Comparison of 8 present day samplers IOM,CIP10-I GSP and others 1998

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**Instrument Performance Criteria**

# Inhalable Aerosol Samplers

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## Introduction

This column provides a ranking of presently available personal samplers designed to estimate the inhalable fraction of airborne aerosol. Specifically, the IOM,[1] CIP10-I,[2] and GSP[3] samplers exhibited the lowest bias. The inhalable convention specifies a particle size-dependent efficiency with which an acceptable sampler is expected to capture aerosol particles. The inhalable, together with the respirable and thoracic, conventions have been adopted by the International Standards Organization, the Comité Européen de Normalisation, the American Conference of Governmental Industrial Hygienists (ACGIH),[4] and by the American Society for Testing and Materials.

The inhalability convention was developed[5–10] so as to mimic aerosol capture by the human head and is in line with many health effects studies reviewed[11] by ACGIH. The convention is specified in terms of a curve giving the sampling efficiency versus aerodynamic aerosol diameter (defined so as to result in equivalent motion of a unit density sphere in air) up to 100 μm, representative of human exposure, for wind speeds less than 4 m/s, averaging over all wind directions. As such, the largest particles of significance to health are covered. Since large aerosol particles are difficult to handle experimentally, much less information is available for characterizing inhalable aerosol samplers than, for example, respirable samplers. Nevertheless, information exists which suggests choices among several specific samplers available at present.

The most recent comparison of presently used inhalable aerosol samplers is that carried out under the auspices of the European Commission (EC),[12,13] which generally corroborates earlier sampler studies.[1,14] This research was begun at the Warren Spring Laboratory, Stevenage, United Kingdom, and, upon the closure of this laboratory, was completed at the Atomic Energy Authority, Harwell, United Kingdom. Eight samplers in present use were tested: CIP10-I (France), 37-mm closed-face cassette (Spain and United States), 37-mm open-face cassette (Sweden), PAS-6 (Netherlands), PERSPEC (Italy), GSP (Germany), IOM (United Kingdom), and the seven-hole sampler (United Kingdom).

Conditions of the experiment included measurements of sampler collection efficiencies for aerosol particles as large as 100 μm at wind speeds of 0.5, 1.0, and 4 m/s. Samplers were positioned on a manikin rotating slowly within a wind tunnel. The samplers were all purportedly conductive, the 37-mm plastic cassette samplers having been painted with a conductive coating. The results of this experiment indicated negligible intersampler variability within each sampler type. However, each sampler type exhibited bias relative to the sampling convention.

Within the EC study, the most reliable data pertain to the lower ambient wind speeds (0.5 or 1.0 m/s), which therefore become the focus of this column. A recent study[15] of wind speeds characteristic of indoor workplaces indicates a mean wind speed of about 0.2 m/s, including normal worker motion, and a 95 percentile range of up to 0.8 m/s. Thus the range considered here evidently extends beyond indoor workplace conditions to a degree.

The samplers discussed in this column were ranked in terms of the bias relative to the convention as follows: Experimentally determined sampling efficiencies versus aerodynamic diameter were modeled mathematically. Correction factors were computed by minimizing the absolute value of bias of mass concentration estimates (relative to the ideal inhalability convention) over aerosol size distributions characterized by a mass median diameter (MMD) of <50 μm and a geometric standard deviation (GSD) of ≥1.5. This range of size distributions is considered representative of components of aerosol size distributions found in the workplace[16] (see also Reference 8 and the CEN Pre-Standard on Workplace Atmospheres: Assessment of the Performance of Instruments for Measurement of Airborne Particles). The correction factors were optimized so as to accommodate wind speeds of 0.5 and 1.0 m/s simultaneously. Samplers were considered acceptable (regarding sampling efficiency) if, for any size distribution in the test range, |bias| is <50 percent at 95 percent confidence in the sampler characterization.

This column then provides a list of samplers together with conversion factors for sampling according to the inhalable aerosol sampling convention. The suggestions are based on limited data existing at present. As information on these or other samplers and physiological inhalability itself develops, the list, together with its calibration factors, may change.

## Basic Operating Principles

All of the samplers considered here sample particles at a fixed sampled air flow rate through an orifice of fixed diameter. The flow rate, orifice, and external dimensions of the sampler are carefully designed so as to best comply with the sampling convention. The samplers operate similarly to the human body: the more massive a particle, the more difficult for it to follow air flow streamlines so as to land inside the sampler for capture by a suitable sampling medium (filter or foam). Once captured by the sampler, the particles are generally weighed. However, there are many instances in which chemical analyses are carried out.[17] In this regard, the data of Reference 13 suggest that a 5 percent increase in the calibration constant (averaged over 0.5- and 1.0-m/s wind speeds) may compensate for using IOM filter samples only, rather than the entire deposit on filter and cassette combined, although more data may be needed to justify this point.

Regarding the weighing of sampling media, specific problems have recently been uncovered[18] regarding the weight stability of collection media. For example, considering samplers mentioned in this column, the entire body of the IOM sampler cassette is weighed along with the filter itself. The cassettes are available in both plastic and stainless steel versions. Because the plastic cassette can capture or lose up to 1 mg water, field blanks may be used to correct weights when a high degree of accuracy is required at low filter loadings. Alternatively, stainless steel cassettes have been found[18] to be extremely weight stable. Relatedly, the filter used in the GSP sampler is weighed separately from its plastic filter holder ring because of potential water absorption by the ring. Similarly, foam inserts may be used as field blanks for CIP10-I sample correction if necessary.

### Uses

Of the three sampling conventions, the inhalable convention would be used to sample airborne substances that pose a threat to the respiratory system in general, as opposed, for example, to only the alveolar regions. For example, if an aerosol is extremely soluble (e.g., KCN), then it could have an effect everywhere following inhalation. Historically, the closed-face cassette has been applied for this purpose in the United States. However, samplers that are more efficient in capturing large particles which can enter the respiratory system are expected to be favored in the future. The conventions' recognized tie to health effects should permit more accurate prediction and control of aerosol-induced disease.

In addition to assessing health effects, particle size-selective samplers are used in testing for compliance with occupational exposure limits. The samplers may soon be applied in the United States as well as in Europe (MDHS 14/2) for this purpose. Specifically, the inhalable aerosol sampler may, in some instances, replace the closed-face cassette as the sampler of choice. This complicated issue, which has inspired several side-by-side field comparisons of samplers, is not addressed further in this column.

### Limitations

The fraction of a given airborne aerosol which is inhaled depends on the specific air speed and direction, on the breathing rate, and on whether breathing is by nose or mouth. The values given by the inhalable convention are for representative breathing rates, whereas truly inhaled fractions may vary from individual to individual and with the breathing pattern.[19] Furthermore, the conventions represent averages over all wind directions. The conventions are approximations to the average case.

Second, the convention applies strictly to the fraction entering the respiratory system, rather than depositing. Therefore, samples collected according to the inhalability convention may only approximate correlations with biological effects. This is because the smaller particles encountered in the workplace—diesel particulate, for example—may be inhaled, but then a sizable fraction is exhaled without being deposited.[19] In many workplaces these are the smaller particles which contribute insignificantly to the entire inhaled sampled mass. Also, the large variability between individuals and the details of clearance may be as important as this type of effect. On the other hand, there may be instances where the distinction between penetration and deposition is important.

Another limitation is indicated by unpublished data[20,21] on inhalability and sampler behavior at very low wind speeds, (i.e., less than 0.1 m/s). Evidently, the efficiency of capture both by the human head and by the inhalable aerosol samplers increases markedly at the smallest sizes. No corresponding convention has yet been adopted.

Finally, the inhalable aerosol convention is defined at present for aerodynamic diameters only as large as 100 $\mu$m. A recent study[22] of the IOM sampler indicates that the sampling efficiency may increase to about 150 percent at sizes close to 300 $\mu$m, whereas capture efficiency by the human head may decrease by an order of magnitude. How to deal with particles that are projected into sampler or respiratory system has not yet been decided.

### Sampler Evaluation Results

Figures 1 and 2 depict, for wind speeds of 0.5 and 1.0 m/s, the measured sampling efficiencies versus aerodynamic diameter. Note the unexpected result that the measured sampling efficiencies generally do not approach 100 percent at the smaller particle diameters studied. Why this is so is not yet understood. As the test particles were not discharged, it is possible that electrostatic effects produced this result. Similar effects would then be expected with actual workplace aerosols, which, like the test particles, often are highly charged.

All the samplers tested in the EC project were modeled as to sampling efficiency so as to compute biases relative to convention in sampling aerosols distributed in size. This modeling is purely for calculational use and is not to be confused with modeling a sampler from the point of view of physics.[23] The model chosen has the following characteristics:

1. The curve is a simple decreasing function of aerodynamic particle diameter.
2. The sampling efficiency can differ from 100 percent at the smallest sizes to account for the anomaly mentioned above.
3. The curve can take on nonzero values at the largest of particle sizes.
4. The slope of the curve can be fixed at a specific aerosol diameter.

The function, therefore, has four model parameters which were fit to the data by least-squares analysis. The model curves that best fit the means of the data at each diameter, and the international inhalability convention, are also shown in Figures 1 and 2.

Calibration constants were determined by optimizing the bias of the modeled samplers relative to the sampling convention over an MMD of $<50$ $\mu$m and a GSD of $\geq 1.5$. This optimization was determined for wind speeds equal to 0.5 and 1.0 m/s simultaneously. Conservative confidence limits on the bias magnitude at the 95 percent level were then computed[24] by taking advantage of the five or six degrees of freedom available after fitting the four-model parameters using the nine or ten diameters of each experiment.

Note that the sampling efficiencies (and the convention itself) are uncertain at aerodynamic diameters larger than 100 $\mu$m. This uncertainty leads to inaccuracy in the values of bias at MMD = 50 $\mu$m, for example, for broadly distributed aerosol sizes. In most cases, however, the worst-case biases occurred at GSD = 1.5 (the narrowly distributed sizes), so that

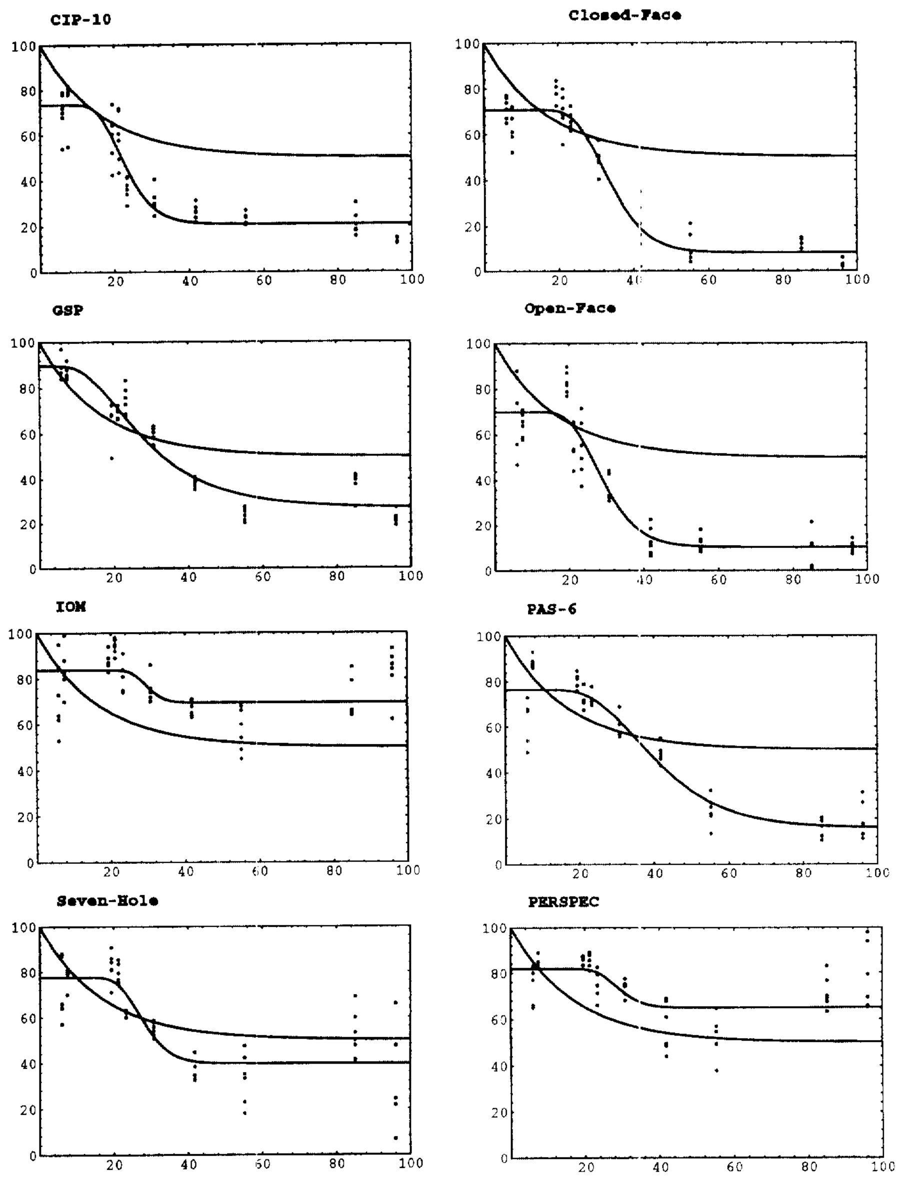


FIGURE 1. Sampling efficiency (%) versus aerodynamic diameter (in micrometers) for inhalable aerosol samplers in use at wind speed = 0.5 m/s. The smooth curve common to all the graphs is the inhalability convention.

the calibration constant determination is insensitive to this inaccuracy.

The calibration constants are also insensitive to details of the modeling, especially regarding small-diameter constraints. To test this assertion, the data were modeled as in Reference 13 using a polygonal model in which the means of data at each diameter are simply joined by lines. Furthermore, the polygonal model was forced to 100 percent at diameter = 0 $\mu$m. The resulting bias ranges agree with what was obtained with smooth curve modeling without constraint at diameter = 0 $\mu$m.

How sensitive the calibration constants are to the wind speeds (0.5 and 1.0 m/s) chosen in the EC experiment is not yet known, as no convention has been adopted to cover specifically very low wind speeds. Nevertheless, if the convention were set up to correspond with recent inhalability measurements,[20,21] then the IOM sampler's calibration given below is invariant upon including data at low speeds. Furthermore, the GSP sampler's calibration decreases by only about 10 percent for use exclusively at very low wind speeds. Data are not yet available for the other samplers.

The extreme values of the confidence limits on the bias magnitude for all eight of the sampler types measured are given in Figure 3. As can be read from the graphs, only for the IOM sampler (with calibration factor = 0.95), the GSP sampler (with calibration factor = 1.21), and the CIP10-I sampler (with calibration constant = 1.47), is the 95 percent confidence limit on the bias <50 percent at an MMD ranging up to 50 $\mu$m and a GSD of >1.5. Interestingly, the IOM sampler also fulfills this criterion with a calibration constant of 1.00. Note the undesirable effect of undersampling by the 37-mm cassette, presently used in the United States for total aerosol sampling.

Note that, aside from the IOM sampler, these suggested calibration factors differ somewhat from those given in Reference 13 (1.00 and 1.15 for the GSP and CIP10-I samplers, respectively). The main difference is that the range of particle sizes in this column, with an MMD of up to 50 $\mu$m, is broader than the 25-$\mu$m range covered in Reference 13. It is expected that the calibration constants provided in this column for the IOM, GSP, and CIP10-I samplers will allow use over a broad range of aerosols present in the workplace.

The increased range of particle sizes considered here has another effect. Distinctions between the various samplers are enhanced when classified by bias as in Figure 3. Considering the closed- and open-face cassette samplers, for example, this is because the undersampling relative to convention becomes important mainly at diameters larger than 40 $\mu$m (see Figures 1 and 2).

## Conclusion

Upon examining the bias of presently available inhalable aerosol samplers, the IOM, GSP, and CIP10-I samplers are highlighted, with calibration constants differing from unity for the latter two sampler types. Aside from exhibiting acceptable sampling efficiency versus aerosol diameter, these three sampler types have other attractive features. All can be fashioned out of a conductive material. The CIP10-I has a unique advantage in employing an internal pump (operating at a flow rate of 10 L/min), which obviates the inconvenience of sampler connection to an external pump, whereas the IOM and GSP samplers require personal

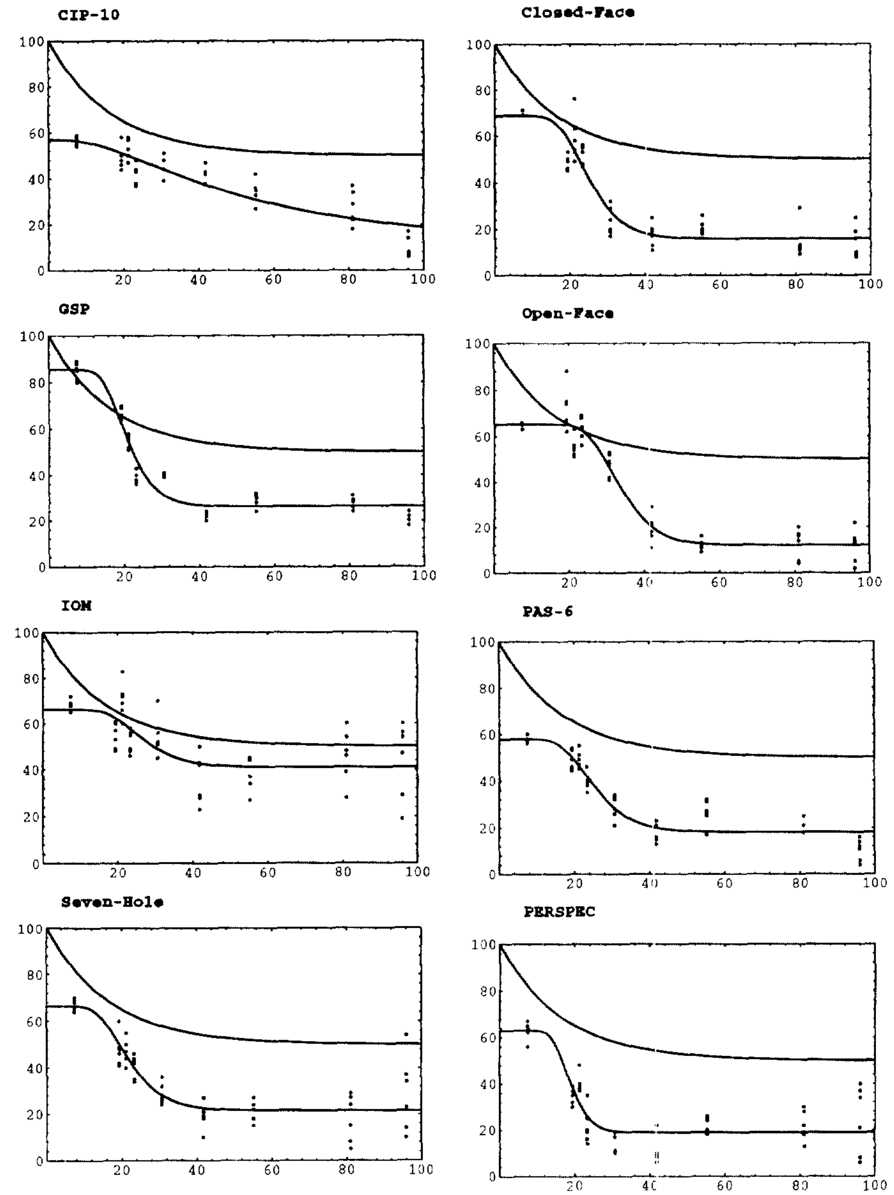


FIGURE 2. Sampling efficiency (%) versus aerodynamic diameter (in micrometers) for inhalable aerosol samplers in use at wind speed = 1.0 m/s.

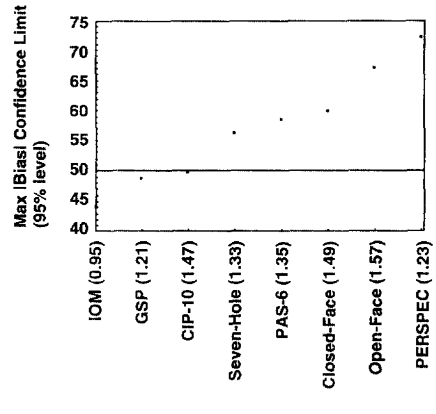


FIGURE 3. Worst-case 95 percent confidence limits on bias relative to the sampling convention versus inhalable aerosol sampler at wind speed up to 1.0 m/s. Calibration constants are in parentheses.

sampling pumps which can perform well at 2.0 and 3.5 L/min, respectively. All three sampler types can be operated so as to enhance sampling medium stability: by using polyvinylchloride or other similar hydrophobic filter material, by using a stainless steel sampling cassette in the IOM sampler and weighing only the filter in the GSP sampler, or, alternatively, by using field blanks for correction of humidity effects. For the present, these three sampler types may be the best choice for implementing the inhalable sampling convention.

## Standards

ASTM, D 6062M—Standard Guide for Personal Samplers of Health-Related Aerosol Fractions

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

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

CEN—Pre-Standard on Workplace Atmospheres. Assessment of the Performance of Instruments for Measurement of Airborne Particles, Brussels, CEN/TC 137/WG 3

MDHS 14/2—General Methods for Sampling and Gravimetric Analysis of Respirable and Total Inhalable Dust, Health and Safety Executive, United Kingdom

## Manufacturers' List

1. IOM sampler: SKC Inc., 863 Valley View Road, Eighty Four, Pennsylvania 15330; phone: (800) 752-8472; fax: (800) 752-8476; skcorder@skcinc.com
2. CIP10-I sampler: Arelco, Avenue Ernest Renan, Fontenay-sous-Bois, 94120 France
3. GSP sampler: Ströhlein GmbH & Co., Postfach 101460, Girmeskreuzstrasse 55, D-41546 Kaarst, Germany; phone: (49 21 31) 606-0; fax: (49 21 31) 606-166
4. GSP sampler: BGI Incorporated, 58 Guinan Street, Waltham, Massachusetts 02154; phone: (617) 891-9380; fax: (617) 891-8151

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