collected or measured, which approximate to the fractions penetrating to regions of the respiratory tract under average conditions. Measurement conducted according to these conventions will probably yield a better relationship between measured concentration and risk of disease. For further information on the factors affecting inhalation and deposition, and their application in standards, see Stuart et al. (1986), Phalen et al. (1986), Lippmann et al. (1983), Heyder et al. (1986), Miller et al. (1988), Rudolph et al. (1988), Vincent (1989), Ogden and Birkett (1977), and Soderholm (1989).

1. Scope

This standard defines sampling conventions for particle size fractions for use in assessing possible health effects of airborne particles in the workplace and ambient environment. Conventions are defined for the inhalable, thoracic and respirable fractions; extrathoracic and tracheobronchial conventions may be calculated from the defined conventions. (The inhalable fraction has sometimes been called inspirable - the terms are equivalent. The nomenclature of the fractions is discussed in Annex 1.) Assumptions are given in 4. The convention chosen will depend on the region of effect of the component of interest in the airborne particles (see 3). In this standard, conventions are stated in terms of mass fractions, but they may also be used when the intention is to evaluate the total surface area or the number of particles in the collected material. The conventions should not be used in association with limit values defined in other terms; for example, for fibre limit values defined in terms of the length and diameter of the fibres.

2. Definitions

2.1 Sampling convention: a target specification for sampling instruments which approximates to, for each particle aerodynamic diameter:

- in the case of the inhalable convention, the ratio of the mass concentration of particles entering the respiratory tract to the corresponding mass concentration in the air before the particles are affected by the presence of the exposed individual and inhalation;

- in the case of the other conventions, the ratio of the mass concentration of particles entering the specified region of the respiratory tract to the mass concentration of particles entering the respiratory tract. (These other conventions can also be expressed as ratios to the mass of total airborne particles.)

2.2 **particle aerodynamic diameter**: the diameter of a sphere of density 1 g/cm^3 with the same terminal velocity due to gravitational force in calm air, as the particle, under the prevailing conditions of temperature, pressure and relative humidity (see 4).

NOTE -

For particles of aerodynamic diameter less than 0.5 μm, the particle diffusion diameter should be used instead of the particle aerodynamic diameter. The particle diffusion diameter means the diameter of a sphere with the same diffusion coefficient as the particle under the prevailing conditions of temperature, pressure and relative humidity.

2.3 **inhalable fraction**: the mass fraction of total airborne particles which is inhaled through the nose and mouth.

NOTE -

The inhalable fraction depends on the speed and direction of the air movement, on breathing rate and other factors.

2.4 **inhalable convention**: a target specification for sampling instruments when the inhalable fraction is the fraction of interest.

2.5 **extrathoracic fraction**: the mass fraction of inhaled particles which fails to penetrate beyond the larynx.

2.6 **extrathoracic convention**: a target specification for sampling instruments when the extrathoracic fraction is of interest.

2.7 **thoracic fraction**: the mass fraction of inhaled particles penetrating beyond the larynx.

2.8 **thoracic convention**: a target specification for sampling instruments when the thoracic fraction is of interest.

2.9 **tracheobronchial fraction**: the mass fraction of inhaled particles which penetrates beyond the larynx, but which fails to penetrate to the unciliated airways.

2.10 **tracheobronchial convention**: a target specification for sampling instruments when the tracheobronchial fraction is of interest.

2.11 **respirable fraction**: the mass fraction of inhaled particles which penetrates to the unciliated airways.

2.12 **respirable convention**: a target specification for sampling instruments when the respirable fraction is of interest.

2.13 **total airborne particles**: all particles surrounded by air in a given volume of air.

NOTE -

Because all measuring instruments are size-selective to some extent, it is often impossible to measure the total airborne particle concentration.

3. Principle

The sampling conventions recognise that only a fraction of the airborne particles which are near to the nose and mouth is inhaled. This fraction is called the inhalable fraction (see 2.3). For some substances, the sub-fractions of this which penetrate beyond the larynx, or to the unciliated airways, are of special significance for health.

This standard presents conventionalised curves approximating to the fraction inhaled and the sub-fractions penetrating beyond the larynx or to the unciliated airways. These curves are called the inhalable convention (2.4), the thoracic convention (2.8) and the respirable convention (2.12). Extrathoracic (2.6) and tracheobronchial (2.10) conventions may be calculated from these. Instruments used for sampling should conform with the sampling convention appropriate to the region of the respiratory tract where deposition of the substance being measured might lead to biological effect. For example, the inhalable convention would be chosen if the substance might lead to a condition wherever it deposited, the thoracic convention would be chosen if the region was the lung conductive airways (bronchi), and the respirable convention if the region was the gas exchange region extending from the respiratory bronchioles to the alveoli.

In children and in adults with certain chest diseases, the tracheobronchial region is more effective at collecting particles of small aerodynamic diameter than it is in healthy adults. This is accounted for in the conventions by a second respirable convention, centred at smaller aerodynamic diameters, which gives a corresponding tracheobronchial convention extended to smaller aerodynamic diameters. This tracheobronchial convention should be used when the exposed population includes these 'high-risk' groups, and the 'high-risk' respirable convention may be used in these circumstances.

Instruments can be used to collect individual fractions according to the conventions, or to collect several fractions simultaneously. For example, an instrument could collect particles from the air according to the inhalable convention, and then separate this material into portions according to the thoracic, tracheobronchial and respirable conventions. Alternatively, an instrument might just collect the respirable fraction from the air. In this case, the design would have to ensure that selection at the entry due to aerodynamic effects, and subsequently within the instrument, was such that the overall selection was in accordance with the conventions. (The performance re-

quirements of instruments are summarised in Section 9.)

4. Assumptions and approximations

Approximations and assumptions are unavoidable in simulating by sampling conventions the very complex interaction of variables that governs respiratory tract entry and penetration.

The conventions are necessarily only approximations to respiratory tract behaviour, and the following assumptions should be noted.

- The inhalable fraction depends on air movement - speed and direction - on 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 averaged for all wind directions. This is appropriate for an individual uniformly exposed to all wind directions or predominantly to wind from the side or from behind, but the convention would usually underestimate the inhalable fraction of larger particles for an individual who usually faced the wind.

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

- Each convention approximates to the fraction penetrating to a region, not to the fraction depositing there. In general, particles must deposit to have a biological effect. In this respect, the conventions will lead to an overestimate of the potential biological effect. The most important example is that the respirable convention over-estimates the fraction of very small particles which are deposited in the unciliated airways, because a fraction of these particles is exhaled without

being deposited. In many workplaces, these very small particles do not contribute much to the sampled mass.

- The thoracic convention approximates to the thoracic fraction during mouth breathing, which is greater than the thoracic fraction during nose breathing. The extrathoracic convention may therefore underestimate the 'worst case' extrathoracic fraction, which occurs during nose breathing.

5. Inhalable convention

The target sampling curve for instruments collecting the inhalable fraction, when averaged over all wind directions, shall be as follows for windspeeds $U < 4$ m/s. The percentage E_I of airborne particles of aerodynamic diameter D(μm) which are to be collected is given by

$$E_I = 50\,(1 + \exp[-0.06\,D]) \qquad (1)$$

Some values of E_I are given in table 2 and illustrated in figures 1 and 2.

NOTE -

Experimental data on the inhalable fraction do not yet exist for $D > 100$ μm, and the convention should not be applied to larger particles. For windspeeds $U > 4$ m/s, equation (2) is tentatively suggested. Equation (2) should not be applied for $D > 90$ μm or $U > 9$ m/s, which are the limits of the experimental data.

$$E_I = 50\,(1 + \exp[-0.06D]) + 10^{-3}\,U^{2.75} \exp[0.055D] \qquad (2)$$

6. Thoracic convention

The target sampling curve for instruments collecting the thoracic fraction is as follows. The percentage E_T of the inhalable convention which is to be collected at an aerodynamic diameter D is given by a cumulative log-normal distribution with a median of 11.64 μm and a geometric standard deviation of 1.5. A numerical approximation for ease of calculation is given in Annex 2. Note that E_T is calculated from the inhalable convention. The fraction of the total airborne particles (see 2.13) at an aerodynamic diameter D is obtained by multiplying E_T by 0.01 E_I from equation (1). The values obtained are given in tables 1 and 2 and illustrated in figure 1. It will be seen from the table that 50 % of total airborne particles with D = 10 μm are in the thoracic fraction.

7. Respirable conventions

7.1 - Target population: sick and infirm, or children

When the population that it is desired to protect are children, or the sick or infirm (the 'high risk' group), the target sampling curve for instruments collecting the respirable fraction is as follows. The percentage E_R of the inhalable convention which is to be collected at an aerodynamic diameter D (μm) is given by a cumulative lognormal distribution with a median diameter of 2.5 μm and a geometric standard deviation of 1.5. A numerical approximation for ease of calculation is given in Annex 2. Note that E_R is a fraction of the inhalable convention. The fraction of the total airborne particles (see 2.13) at an aerodynamic diameter D is obtained by multiplying E_R by 0.01 E_I from equation (1). The values obtained are given in tables 1 and 2 and illustrated in figure 1.

NOTE -

When the population is the 'high risk' group, the healthy adult respirable convention may be used and will then give an extra safety margin. The chief purpose of the 'high risk' respirable convention is to generate a 'high risk' tracheobronchial convention (section 8) which gives better protection for this group.

7.2 Target population: healthy adults

The percentage E_R of the inhalable convention which is to be collected at an aerodynamic diameter D (μm) is given by a cumulative lognormal distribution with a median diameter of 4.25 μm and a geometric standard deviation of 1.5. A numerical approximation for ease of calculation is given in Annex 2. Note that E_R is a fraction of the inhalable convention. The fraction of the total airborne particles (see 2.13) at an aerodynamic diameter D is obtained by multiplying E_R by 0.01 E_I from equation (1). The values obtained are given in tables 1 and 2 and illustrated in figure 1.

8. Extrathoracic and tracheobronchial conventions

The extrathoracic convention is calculated as (E_I-E_T) (see sections 5 and 6) at each aerodynamic diameter D. The tracheobronchial convention is calculated as (E_T-E_R) (see sections 6 and 7) at each aerodynamic diameter D. The two tracheobronchial conventions corresponding to the two respirable conventions are given in tables 1 and 2 and are illustrated in figure 2. The 'high risk' tracheobronchial convention should be used when the exposed population includes children or the sick or infirm.

9. Performance of instruments

It may not be possible to construct instruments whose characteristics exactly match the conventions in 5 to 8. In any case, experimental error in the testing of instruments, and possible dependence on factors other than aerodynamic diameter, mean that it is only possible to make a statement of probability that an instrument's characteristic falls within a certain range. The comparison of instruments with the conventions is dealt with in another ISO publication. Amongst other possibilities, this allows verification over restricted ranges of variables if this is all that is necessary. For example, for ambient air instruments, it may be satisfactory to assess performance for a particle size range terminating below 100 μm, and then to restrict use to atmospheres where larger particles are not present.

10. References

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ANNEX 1

Nomenclature of inhalable and respirable fractions in English

The term 'inhalable' is used in the English version of this standard because it is the word most naturally describing the meaning of the fraction for which it is used. There has been some confusion over terminology in the past. 'Inhalable' was used in the late 1970s in European English-language literature with the same meaning as in this standard. ISO (1983) and the amended European directive 88/642/EEC used the name 'inspirable' for this fraction, and the terms 'inspirable' and inhalable' are equivalent. The US Environmental Protection Agency for a time used 'inhalable' for what is now called 'total thoracic particulate' or 'PM_{10}'. EPA no longer uses the term 'inhalable', and so this standard has readopted the term with its original meaning.

The term 'respirable' has been used in English since at least 1952 for the fraction penetrating to the unciliated airways (Hamilton and Walton, 1961, Lippmann and Harris, 1962). ISO (1983) adopted the term 'alveolar', partly because of the similarity of 'respirable' to its term 'inspirable', but as this standard uses the term 'inhalable' this argument no longer applies, and the familiar term 'respirable' has been readopted.

There has been no corresponding confusion in French and German, but for clarity the recommended terms are:

German	French	English
einatembar	inhalable	inhalable
alveolengängig	alvéolaire	respirable
thorakal	thoracique	thoracic

ANNEX 2

Numerical approximations to cumulative log-normal distributions

For convenience of calculation, the following approximations may be used in calculating E_T and E_R. (Hastings, 1955; Soderholm, 1989). This formula gives E_T and E_R as a percentage.

$$E = 100\,(1 - G) \quad \text{if} \quad D \leq M$$

$$E = 100\,G \quad \text{if} \quad D \geq M$$

$$y \text{ is absolute value of } \frac{\log_e (D / M)}{\sqrt{2}\,\log_e 1.5}$$

$$G = 0.5(1 + 0.14112821\,y + 0.08864027\,y^2 + 0.02743349\,y^3 - 0.00039446\,y^4 + 0.00328975\,y^5)^{-8}$$

For Thoracic Fraction, $E = E_T$ if $M = 11.64\ \mu m$, D (μm) is particle aerodynamic diameter.

For healthy adult Respirable Fraction, $E = E_R$ if $M = 4.25\ \mu m$; D in μm.

For high risk Respirable Fraction, $E = E_R$ if $M = 2.5\ \mu m$; D in μm.

aerodynamic diameter D (μm)	inhalable convention E_I (%)	thoracic convention E_T (%)	respirable convention E_R (%)	"high risk" respirable convention E_R (%)	tracheobronchial convention (%)	"high risk" tracheobronchial convention (%)	aerodynamic diameter D (μm)
0	100	100	100	100	0	0	0
1	100	100	100	98.8	0	1.2	1
2	100	100	96.8	70.9	3.2	29.1	2
3	100	100	80.5	32.6	19.5	67.3	3
4	100	99.6	55.9	12.3	43.6	87.3	4
5	100	98.1	34.4	4.4	63.7	93.8	5
6	100	94.9	19.8	1.5	75.1	93.3	6
7	100	89.5	10.9	0.6	78.6	89.0	7
8	100	82.2	5.9	0.2	76.3	82.0	8
9	100	73.7	3.2	0.1	70.5	73.6	9
10	100	64.6	1.7	0	62.9	64.6	10
11	100	55.5	0.9		54.6	55.6	11
12	100	47.0	0.5		46.5	47.0	12
13	100	39.3	0.3		39.0	39.3	13
14	100	32.4	0.2		32.3	32.4	14
15	100	26.6	0.1		26.5	26.6	15
16	100	21.6	0.1		21.6	21.6	16
18	100	14.1	0		14.1	14.1	18
20	100	9.1			9.1	9.1	20
25	100	3.0			3.0	3.0	25
30	100	1.0			1.0	1.0	30
35	100	0.3			0.3	0.3	35
40	100	0.1			0.1	0.1	40
50	100	0			0	0	50
60	100						60
80	100						80
100	100						100

Table 1. The conventions as percentages of the inhalable convention

aerodynamic diameter D (μm)	inhalable convention E_I (%)	thoracic convention $E_T \times E_I$ (%)	respirable convention $E_R \times E_I$ (%)	"high risk" respirable convention $E_R \times E_I$ (%)	tracheobronchial convention (%)	"high risk" tracheobronchial convention (%)	aerodynamic diameter D (μm)
0	100	100	100	100	0	0	0
1	97.1	97.1	97.1	95.9	0	1.2	1
2	94.3	94.3	91.4	66.9	3.0	27.5	2
3	91.7	91.7	73.9	30.0	17.9	61.8	3
4	89.3	89.0	50.0	11.0	39.0	78.0	4
5	87.0	86.4	30.0	3.8	55.5	81.6	5
6	84.9	80.5	16.8	1.3	63.8	79.2	6
7	82.9	74.2	9.0	0.5	65.1	73.7	7
8	80.9	66.6	4.8	0.2	61.8	66.4	8
9	79.1	58.3	2.5	0.1	55.8	58.3	9
10	77.4	50.0	1.3	0	48.7	50.0	10
11	75.8	42.1	0.7		41.4	42.1	11
12	74.3	34.9	0.4		34.6	34.9	12
13	72.9	28.6	0.2		28.4	28.6	13
14	71.6	23.2	0.2		23.1	23.2	14
15	70.3	18.7	0.1		18.6	18.7	15
16	69.1	15.0	0		14.9	15.0	16
18	67.0	9.5			9.4	9.5	18
20	65.1	5.9			5.9	5.9	20
25	61.2	1.8			1.8	1.8	25
30	58.3	0.6			0.6	0.6	30
35	56.1	0.2			0.2	0.2	35
40	54.5	0.1			0.1	0.1	40
50	52.5	0			0	0	50
60	51.4						60
80	50.4						80
100	50.1						100

Table 2. The conventions as percentages of the total airborne particles

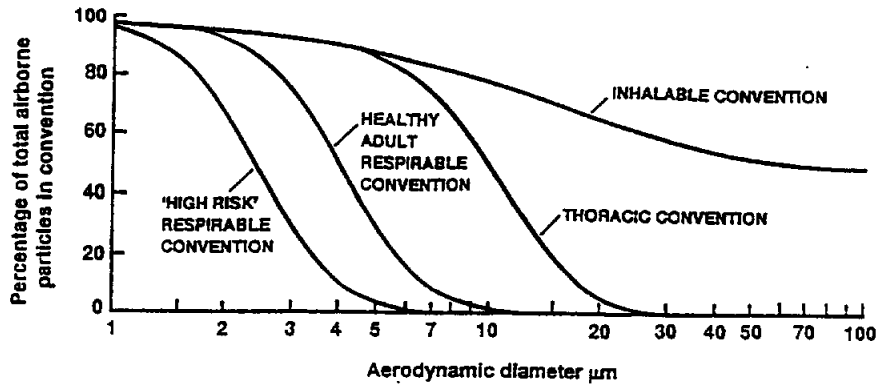

Figure 1. The inhalable, thoracic and respirable conventions as percentages of total airborne particles.

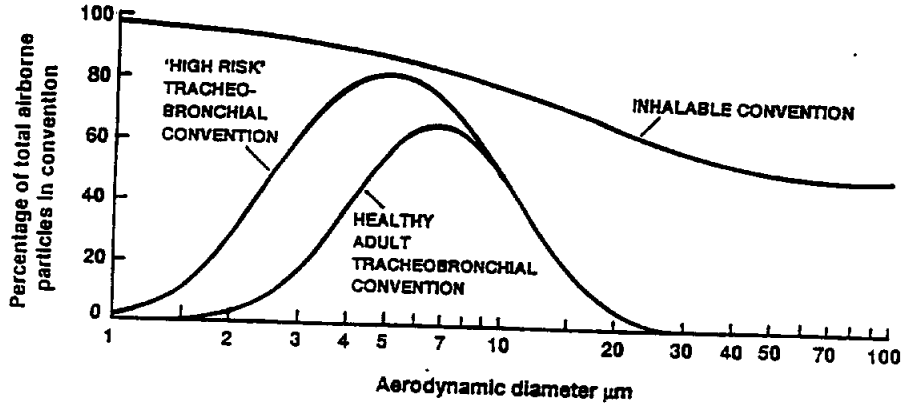

Figure 2. The tracheal and tracheobronchial conventions as percentages of total airborne particulates.