

General principles for

Sampling airborne radioactive materials

UDC 614.876:621.039.766.620.113

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- Institution of Nuclear Engineers
- Lloyd's Register of Shipping
- National Radiological Protection Board*
- Scientific Instrument Manufacturer's Association of Great Britain*
- United Kingdom Atomic Energy Authority*

The Government department and scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

- Association of University Radiation Protection Officers
- British Institute of Radiology
- British Steel Industry
- Control and Automation Manufacturers' Association (BEAMA)
- Hospital Physicists Association
- Ministry of Defence
- Society for Radiological Protection

This British Standard, having been approved by the Nuclear Energy Industry Standards Committee, was published under the authority of the Executive Board on 30 September 1975

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The following BSI references relate to the work on this standard:
Committee reference NCE/2
Draft for comment 72/44470 DC

ISBN 0 580 08735 2

Amendments issued since publication

Amd. No.	Date of issue	Comments

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Foreword

This British Standard is based on and does not conflict with International Standard ISO 2889 “*General principles for sampling airborne radioactive materials*”, except in the sense that revised data have been incorporated and a different system of symbols has been used for the quantities specified in the equations, etc.

The following British Standards may be of interest in connection with this subject.

BS 893, *Method of testing dust extraction plant and the emission of solids from chimneys of electric power stations*.

BS 1042, *Methods for the measurement of fluid flow in pipes*.

BS 1756, *Methods of sampling and analysis of flue gases — Part 1: Methods of sampling*.

BS 2069, *Gas sampling tubes*.

BS 3048, *Code for the continuous sampling and automatic analysis of flue gases. Indicators and recorders*.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 30, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

0 Introduction

The object of a continuously operating environmental monitoring programme is to confirm the maintenance of satisfactory operating conditions or, where such conditions no longer exist, to give early warning of the change and identification of the workers at risk. The amount of effort put into such a programme will depend on the degree of difficulty experienced in maintaining satisfactory operating conditions. Where radioactivity is being handled on a small scale, the common procedures of good housekeeping will generally provide adequate freedom from air contamination; confirmation of this can usually be obtained from the results of monitoring for surface contamination. Where large amounts of radioactive material are being handled, inhalation is a common route of intake by workers. The potential hazard from breathing airborne radioactive materials should be evaluated through the measurements of the levels and nature of the airborne contaminant and should be controlled so that the resulting absorbed doses to the organs of the body do not exceed those specified in regulations.

It should be realized that the statistics of air sampling are such that the variance on individual sample results is high. The important parameter in the protection of the individual worker under routine conditions is the long-term average concentration of radioactivity breathed and not the instantaneous value of the concentration reflected in the results of single samples.

Although the most important and ultimate objective of samplings is to ensure that individuals are not subjected to excessive exposure from internally deposited radioactive materials, other desirable objectives are realized in a well-developed sampling and evaluation programme. Some of these objectives are as follows:

- a) to provide the supporting documentation of working environments to demonstrate compliance with regulations. Well-kept records of air contamination levels along with other data may assist in supporting or refuting claims of radiation injury by workers or others;
- b) to call attention to deteriorating equipment, faulty processes, or other conditions leading to loss of effective control of airborne materials in an operation, and subsequently to determine the effectiveness of corrective measures;
- c) to provide warning of radioactive releases to the workers who are potentially exposed; and to provide a means of estimating the probable upper limit of intake of radioactivity by the bodies of such workers;

d) to measure the release of radioactive materials to the environment by means of sampling near the point of release. Sampling of effluents will assist in evaluating and controlling the exposure of the worker to radiation at the installation, but the results of effluent sampling are generally of greater importance in establishing that people in the environment are not exposed to airborne materials exceeding prescribed levels.

In non-routine incidents, effluent samples are of material worth in estimating the possible consequences and the necessary corrective action or, in some cases, in determining the cause and sequence of abnormal events.

Sampling should permit integrated radioactive contamination released to the environment to be measured over various time periods.

1 Scope and field of application

This British Standard sets forth the general principles which apply in obtaining representative samples of airborne radioactive materials and prescribes acceptable methods and materials for gas and particle sampling.

These general principles are limited to the collection of samples and do not extend to the measurement of the radioactive materials collected. Exclusion of radiochemical measurement from the field of application has not to be construed to mean that the measurement and evaluation of samples are of lesser importance than sampling; to the extent that the sample obtained reflects the existing conditions, accurate measurement and evaluation are vitally necessary.

These general principles are further limited to guides for sampling airborne radioactive materials in installations where work with radioactive materials is conducted, with the primary emphasis on the radiological protection of the worker.

However, they do include sampling effluent gases prior to, or at, the point of release to the atmosphere from the installation. Although this therefore excludes certain sampling techniques such as those used in environmental and free atmosphere sampling, the principles defined and most of the methods discussed are in most cases generally applicable.

These general principles do not deal in detail with the application of various collectors to specific problems.

2 References

The titles of the British Standards referred to in this standard are listed on the inside back cover.

3 Definitions

For the purposes of this British Standard the following definitions apply.

3.1

absorbent

a solid or liquid material which takes up molecules of gases or liquids through the action of diffusion allowing the latter to penetrate into the structure of the material (if a solid) or to dissolve in it (if a liquid)

3.2

adsorbent

a material, generally a solid, which retains the molecules of a substance with which it comes into contact by means of the short range molecular forces which bind the adsorbed substance at the surface of the material. Adsorption can be either physical or chemical (chemisorption) in nature

3.3

aerodynamic diameter

in relation to an airborne particle of any density or shape, its aerodynamic diameter is the diameter of a sphere of unit density which has the same settling velocity, or is acted upon by air drag to the same degree as the particle

3.4

aerosol

a dispersion of solid or liquid particles in air or other gases

3.5

anisokinetic

a condition in which the velocity of air entering a sampling probe or the collector, when held in the airstream, is different from the velocity of the airstream being sampled at that point

3.6

breathing zone

that region adjacent to a worker's mouth and nostrils from which air is drawn into the lungs while he performs his assigned work. Air taken from this region will most nearly represent the air the worker is breathing while he works, whether standing, sitting or moving

3.7

burial

the embedding of a particle in a filter medium

3.8

droplet

a very small quantity of a liquid in the general form of a sphere

3.9

impaction

process by which a particle or droplet is removed from an airstream by striking an object in the airstream

3.10

isokinetic

a condition in which the velocity of air entering a sampling probe or the collector, when held in the airstream, is identical to the velocity of the airstream being sampled at that point

3.11

membrane filter

a filter medium consisting generally of very thin organic-based films having a porosity and composition controlled within a selected range (Very thin porous metallic filters are also known as membrane filters.)

3.12

monitor

- a) A device whose purpose is to measure the level of ionizing radiation or quantity of radioactive material, and possibly to give warning when it departs from prescribed limits. It may also give quantitative information.
- b) A person who uses such a device.

3.13

particle

an aggregate of molecules in the solid or liquid phase, of size ranging from a few molecular diameters to some tenths of millimetres (several hundred micrometres)

3.14

penetration

the passage of airborne contaminants completely through a filter or other collector

3.15

permissible level

that concentration of airborne material which has been established as a local guide or regulation, compliance with which will limit the quantity of radioactive materials inhaled. Permissible levels may be different depending upon the nature of the airborne material, the duration of anticipated exposure, and the protection afforded by special clothing or other barriers

3.16

representative sample

a portion of the medium of interest, or one or more separated constituents from this medium, which has the same quality and characteristics as possessed by the whole medium

3.17**scrubber**

a device for allowing air and liquid to achieve intimate contact to effect a transfer of gases, liquids or solids carried in the gas to the liquid stream. The liquid may be a static pool through which the gas rises or may be sprayed into a column or passed through packing

3.18**sorption**

the process of taking up a gas or a liquid by a solid, without specification as to whether by absorption or adsorption (q.v.)

3.19**spot sample**

a randomly taken, single sample removed from a stream over a short interval of time

3.20**sub-isokinetic**

a condition which prevails when the velocity of air entering a sampling probe or the collector, when held in the airstream, is less than the velocity of the airstream being sampled at that point

3.21**super-isokinetic**

a condition which prevails when the velocity of air entering a sampling probe or the collector, when held in the airstream, is greater than the velocity of the airstream being sampled at that point

4 Principles for effective sampling

Certain principles have to be recognized and used as guides if effective sampling is to be realized. These are discussed in this clause.

4.1 Representative samples. A sample has to be representative of the bulk stream or volume from which it is taken. "Representative" embodies various qualities of the sample.

4.1.1 Representative according to spatial location

4.1.1.1 Sampling in a zone occupied by workers. The sample should ideally be drawn from a point or series of points within the "breathing zone" of the worker. The actual sampling point would ideally be close to the man's nostrils and mouth throughout all the worker's activities. For routine monitoring this is impractical and some compromises are usually necessary. For many purposes a battery-operated sampler with a collector fastened near the breathing zone is an acceptable compromise, provided that adequate sensitivity can be achieved and worker comfort and safety are not jeopardized by wearing the device.

In the interests of simplicity, air samples are frequently taken with fixed position samplers. When fixed sampling positions are used, care should be taken in the selection of the position and number of samplers in a given work area. The location selected should be as close to the breathing zone as is practical without interfering with the work and the worker. Sampling with fixed position samplers compromises to a degree the principle of a sample being representative according to spatial location of the sampling point; however, with judicious placing of the sampling point and correlation with true breathing zone samplers, the fixed position sampler can be useful.

Routinely obtained samples from fixed locations will signal changes in general air concentrations and help in determining the source of the contamination. When room ventilation arrangement is such that room air is exhausted through a single or a few ducts, samplers placed at the ventilation duct exits, before the air filters, may provide a better integrated average of the air concentration, but could be unrepresentative of actual air breathed. This would be particularly true if the source were an isolated leak from one point in the room near a breathing zone or if the particles concerned had a large aerodynamic diameter since these will tend to settle out over a relatively short path length. Several studies have called attention to the problems of obtaining a representative sample from fixed position samplers (see **D.12**, **D.19**, **D.21** and **D.23**).

Air samplers may be installed slightly above head height and in front of the worker, or they may be installed at the front face of the hood, gloved box or other enclosure used to contain the radioactive material processed. The collector filter is most frequently oriented in a vertical plane to reduce the potential for the collection of larger particles by gravity settling. Although the principle of isokinetic sampling is not achieved in fixed room air samplers, the particles of interest are almost always of sizes sufficiently small that anisokinetic sampling errors are not of serious concern.

Due consideration should be given to the number, location, and air-moving requirements of samplers during the design of a facility in which radioactive materials are to be processed.

4.1.1.2 Sampling from a duct or exhaust stack. To withdraw representative samples from a duct or stack requires attention to the placement and number of entry nozzles and the configuration of the nozzle used. Arrangements in which the collector can be held in the airstream are to be preferred over those in which delivery lines between sampling points and collector are used (see 4.1.2). Some recommended probe configurations and guides locating exhaust points in ducts and stacks are given in Appendix A.

The sampling point for a reasonable degree of mixing should be a minimum of five, and preferably 10, duct diameters (or five to ten times the major dimension for rectangular ducts) downstream from abrupt changes in flow direction or prominent transitions.

4.1.2 Representative with respect to physical and chemical composition

4.1.2.1 Sampling without differentiation or bias as to particle size or kind. A representative sample has to have the same radiochemical and physical composition as the air in the environment of the worker in the area sampled. In addition to the requirement of correct spatial location is the requirement that the sampler does not fractionate by particle size, or in other ways distort the physical and chemical properties of the airborne radioactive constituents. This requirement is difficult-often impossible-to accomplish perfectly. Any delivery line through which the sample is carried to the collection device will preferentially remove large particles, either through gravitational settling when the flow is too low, or through turbulent impaction when the flow is too high. Density of the particles in the air is also of importance in the fractionation by particle size. Some guides are presented in Appendix B to allow estimates to be made of particle loss in sampling lines due to gravity settling and turbulent flow.

A sample obtained with a delivery line and collector which do not discriminate between particles of various sizes can be evaluated accurately as to radiological significance only after knowledge of the physical and chemical properties of the airborne material is obtained. Separate study may be necessary to establish in given circumstances the size distribution and chemical nature of the airborne material.

Changes in the nature of airborne materials are to be anticipated with changes in operations. Characterization of the airborne constituents has to be performed frequently enough to ensure statistically significant information of the nature of the airborne material.

4.1.2.2 Sampling with deliberate differentiation as to the particle sizes. Because knowledge of particle size distribution is important to a correct evaluation of radiological effects, samplers and collectors may be deliberately designed to identify two or more size fractions of the airborne material. Measurement of the radioactivity associated with each size fraction will permit a determination of the radioactivity which will be preferentially retained in various portions of the respiratory tract¹⁾. Although not capable of high resolution, these devices can reasonably well distinguish radioactivity associated with particles which will be retained in the upper respiratory passages, and the much smaller particles which would be accessible to the alveoli of the lungs. These sampling devices have considerable merit and, in the absence of knowledge of particle sizes in the air sampled, are recommended.

Bibliographical references **D.8, D.9, D.10, D.13, D.15, D.16, D.21** and **D.25** describe some of these devices.

¹⁾ The Task Group on Lung Dynamics for Committee II of the International Commission on Radiological Protection has developed and recommended a dust deposition model which utilizes and depends upon knowledge of particle sizes obtained through air samples (see **D.5**). When particle size distributions are known, the fractional deposition in each of three regions of the respiratory tract can be estimated from this model. When specific particle size data are lacking, the Task Group suggests that an AMAD of 1.0 μm be assumed, allowing an estimate of the depositions in the respiratory tract to be made. It is also necessary to know in some detail the physico-chemical properties of the particles in order to estimate the rate of clearance from the deposition site (see **D.11**).

4.1.2.3 Particle size fractionation due to anisokinetic sampling. Distortion in particle size distributions may occur when the velocity of the sampled air entering the sample probe (or collector, when supported directly in the stream to be sampled) is significantly different from the velocity of the air in the stream sampled. When the air drawn through the sampler or collector in the stream is at a much lower velocity than the stream velocity, larger particles will be preferentially collected. When the air velocity through the sample probe and collector is greater than the stream velocity, smaller particles will be collected preferentially. The degree to which the fractionation occurs is a function of particle size, density, the particle size distribution, and the difference between the isokinetic velocity and the anisokinetic velocity employed. Except in very unusual situations, particles smaller than aerodynamic diameter of about $5\text{ }\mu\text{m}$ are able to follow the streamlines of the air and the fractionation error is not great. Appendix C presents data showing the error which would be made for various conditions of anisokinetic sampling.

Obviously, the sizes and density of particles being sampled must be known before this error can be evaluated. In applications in which particle sizes may be expected to vary, particularly when particles larger than $5\text{ }\mu\text{m}$ are anticipated, it is recommended that the sampler arrangement be designed to permit near isokinetic flow into the sampler entry probe or through the collector when the collector is facing into the stream sampled. A potential source of non-representative sampling may thus be avoided.

4.1.2.4 Sample distortion due to chemical reactions and related effects. Extreme care has to be exercised in extracting a sample from an airstream when the air may contain chemically reactive forms of radionuclides. Reactive vapours such as radioiodine may be largely adsorbed on, or may react with, materials which might be considered for sampling lines, e.g. rubber, copper and some plastics materials.

Some collectors, such as impingers, trap materials in a liquid with varying efficiency, depending upon the solubility and particle size. Condensate on the inner surfaces of sampling lines may form pockets and act as traps, or provide wetted surfaces to which the material of interest may adhere. In extreme situations traps and pockets may act as effective scrubbers for the radioactive material transported. Sampling lines have also to be free from dust, oil and grease, all of which may lead to increased deposition of transported radioactive material.

When the air to be sampled is nearly saturated with water vapour, condensation may occur on the collector itself. Excessive moisture may destroy filter media usefulness either by blocking the air passageways through the pores or by weakening it to a point that it tears or breaks easily. When heavy moisture loadings are anticipated, heated sampling lines will be required to prevent condensation in the lines to raise the collector temperature well above the dewpoint.

All possible interactions which may change the sample quality from the point where it is diverted to the collector have to be carefully considered. The chemical form as well as the physical nature of the airborne constituents to be sampled has to be known before a representative sample can be ensured.

4.1.2.5 Qualification of sampling methods and equipment. In each case, the sampling methods and equipment used should be carefully studied and tested to make certain that, in use, they will perform as intended. Leaktightness, general integrity, and general methods for sample handling have to be thoroughly reviewed.

4.2 Sample programming. Many factors enter into the design of a sampling programme. The sampling programme includes the frequency, duration and volume rate of sampling. In most cases the selection of these three elements in programming will be a compromise between ideal values and those which provide adequate information for the evaluation of operational safety and yet are technically, economically and conveniently achieved.

4.2.1 Sensitivity of detection and measurement. The sensitivity and accuracy of the analytical or counting method will determine the minimum volume of air which has to be sampled to obtain the requisite accuracy and precision of results.

4.2.2 Permissible levels at point of sampling. The permissible concentration of the radionuclides of interest will also determine the minimum volume to be sampled. If possible, the sample should be large enough to permit one-tenth the permissible level to be determined with reliability. In some cases the sample needs to be sufficiently large to permit the effective measurement of activity levels equal to or less than the ambient levels (see also 4.2.4).

4.2.3 Radioactivity decay. The radioactive half-life of the nuclide to be measured is an important consideration. For short half-life materials the sampling period may be short with a large volume throughput and rapid measurement. An alternative procedure is to sample until the radioactive material collected has reached equilibrium. At such time the decay rate is equal to the accumulation rate. Evaluation requires a method of quantification during or immediately following collection. Long-lived materials, being low in radioactivity per unit mass, may require sampling of large volumes to achieve the necessary degree of accuracy using radiometric analyses.

4.2.4 Natural radioactive material. The presence of natural radioactive materials of short half-life may mask the presence of significant quantities of longer-lived materials, necessitating delays between collection and counting, repeated counting at subsequent times, or special methods, for example, energy discrimination, pseudo-coincidence counting (see **D.2** and **D.27**), or particle size discrimination sampling methods such as the annular impactor and particle size selective filter technique (see **5.1.2**).

4.2.5 Specific nature of the operation or process. The nature of the operation which creates the potential for airborne radioactive materials may influence the sampling programme. An operation or process being instituted for the first time may require more frequent and extensive sampling than one which is well established and proven. The potential for release of radioactive material and the consequences of accidental air contamination have to be considered in establishing frequency and duration of sampling.

When the purpose of sampling is to establish the total release of radioactive materials to the environment, the sampling programme has to be designed to ensure obtaining an adequate sample during accidental releases. Under normal operations, intermittent, relatively infrequent sampling may be adequate, but when due account is taken of the non-standard or accident situation, it may be necessary to sample continuously. The relative levels of radioactivity contained in the sample during an accidental release have to be anticipated. This consideration may influence the volume rate of sample withdrawal for non-standard situations. In some cases, two separate sampling systems may be justified, one to obtain a sample during non-routine high level releases, the other for day-to-day release evaluation. The collection method may also be different for the two purposes.

The unusual conditions following a serious radiation incident have to be anticipated when sampling is required for assessing the levels of airborne radioactive materials present in an area affected by the incident. For example, representative samples from a contained atmosphere following a reactor accident will have to be obtained. Sampling under adverse conditions has to be anticipated and the necessary provisions designed into the system.

5 Methods of sampling

The two forms of airborne radioactive materials are particles and gases; the particles can be solid or liquid, although particles are more generally considered to be very small fragments of solids. The sampling methods for airborne radioactive material can be discussed according to the application to gases or particulate materials.

5.1 Particles. The principles concerning the removal of a representative portion of a contained stream as from a large duct have been presented. A sample line designed according to these principles will deliver a representative sample to the collector. For samples drawn from an atmosphere such as room air, delivery lines are not required.

Various collectors are applicable to sampling airborne radioactive particulate material. Two general categories are

- a) gross particle collectors without significant size differentiation, and
- b) particle collectors with size differentiation.

5.1.1 Collectors without significant particle size differentiation. The detailed evaluation of the radiological significance of airborne particles requires a knowledge of the particle sizes and the chemical nature of the material. This information may be determined by methods other than routine sampling. After such special studies have characterized the airborne material, subsequent particle collection without particle size differentiation may be performed provided that the operation creating the potential for airborne contamination is not changed significantly. At regular intervals and when any change is anticipated, the airborne material should be characterized as to physical and chemical nature. This procedure should also be adopted in the case of incidents because of the likelihood of a change in the general characteristics of the airborne contaminant and much higher levels leading to a risk of significant exposure.

5.1.1.1 *Electrostatic precipitators.* Electrostatic precipitation removes particulate matter from a moving airstream by imparting a charge to particles in the stream and collecting them on an oppositely charged surface. Well-designed electrostatic precipitator collectors operated according to the manufacturer's recommendations can effectively remove particles of radiological health concern. The voltage and collector geometry can be chosen to ensure efficient removal of virtually all particles of interest. Several units covering a range of flows are commercially available. Electrostatic precipitators have the distinct advantage that sample accumulation is not accompanied by an increase in flow resistance. Samples can be directly counted on the collecting plate with little or no correction for self-absorption. Operating maintenance problems and safety considerations due to the high voltage required often limit their applications to special radioactive air sampling over short sampling periods. However, electrostatic precipitators represent a valuable supplementary tool for radioactive air monitoring programmes.

5.1.1.2 *Thermal precipitators.* Particle collection with a thermal precipitator depends upon the force exerted on a particle as it passes through a region between a hot wire and a collector. Thermal precipitators are useful in collecting sub-micrometre particles for electron microscopic examination but, because the required sampling flow rates are so low, thermal precipitators find little application in routine air sampling for radioactive particles.

5.1.1.3 *Related equipment for sampling using precipitators.* Collectors for the electrostatic precipitator are discs or sheets, generally of thin metal. For the thermal precipitator the collector is a small disc. One or more electron microscope grids with appropriate films can be mounted directly under the hot wire.

Air flow is usually maintained with an integrally incorporated air pump. Flow is critical in these devices and flow measurements are made using one of the methods discussed under 5.1.4.3. The manufacturer's recommendations should be carefully followed.

5.1.1.4 *Individual monitoring.* Individual monitors enable samples to be taken in the breathing zones of workers. These devices consist of a filter holder small enough to be worn on the coat lapel or collar, and connected by means of a flexible tube to a small pump unit powered by rechargeable batteries carried at waist level. The samples are collected over relatively long periods due to the low air flow rate, monitored by a rotameter attached to the filter holder.

Individual monitors (also called personal air samplers [see D.24]) are used in special work areas where it is difficult to interpret the results of sampling with high flow rate static air samplers placed at fixed positions in the work place.

5.1.1.5 *Gravity settlers.* Gravity settlers in the form of open, "fall-out" trays are frequently used downwind from source release points to determine the extent of radioactive surface deposition. With sufficient trays, useful information can be obtained regarding surface contamination profiles. However, fall-out trays are not directly applicable to determination of gross airborne concentration of particulate radioactivity.

A shortcoming of fall-out trays is that surface winds may sweep previously deposited particles off the collector. These losses may be reduced by applying an adhesive coating to the tray, by covering the tray with gummed paper, or by using a water-alcohol solution in the tray. Unfortunately, adhesives are subject to weather deterioration so that exposure life is often limited. Liquids have to be replenished to compensate for evaporation.

A similar type of particle collector known as a "tackysade", which consists of cloth impregnated with a tacky resin and stretched over a wire frame, is used to measure airborne particulate radioactivity.

5.1.2 *Particle collectors with size differentiation.* Separation and collection of particles into size ranges is accomplished by samplers which make use of the inertial properties of the particles and gravity settling. The aerodynamic diameter of the particles is therefore the parameter of importance in the size separation of the particles.

The size distribution of very small particles can be determined by diffusion to the walls due to Brownian motion as the particles are passed through a tube or channel. Because diffusion coefficients of particles are so small, the latter method is of interest when particle size distribution, comprising particles below sizes of about 0.05 μm , is to be differentiated (see D.28).

Size-differentiating collection will find application when prior study has determined that a highly significant fraction of large particles is present and that a non-differentiating collector would materially overestimate the respirable particle concentration.

Particle size selective samplers have been designed for use both as instruments for static positioning in the work place and as individual monitors to be worn by workers.