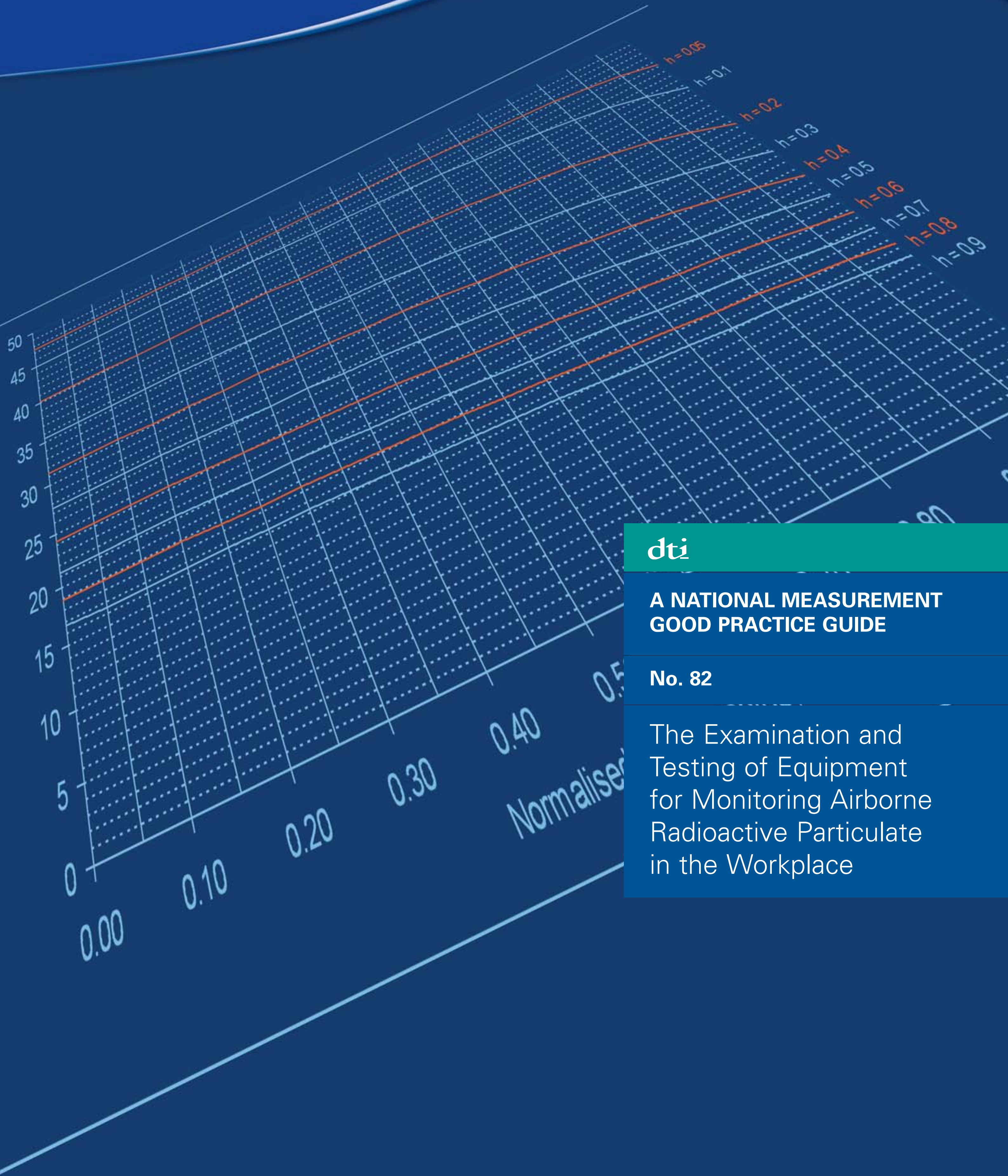
National Physical Laboratory



A NATIONAL MEASUREMENT GOOD PRACTICE GUIDE

No. 82

The Examination and Testing of Equipment for Monitoring Airborne Radioactive Particulate in the Workplace

The DTI drives our ambition of 'prosperity for all' by working to create the best environment for business success in the UK.
We help people and companies become more productive by promoting enterprise, innovation and creativity.

We champion UK business at home and abroad. We invest heavily in world-class science and technology. We protect the rights of working people and consumers. And we stand up for fair and open markets in the UK, Europe and the world.

This Guide was developed by the National Physical Laboratory on behalf of the NMS.

Measurement Good Practice Guide No. 82

The Examination and Testing of Equipment for Monitoring Airborne Radioactive Particulate in the Workplace

Andrea Woodman
National Physical Laboratory

Max Pottinger
Thermo Electron Corporation

David Ryden
Canberra Harwell Ltd

Julian Dean
National Physical Laboratory

ISSN: 1368-6550

October 2006

National Physical Laboratory
Teddington, Middlesex, United Kingdom TW11 0LW

Website: www.npl.co.uk

This Good Practice Guide has been written by a working party of the Airborne Radioactivity Monitoring Users' Group. Membership of the working party was as follows:

Working Group

Derek Brazer	AWE
Peter Burgess	National Physical Laboratory
Julian Dean	National Physical Laboratory
Les Martin	British Nuclear Fuels plc
Martin Oliver	Laboratory Impex Systems
Max Pottinger	Thermo Electron Corporation*
David Ryden	Canberra Harwell Ltd
John Simpson	NUKEM
Eliot Williams	UKAEA
Andrea Woodman	National Physical Laboratory
Mike Woods	IRMC

Writing Sub-Group

Andrea Woodman	National Physical Laboratory
Max Pottinger	Thermo Electron Corporation*
David Ryden	Canberra Harwell Ltd
Julian Dean	National Physical Laboratory

* The majority of the work on this guide was undertaken while this author was employed by BIL Solutions Ltd

Foreword

This Good Practice Guide has been written by the UK Airborne Radioactivity Monitoring Users' Group* in collaboration with the radiation user community. It describes recommended procedures for the examination, testing and calibration of air monitoring equipment. Test procedures recommended in this document are not legally binding; they are general methods based on current accepted good practice.

The current statutory requirement for air monitoring equipment tests is stated in the Ionising Radiations Regulations 1999[1]. All employers who work with ionising radiation must ensure that levels are adequately monitored and that instruments are suitable for this purpose.

Although the testing regimes presented here are for general application, Qualified Persons responsible for the calibration of radiation protection instruments may, with the agreement of the Radiation Protection Adviser, modify them as necessary to suit their particular purpose, provided that the employer can demonstrate that the overall quality of the testing is not compromised.

---

*The Airborne Radioactivity Monitoring Users' Group consists of representatives of UK establishments and organisations actively involved in air monitoring for radioactivity, including monitoring for particulate or gaseous radioactivity at environmental, workplace and process control levels. It is the aim of the group to facilitate the exchange of information regarding UK calibration facilities and their efficient use by those required to comply with the regulations.

Contents

List of Tables

List of Figures

1

Introduction

The examination and testing of radiation protection instruments is a legal requirement for those carrying out work with ionising radiations[1,2]. Sufficient equipment must be available to comply with the regulations, and the instruments must be examined, tested and calibrated at appropriate intervals to ensure that they remain fit for use. Many types of air monitoring equipment are either installed or not readily transportable; it is, therefore, often not possible to transport these instruments to a suitable calibration laboratory. Consequently, periodic examination and testing of such equipment will frequently be carried out in the workplace. This minimises risk of damage caused by removal, transport and re-installation of equipment. It also permits tests of auxiliary indicators, such as remote warning lights.

This Good Practice Guide provides recommended procedures for the general examination, testing and calibration of air monitoring equipment used for the purpose of radiation protection. It follows a similar format to GPG14[3] and GPG29[4], which provide advice for portable and installed dose rate and contamination radiation protection instruments respectively. Recommendations made in documents published by national and international organisations have been consulted during the preparation of this guide.

The procedures detailed in this guidance provide the minimum level of testing that is recommended for instruments used in normal operating conditions. There may be special cases where testing requirements will go beyond these recommendations (for example, where instruments are used in conditions outside those envisaged in the standards above, such as in emergencies). In such circumstances, the employer may need to design alternative test procedures.

The testing regimes contained herein have no legal standing, and employers may implement their own schemes, provided they ensure compliance with the relevant regulations.

The objective of testing is to demonstrate that the instrument is suitable and fit for use. This guide is intended to cover all equipment that is used to assess the concentration of airborne radioactive particulate in the workplace. It therefore includes air samplers, air monitors and laboratory based counting equipment that is used to assess the quantity of radioactive particulate on filter papers. These types of instruments are described in detail in Section 3. Further guides may be produced to cover equipment for other radioactivity in air monitoring applications, notably tritium in the workplace and possibly radioactive particulate in gaseous effluents.

The examination and testing of personal air samplers is not covered in this guide.

Some air monitors also perform non-air-monitoring functions. For example, an air monitor may also measure ambient gamma dose-rate. This guide does not cover the testing of these functions, although it is likely that they would be tested at the same time as the air monitoring functions.

Testing Regime

2

IN THIS CHAPTER

- Type Tests
- Tests Before First Use
- Periodic Tests
- Function check
- Retest after repair/ adjustment
- Analysis of test results

For the purposes of this guidance, a **test** is defined as a procedure to evaluate an instrument's performance in order to establish its suitability, or its continued fitness, for a particular type or types of measurement in operational radiation protection. A test may involve an element of **calibration**, which may be defined as the measurement of the response of the instrument to a known influence quantity, such as flow rate or activity. It is important to recognise that the terms **test** and **calibration** are not synonymous: this is because a test will also involve a degree of **examination**, which may include, for example, an inspection of the mechanical and electrical state of the instrument.

Air monitoring equipment should undergo Tests Before First Use (TBFU) and subsequently Periodic Tests, which should be performed at suitable intervals in compliance with current national regulations and associated codes of practice. The findings of these tests must be compared with any previous test information and the appropriate Type Tests (see Section 2.1 below) to confirm that the instrument is meeting its specification and is suitable for its intended use. The Type Tests are normally carried out by, or on behalf of, the instrument manufacturer. TBFU and Periodic Tests are carried out by, or on behalf of, the employer. Table 1 lists recommended TBFU and Periodic Tests.

It is recommended that additional function checks are carried out more frequently to ensure that the instrument remains fit for use and that there has been no unexpected change in performance.

A full record of test results, including details of any adjustments made to the instrument, should be kept for a period to be determined by the employer.

2.1 Type Tests

Before purchasing an instrument, it is the responsibility of the employer to ensure that it is suitable for the intended use. Decisions about instrument selection should be made taking into account advice from the Radiation Protection Adviser (RPA), information from the manufacturer and other authoritative data that might be available.

The body of information regarding the characteristics and expected performance of instruments is called Type Test data and is usually based on recommendations from international organisations such as IEC and ISO. A number of IEC documents exist which detail the tests that are appropriate for the Type Testing of particular types of instrument. Some of these IEC documents have been adopted as British and European standards (BS EN). Typical documents for testing air monitoring equipment are IEC 61172[5] (for radioactive particulate air monitors used within the environment) and BS EN 60761 parts 1[6] and 2[7] (for radioactive particulate in effluent). There are no IEC standards specific to laboratory counting equipment, although much of the equipment is similar in principle to portable contamination monitoring equipment, which is covered by BS EN 60325[8]. Type Tests are very comprehensive and may require specialised facilities. They should be performed by someone with appropriate expertise and insight into the use of the instruments and in a laboratory with secondary standard or similar status (for example, a laboratory accredited by UKAS) using measurement quantities specified by the International Commission on Radiological Units and Measurements (ICRU), and ISO-specified calibration sources.

The results of any tests carried out during the lifetime of an instrument should be compared with Type Test data to ensure that it continues to operate as expected; therefore, it is necessary to have access to the Type Test data for each instrument tested. As a minimum requirement, the Type Test data should include results of tests that are equivalent to those defined in this guide as TBFU (see Table 1).

For most new instruments, the manufacturers, suppliers or other organisations may provide Type Test data that will enable the employer to decide the necessary scope of TBFU. In the absence of Type Test data, the employer should perform their own Type Test to establish their own baseline data at the TBFU stage.

2.2 Tests Before First Use

The TBFU are intended to demonstrate that the instrument conforms to type and is suitable for its intended use.

These tests should identify any potential faults and identify any limitations of the instrument with respect to its intended use. The tests may be undertaken by the manufacturer, the employer or an independent laboratory.

Table 1 summarises the tests required for the TBFU of air samplers, air monitors and laboratory counting equipment. The recommended procedures for each of the tests are provided in Sections 4 and 5. Some of these tests may need to be repeated periodically as the performance of an instrument can vary with age, key components may deteriorate or fail, and damage may occur during use: these are some of the reasons for the subsequent Periodic Tests.

2.3 Periodic Tests

It is the responsibility of the employer to define the frequency of Periodic Tests based upon considerations such as the age of the equipment, the environment in which it is used, and the frequency of use. It is the recommendation of this guidance that examination, testing and calibration should be performed at least annually. However, the requirements of any regulations published in the future must be adhered to.

The purpose of Periodic Testing is to check that the instrument remains fit for use and to confirm that its performance has not changed significantly since the TBFU.

The tests required for the Periodic Tests are summarised in Table 1. They are broadly similar to those for the TBFU. Specific details of each test are provided in Sections 4 and 5.

Because the instrument may have suffered from wear and tear or misuse, attention should be paid to the performance and the condition of its electrical and mechanical systems. For example, the pump within the air circuit of an air sampler or monitor is particularly vulnerable to wear and tear, and should be examined at least annually. The condition of any warning lights/audible alarms should also be checked, and any lights or indicators to which a user has to respond must be operating correctly. If the instrument is normally connected to other components such as remote alarms and data logging systems, additional tests for the relevant input/output functions should be included.

2.4 Function check

A function check is carried out to ensure, with the minimum of interference, that the instrument is working correctly. The frequency of function checks must fit the application of the instrument and must be determined by the employer. Function checks may involve the following:

Response check
Background check
Flow rate check
Alarm check
Parameter check

If the function check results fall outside prescribed limits, the instrument should be submitted for a Periodic Test. If the instrument requires repair or maintenance, the Qualified Person should consider whether another TBFU is required (Section 2.5).

2.5 Retest after repair/adjustment

After any repair, adjustment or modification that could affect the performance of the instrument, it may be necessary to repeat some of the TBFU or Type tests. The degree of testing depends on the nature of the change. Certain changes may be so fundamental that the some parts of the Type Test should be repeated, for example, replacement with a detector from an alternative manufacturer.

2.6 Analysis of test results

The results of the TBFU should be compared with the Type Test data and the Periodic Tests of an instrument should be compared with the TBFU to confirm that the instrument still conforms to type and remains fit for use.

A full record of test results, including details of any adjustments made to the instrument, should be kept. Current test results should be compared with previous results and any significant changes noted and investigated, even if all the results fall within specification. For example, the performance of an instrument should be regarded as suspect if a previously consistent response is now significantly different, even if it is still within acceptable limits.

Whenever an instrument is adjusted during the course of a Periodic Test or TBFU, a statement indicating the nature and magnitude of the adjustment should be made on the test report or calibration certificate.

An instrument will fail the TBFU or Periodic Tests if the results of any component of the appropriate tests are not within the acceptable limits defined in Tables 2, 3 and 4, or if the instrument's performance is deemed unsatisfactory by the employer.

Instrument	**Tests Before First Use**	**Periodic Tests**
Air Samplers	Parameter Check Pump Test Flow Rate Accuracy Leakage Low Flow Alarm Low Differential Pressure Alarm	Parameter Check Pump Test Flow Rate Accuracy Low Flow Alarm Low Differential Pressure Alarm
Air Monitors	Parameter Check Pump Test Flow Rate Accuracy Leakage Low Flow Alarm Low Differential Pressure Alarm Background Activity Alarm Test Detection Efficiency Energy Response Cross Response Gamma Compensation	Parameter Check Pump Test Flow Rate Accuracy Low Flow Alarm Low Differential Pressure Alarm Background Activity Alarm Test Detection Efficiency
Laboratory Counting Equipment	Parameter Check Background Activity Alarm Test Detection Efficiency Energy Response Cross Response Linearity of Response - Activity	Parameter Check Background Activity Alarm Test Detection Efficiency

Table 1. Summary Of Tests Before First Use And Periodic Tests

Instruments

3

IN THIS CHAPTER

- Measurement displays
- Airborne particulate samplers
- Airborne particulate monitors
- Laboratory counting equipment

The type, nature and intensity of radiation that an instrument may encounter, and the conditions under which it may be used, should be considered when selecting an instrument. The employer should seek advice from his RPA when an instrument selection is made.

3.1 Measurement displays

Air monitoring equipment has a variety of indications. Older air samplers and monitors are fitted with simple variable aperture flow meters. These monitors do not use the measured flow rate to derive the activity concentration; the flow rate is either assumed to be a constant or is averaged over the sampling period. Recent air samplers and monitors provide a digital indication: for air monitors, the digital indication usually means that the flow rate is being measured and may mean it is being used to derive the activity concentration.

Most modern air monitors will display the concentration of radioactivity in air, in digital format. There is a variety of units, including $Bq.m^{-3}$, $Bq.h.m^{-3}$, DAC and DAC.h. This displayed indication will be the result of internal processing within the instrument, which takes account of detector efficiencies, counting times, background count rates and flow rate. Some of the older air monitors will not estimate the air concentration, but will rely on alarm indications when certain count rate (or current) thresholds have been exceeded.

Laboratory counting equipment will display count rates, or possibly activity or activity concentration, where the appropriate calibration factors have been programmed into the equipment. It is likely that many of the results indicated by the equipment will be below the detection limit, therefore it is important to evaluate the detection limit for each counting assembly and state this clearly with the associated results.

3.2 Airborne particulate samplers

An air sampler is a means of collecting a particulate sample for later analysis. Air samplers allow a sample of air to be drawn from the workplace air through a filter.

They usually contain a pump assembly which generates the necessary vacuum, and a flow meter to measure the flow rate through the filter. However there are some samplers which do not have their own dedicated pump, but rely on a building vacuum system.

Modern samplers will measure both the flow rate through the filter, and the volume of air sampled.

3.3 Airborne particulate monitors

In addition to the features of an airborne particulate sampler, monitors have at least one detector mounted directly above the sampling medium (a filter), and optionally a second detector which is used for gamma compensation. These instruments monitor the build-up of radioactivity on the filter, and are set to sound an alarm at pre-set thresholds. All alpha monitors should have some capability to differentiate between long-lived hazardous radioactivity, such as ^{241}Am or ^{239}Pu, and naturally occurring radon or thoron daughters. Some beta monitors may also have this capability.

Older types of air monitor were designed to detect either alpha or beta activity but not both, whereas newer monitors are able to detect both radiation types.

Most monitors have a detector mounted above a fixed filter, which is manually replaced with a clean filter periodically. This allows for an assessment of the used filter by laboratory counting equipment. However, some air monitors utilise a moving tape, which automatically advances to a clean filter based upon criteria such as time, or dust build-up. The moving tape filter is less suitable for assessment with laboratory counting equipment.

3.4 Laboratory counting equipment

This equipment is used to assess retrospectively the activity of alpha-, beta- or photon-emitting particulate on a filter. The equipment will vary from a simple contamination probe connected to a scaler-timer to a sophisticated multi-detector instrument.

This guide does not cover equipment where the sample requires treatment before it is counted (such as liquid scintillation counters). It also does not cover gamma spectrometry equipment.

Test required	Comments	Pass/fail criteria	Test Before First Use	Periodic Test	Detailed reference
PARAMETER CHECK Check that all accessible parameter settings are correct.			Yes	Yes	4.1
PUMP TEST Confirm the flow rate under minimum and maximum load conditions.	This check is to demonstrate the pump is adequate for purpose.	Acceptable limits to be decided by user.	Yes	Yes	4.2
FLOW RATE ACCURACY Test the flow rate over the range encountered.	If variations of >20 % from true value then investigations should be carried out.	Failure if > 20 % away from true value.	Yes	Yes	4.3
LEAKAGE This test should be undertaken by the manufacturer.			Yes	No	4.4
FAULT ALARM CHECK: LOW FLOW Activate by manually reducing the flow rate. LOW DIFFERENTIAL PRESSURE Check the alarm is activated by removing the filter material.	Alarms are not present on all instruments.		Yes	Yes	4.5

Table 2. Tests required for air samplers and air monitors

Test required	Comments	Pass/fail criteria	Test Before First Use	Periodic Test	Detailed reference
BACKGROUND Measure the background with no air flowing and with a clean filter.			Yes	Yes	5.2
ACTIVITY ALARM TEST Activate the alarm with a source in excess of the alarm threshold.		Confirm correct operation of all alarm functions.	Yes	Yes	5.3
DETECTION EFFICIENCY Use suitable alpha or beta sources as recommended by the manufacturer.	Use a source of the same active area and construction as that recommended by the manufacturer.	Within 20 % of the value recommended by the manufacturer.	Yes	Yes	5.4
ENERGY RESPONSE To cover energies encountered in the workplace.			Yes	No	5.5
CROSS RESPONSE Check that high energy beta-emitters do not produce a significant response in the alpha channel.		<0.1 % of betas in alpha channel	Yes	No	5.6
GAMMA COMPENSATION TEST Measure the sensitivity of both detectors to gamma radiation in a reproducible geometry.	For beta monitors only. See detailed reference regarding positioning of detectors and source of gamma radiation.	Sensitivities should be within 10% of each other	Yes	No	5.7

Table 3. Further tests required for air monitors

Test required	**Comments**	**Pass/fail criteria**	**Test Before First Use**	**Periodic Test**	**Detailed reference**
PARAMETER CHECK Check that all accessible parameter settings are correct.			Yes	Yes	5.1
BACKGROUND Measure the background in count mode.	This is dependent on the local environment.		Yes	Yes	5.2
ACTIVITY ALARM TEST Activate the alarm with a source in excess of the alarm threshold.	Confirm correct operation of all alarm functions.		Yes	Yes	5.3
DETECTION EFFICIENCY Use sources as recommended by the manufacturer.	Use a source the same size as the sample area and same distance from detector or else apply a suitable correction.		Yes	Yes	5.4
ENERGY RESPONSE To cover energies encountered in the workplace.			Yes	No	5.5
CROSS RESPONSE Check that high energy beta-emitters do not produce a significant response in the alpha channel.		<0.1 % of betas in alpha channel	Yes	No	5.6
LINEARITY OF RESPONSE - ACTIVITY: Use at least three reference sources.	This is not practicable for alpha detectors. Sources should be of identical construction and should cover the range of activities which may be encountered.	The response should not differ by > 30 % from the mean.	Yes	No	5.8

Table 4. Tests required for laboratory counting equipment

Specific tests on the air circuits of air samplers and air monitors

4

IN THIS CHAPTER

- Parameter check
- Pump test
- Flow rate accuracy
  - » Single point test
  - » Flow rate linearity
- Leakage
- Fault alarm check
  - » Low flow
  - » Low differential pressure

Care should be taken not to suddenly block the air inlet to avoid damage to the detector.

4.1 Parameter check

Where the monitor or sampler has parameter settings stored within its electronic memory, these should be checked to ensure that they do not vary from the preset parameter settings. If these parameters are controlled by a high level of security (e.g. via a supervisor password), this test may be conducted as part of the Periodic Test rather than the function check.

4.2 Pump test

Record the flow rate under minimum and maximum load conditions and confirm it is within acceptable limits. A method for simulating maximum load conditions, in the case of a filter paper sampling medium, is to replace the medium with multiple filters.

Note that modern air samplers and monitors measure the sample volume as well as the flow rate. In this way, any reduction in flow rate due to loading of the filter paper is less critical and therefore confirmation of the correct functioning of the low flow alarm is sufficient (see Section 4.5.1)

4.3 Flow rate accuracy

Where the flow rate during the sampling period does not vary by more than 10 % from the standard flow rate, a test of flow rate accuracy at a single test point is acceptable. However, where more significant variations in flow rate occur, a flow rate linearity test is appropriate.

The percentage discrepancies from the calibrated flow meter indication that are evaluated within this section are due to a combination of three factors: leakage, pressure differential between the calibrated flow meter and the instrument flow meter, and errors in the calibration of the instrument flow meter.

The flow rate accuracy tests will not be possible in some plants, due to the configuration of the air sampling circuit. In this situation the Qualified Person, in consultation with the RPA, should undertake an assessment of the range of uncertainties that are associated with the measurement of flow rate, and include these uncertainties in the estimation of the concentration of airborne particulate. Such an assessment should include information on the accuracy of the flow rate indication gained from the testing of a representative sample of operational equipment.

4.3.1 Single point test

Record the indication on the instrument's flow meter. Place a calibrated flow meter upstream of the inlet of the device and the collection filter. Measure the flow rate on the calibrated flow meter and compare with that recorded for the instrument flow meter. The instrument flow meter indication should not differ by more than 20 % from the calibrated flow meter indication. Where possible, the instrument should be adjusted so that its flow rate indication is within 10 % of that of the calibrated flow meter. If the discrepancies are greater than 10 %, this may indicate leakage and a separate leakage test should be undertaken.

Note that the instrument flow meter indication may change when the calibrated flow meter is used. A variable aperture flow meter can give incorrect results when operating at a pressure other than that at which it was calibrated. For example, errors can occur when introducing an obstruction upstream of a variable aperture flow meter and consequently introducing a pressure drop.

4.3.2 Flow rate linearity

Check the flow rate at three or more points using a calibrated flow meter. A restriction valve should be placed upstream of the instrument inlet, and varied in order to create the necessary flow rates.

The test flow rates should be selected so that they cover the operating flow rate range, including a flow rate close to the setting of the low flow rate alarm. The flow rate should not differ by more than 30 % from the true flow rate over the measurement range of the instrument.

This method of increasing the restriction at the inlet may cause leakage into the air circuit. However this should be clear if there is an increasing discrepancy between the instrument and true flow rates. As the restriction is increased, the pressure differential between the two flow meters will increase; if the instrument flow meter has been calibrated at standard temperature and pressure, this will also lead to an increasing discrepancy between the instrument and true flow rate.

4.4 Leakage

A detailed leakage test should be documented by the manufacturer. The leakage test is only required during the Test Before First Use or when the Qualified Person decides that flow rate accuracy measurements indicate that leakage may be a problem.

4.5 Fault alarm check

4.5.1 Low flow

If a low flow alarm is available, activate the low flow alarm, either by adding a restriction to the air inlet, or by reducing the flow rate via valve control.

4.5.2 Low differential pressure

Set the flow rate to the normal value with a clean filter (or filter card) in place. Place a ‘holed’ filter (or a filter card without a filter) in the sampler. The instrument should activate an alarm that indicates that there is a damaged filter present.

5

Specific tests on the radiation detection assembly for air monitors and laboratory counting equipment

IN THIS CHAPTER

- Parameter check
- Background
- Activity alarm test
- Detection Efficiency
- Energy response
- Cross response
- Gamma compensation test
- Linearity of response to activity

The function of the radiation detection assembly of an air monitor is similar to that of basic laboratory counting equipment. Therefore, the same tests will be conducted on both types of instrument, unless stated otherwise.

5.1 Parameter check

Where the equipment has parameter settings stored within its electronic memory, these should be checked to ensure that they do not vary from the preset parameter settings. If these parameters are controlled by a high level of security (e.g. via a supervisor password), this test may be conducted as part of the Periodic Test rather than the function check.

5.2 Background

If possible record the detector count rate rather than the activity. The purpose of the test is to identify whether the detector is noisy or contaminated. This test should be undertaken with a clean filter and with no air flow. If the air flow cannot be interrupted, the same tests may be conducted without a filter.

5.3 Activity alarm test

Activate the alarm with a source of sufficient activity to trigger the alarm(s). Confirm correct operation of all alarm functions e.g. local audible, visual and any remote indications.

5.4 Detection Efficiency

This test is designed to measure the efficiency of the detector. The active area and construction of the source should be as recommended by the manufacturer. If this is not possible, then the instrument manufacturer should be consulted and any correction factor should be clearly stated with any reported results.

The test radionuclides should be representative of the environment. Suitable radionuclides for alpha radiation are ^{241}Am or ^{239}Pu, and ^{36}Cl is a suitable efficiency test source for beta radiation.

5.5 Energy response

This test is only required as part of the TBFU. However in some situations, for example where there is a wide range of radiation energies in the workplace, this test should also be considered as a Periodic Test.

The test for radiation energy response and the cross response between the alpha and beta channels are closely linked, and will typically be tested at the same time.

For beta or alpha/beta detection assemblies, the beta response as a function of beta energy should be tested using a range of reference beta sources that emit beta particles with energies typical of those emitted by the mix of radionuclides found in the workplace. Typical test radionuclides are ^{14}C, ^{147}Pm, ^{99}Tc, ^{60}Co, ^{137}Cs, ^{36}Cl and ^{90}Sr + ^{90}Y. The beta responses for the mixture of radionuclides present should have been taken into account when setting activity alarm levels.

For alpha or alpha/beta detection assemblies used in a uranium facility, a uranium test source should be used for checking the low-energy alpha response. Commercially available natural uranium sources contain approximately equal activities of ^{238}U and ^{234}U, which predominantly emit alpha particles with approximate energies 4.2 and 4.7 MeV respectively. A natural uranium source contains the beta emitters ^{234}Th and ^{234m}Pa in equilibrium with ^{238}U.

5.6 Cross response

This test is only required as part of the TBFU. This test is closely linked to energy response test, since there is the possibility that high energy beta emissions will be recorded in the alpha channel.

For alpha and alpha/beta detection assemblies, test the assembly to a ^{90}Sr + ^{90}Y test source. Measure the response of the alpha channel to this source. The response of the alpha channel to the beta radiation should be less than 0.1 % of that of the reference radionuclide for that channel (^{241}Am or ^{239}Pu). The limiting criterion may be relaxed for instruments that are to be used where no radionuclides that emit high-energy beta particles will be present.

5.7 Gamma compensation test

This test is only required as part of the TBFU.

Monitors that measure beta-emitting particulates are often provided with a means for compensating for ambient interfering gamma radiation. Typically these monitors will have two detectors: one detector measures alpha and beta activity on the filter as well as background gamma radiation; the other only measures background gamma radiation. The reading on the gamma only detector is used to compensate the activity detector for the interfering gamma radiation background.

The following test shall be undertaken with the detectors installed within the assembly. Measure the sensitivity of both detectors to a known dose rate of gamma radiation. Both detectors should be tested at the same time. The distance between the detectors and the source of gamma radiation should be sufficient to ensure that both detectors are equally irradiated. The sensitivity of an air monitor will vary significantly with orientation, and it is therefore important to always test monitors in an identical orientation. A suitable dose rate is one in excess of 10 $\mu Sv.h^{-1}$ from ^{137}Cs. The ratio of the sensitivities should be within 10% of the ratio stated by the manufacturer for that orientation. To avoid interference from radon and thoron daughters, the tests must be carried out either without a filter or, preferably, with no air flowing and with a clean unused filter.

5.8 Linearity of response to activity

This test is only required as part of the TBFU for beta-activity laboratory counting equipment and where the instrument is expected to make measurements that approach the maximum range of the instrument.

The linearity should be tested with at least three reference sources of identical construction. The range of surface emission rates should span the count rates that the instrument may reasonably encounter in the workplace. The instrument efficiency should be determined for each source and the mean of the efficiencies should be calculated. Each of the individual efficiencies established should then agree with the mean to within ± 30 %.

Facilities and Traceability

6

IN THIS CHAPTER

- Workplace air samplers
- Workplace air monitors and laboratory counting equipment

The majority of the tests described in this document would be performed in the workplace rather than the calibration laboratory. However the TBFU should be performed in an appropriate facility, which ensures measurements are undertaken in a controlled environment. The facilities and traceability required in order to undertake tests on air monitoring equipment in a calibration laboratory are no different from those required for a portable instrument.

6.1 Workplace air samplers

The flow rate on an air sampler may be verified with a calibrated flow meter, typically with a scale from 0 to 100 litres per minute. The typical interval between calibrations of standard flow meters is 3 years.

6.2 Workplace air monitors and laboratory counting equipment

Workplace air monitors and laboratory counting equipment may be calibrated in situ with solid reference sources whose surface emission rates are traceable to primary standards.

The exact activity of the source is not required for traceability, since the self-absorption and scatter characteristics of the source are unlikely to be similar to those of the filter. Therefore it would not be appropriate to use the activity of the source to derive the 4π efficiency. Instead, the traceable alpha or beta surface emission rate of the source should be multiplied by a factor of 2 to give the effective total activity.

For further information on such reference sources and their use, see the Appendix, which includes sections on source calibration and traceability, and the calculation of detection efficiency.

Certification of tests

7

IN THIS CHAPTER

- Calibration laboratory
- Workplace testing
- Test label

The results of tests performed under the current regulations should be communicated to the employer in a formal manner. The precise format of a test certificate or report is not specified in the regulations.

7.1 Calibration laboratory

The information provided for air monitoring equipment that is tested in a calibration laboratory is the same as that required for a portable instrument. The following basic information should be provided by the Test House:

(a) the name and address of customer;

(b) a description of the instrument (including type and serial no.);

(c) the type of test (i.e. Tests Before First Use, Periodic Test or retest after repair);

(d) a basic description of the test, any specific instrument settings used (including the operating voltage if this is variable), and any adjustments or repairs performed;

(e) the results of the tests undertaken to satisfy this document including, for numerical results, a statement of the uncertainty and the confidence level at which the uncertainty has been quoted;

(f) a record of the background count rate and any relevant environmental conditions during the tests;

(g) relevant source details, including the radionuclide, the surface emission rate and the active area;

(h) a statement that the test was carried out for the purposes of complying with the regulations;

(i) the name and signature of the QP supervising the test;

(j) the name, address and contact details (e.g. telephone number or Email address) of the Test House which performed the test;

(k) the date of the test;

(l) the test reference.

7.2 Workplace testing

The results of Periodic tests for air monitoring equipment do not typically require the issue of a certificate for each instrument. However, the Test House should indicate all the information listed above through a combination of documented test procedures that describe the tests to be undertaken and a test report which provides the information that is unique to the instrument. In general, the test report only needs to specify the following:

(a) the location of the instrument;

(b) the type and serial number of the instrument;

(c) the type of test (e.g. Periodic);

(d) the results of the testing, including background indications;

(e) the name and signature of the QP;

(f) the date of the test.

7.3 Test label

As test reports are usually filed away for Quality Assurance purposes and tend not to accompany instruments in the workplace, it is recommended that instruments themselves are labelled with the following information after testing:

(a) a description of the instrument (including type and serial number);

(b) the date of the calibration or test;

(c) the test reference.

If an instrument fails to meet the pass/fail criteria of any component of a test, the Test House should prominently label the instrument as failed and make some indication of the nature of the failure on the certificate or test report.

Quantities and units

8

IN THIS CHAPTER

- Air sampler quantities
- Air monitor quantities

For radioactive particulate-in-air monitors and laboratory counting equipment, the traceable quantity for radioactivity is the surface emission rate of the solid reference source used to determine the instrument's response to a particular radionuclide. Instrument calibration certificates often quote the instrument's response in terms of the source emission rate, but they may also quote the response in terms of activity. To convert the instrument's response from counts.s^{-1} per emission per second to counts.s^{-1} per Bq, a multiplication factor must be applied, which is normally taken to be 0.5.

8.1 Air sampler quantities

For air samplers and the air circuit of air monitors, the traceable quantity is either the sampling flow rate or the volume sampled. The typical units for flow rate are litres per minute, or cubic metres per hour. The typical unit for the sample volume is cubic metres.

8.2 Air monitor quantities

Typically, air monitors will display the quantities *activity in air concentration* and *integrated activity in air concentration*. The activity in air concentration has the units Bq.m^{-3} and the integrated activity in air concentration has the units Bq.h.m^{-3}. The integrated activity in air concentration is derived from the compensated total activity on a filter, whereas the activity in air concentration is derived from the increase in activity on the filter over a prescribed time period.

These two quantities are often expressed with the units Derived Air Concentration (DAC) for air concentration and Derived Air Concentration hours (DACh) for integrated air concentration. The DAC takes account of the radiotoxicity of the measured radionuclides, the Activity Median Aerodynamic Diameter (AMAD) of the particles, the breathing rate of the worker and the maximum period over which the worker might be exposed during the working year.

The alarm setting is often based on the quantity integrated air concentration because it is proportional to committed dose, whereas the air concentration is proportional to the committed dose rate. For alpha monitors in particular, the high radiotoxicity leads to a very low maximum acceptable concentration in air (compared with beta monitors), which consequently makes air concentration measurements statistically challenging.

References

9

1. The Ionising Radiations Regulations, 1999, HMSO, 1999.

2. Work with ionising radiation, approved code of practice, Ionising Radiation Regulations 1999, HMSO, 1999.

3. National Physical Laboratory, Measurement Good Practice Guide No.14, *The examination, testing and calibration of portable radiation protection instruments,* NPL, 1999.

4. National Physical Laboratory, Measurement Good Practice Guide No.29, *The examination, testing and calibration of installed radiation protection instruments,* NPL, 2001.

5. International Electrotechnical Commission, *Radiation Protection Instrumentation - Monitoring Equipment - Radioactive Aerosols in the Environment,* IEC 61172, 1992.

6. British Standard, *Equipment for continuous monitoring of radioactivity in gaseous effluents - Part 1: General requirements,* BS EN 60761-1, 2004.

7. British Standard, *Equipment for continuous monitoring of radioactivity in gaseous effluents - Part 2: Specific requirements for radioactive aerosol monitors including transuranic aerosols,* BS EN 60761-2, 2004.

8. British Standard, Radiation Protection Instrumentation, *Alpha, beta and alpha/beta (beta energy > 60 keV) contamination meters and monitors,* BS EN 60325, 2004.

9. Institute de Radioprotection et de Sûreté Nucléaire (IRSN) Report (in preparation).

10. Huang S, Schery, SD, Alcantara RE, Rodgers JC and Wasiolek PT, *Influence of Dust Loading on the Alpha-particle Energy Resolution of Continuous Air Monitors for Thin Deposits of Radioactive Aerosols,* Health Physics, 83, pp 884-891 (2002).

11. Hinds WC, *Aerosol Technology* (Chapter 9), Wiley Interscience, New York (1999).

12. Lee KW and Mukund R, *Aerosol Measurement Principles, Techniques and Applications* (Chapter 9), Eds. Baron PA and Willeke K, Wiley Interscience New York (2001).

13. Jaffey AH, *Solid Angle Subtended by a Circular Aperture at Point and Spread Sources: Formulas and Some Tables,* Rev. Sci. Inst. 25(4), pp 349-354 (1954).

14. *Advances in Aerosol Filtration* (Chapter 15), Eds Spurny KR, Lewis Publishers (CTC Press) (1997).

15. *Advances in Aerosol Filtration* (Chapter 16), Eds. Spurny KR, Lewis Publishers (CTC Press) (1997).

16. International Organisation for Standardisation, *Reference sources for the calibration of surface contamination monitors – Beta-emitters (maximum beta energy greater than 0.15 MeV) and Alpha emitters,* ISO 8769, Geneva, 1988.

17. *Type Test Report: iCAM Activity in Air Monitor* (March 2002).

18. Ruffle MP, *The computation of certain solid angles and some useful associated functions,* AERE Report R 5419 (1967).

19. Ruby L and Rechen JB, *A Simpler Approach to the Geometrical Efficiency of a Parallel-disk Source and Detector System,* Nucl. Instr. and Meth. 58, pp 345-346 (1968).

20. Ruby L, *Further Comments on the Geometrical Efficiency of a Parallel-disk Source and Detector System,* Nucl. Instr. and Meth A 337, pp531-533 (1994).

Appendix: Reference sources

A

IN THIS CHAPTER

A1.1 General

As far as practicable, the source dimensions and counting geometry should be the same for both the reference sources and the samples. Regarding radionuclides, the optimum situation arises when reference sources are available for the radionuclides being monitored. This is not always possible and, in such cases, the reference radionuclides should be chosen to have radiation characteristics as close as possible to the radionuclides in the sample. Even where the correct reference radionuclides are available, it is important to realise that the energy and angular distribution of the radiations emitted from the reference source may well differ significantly from those emitted from the filter, particularly for short-range emissions, such as those from alpha-emitters and low-energy beta-emitters. These differences can lead to significant differences in detection efficiency.

The manufacturer of the instrument under test may be consulted when selecting suitable reference sources.

A1.2 Alpha energy absorption in filters

Alpha particles lose a significant proportion of their energy in passing through the air gap between a source and the detector but those emitted from a filter will suffer an additional loss of energy. The amount of additional absorption depends on a number of factors, principally:

the alpha particle emission energy
the type of filter
the air sampling rate
the amount, nature and size of the collected aerosol
the duration of sampling

Under some conditions, the loss of energy in the filter may be sufficient to significantly reduce the alpha detection efficiency below that indicated by a thin reference source.

However, measurements with radioactive aerosols of different sizes have shown that although alpha energy spectra from ^{239}Pu aerosols of AMAD 0.4μm and 4μm collected by filters show noticeably more degradation than spectra from thin reference sources, this actually has little effect on the alpha detection efficiency; the latter is similar to that observed with a reference source[9].

Alpha energy losses in filters may increase with dust loading but this is not always the case. Loading a filter with particulates degrades the alpha spectrum from previously collected activity; however, particulates already on the filter often have little effect on the alpha spectrum from newly collected aerosols. Indeed, in some types of filter, the filtration efficiency tends to increase, and the energy degradation decrease, with dust loading[10-15].

Air monitors operating in continuous mode monitor the activity of interest as it is collected by the filter; therefore, readings from such monitors are less likely to be affected by energy-degradation than are measurements made on filters after removal from an air sampler, where a significant proportion of the inactive dust may have been collected after the activity of interest.

A1.3 Calibration and Traceability

Reference sources should comply with the requirements of ISO 8769 which defines sources as Class 1 and Class 2 standards, or Working sources[16].

Class 2 sources are constructed so as to conform as closely as possible to an ideal, infinitely thin source. Working sources do not need to meet this criterion, although some do. The uncertainty (at 95% confidence level) in emission rates is 10% or less for Working sources and 6% or less for Class 2 sources.

It is preferable to use Class 2 sources but Working sources which can be classified as thin according to ISO 8769 are acceptable.

Sources should be calibrated by an accredited calibration service and must be traceable to national standards.

The emission rate from the source should be revalidated every two years. The result of the revalidation must not replace the original calibrated emission rate (after decay correction). A full recalibration should be performed every 4 years or whenever a Qualified Person has reason to believe that there has been a significant change in the emission rate of the source.

A1.4 Detection Efficiency

The **2π Detection Efficiency** is given by the measured net signal count rate (i.e. the gross count rate minus background), in counts per second, divided by the calibrated rate of emission of alpha or beta particles from the surface of the calibrated reference source.

The **4π Detection Efficiency** is given by the measured net signal count rate, in counts per second, divided by twice the calibrated surface emission rate into 2π. It represents the fraction (or percentage) of the alpha or beta rays emitted uniformly in all directions that result in a detected signal count. It is equal to half the 2π Detection Efficiency.

Estimating the sample activity from the measured net sample signal count rate

The alpha or beta activity of a sample may be estimated by dividing the net sample signal count rate (in counts per second) by the appropriate value of the 4π Detection Efficiency (expressed as a fraction). However, this will be a good estimate only if this efficiency takes into account (a) any differences in geometry between reference source and filter sample, and (b) any reduction of efficiency due to particle energy degradation in the filter sample.

Calibrated source activity and emission rate

The emission rate, not the source activity, is used when calculating the detection efficiency.

The rate of emission of alpha particles from a good quality thin alpha reference source is approximately half the activity of the source. The source efficiency of the sources that are used to check air monitors (where the activity is incorporated in a thin anodised layer on an aluminium foil) is typically about 0.47; however, the corresponding value for the more fragile vacuum deposited spectrometry-standard sources is more typically 0.49 to 0.50.

However, the rate of emission of beta particles from a thin beta reference source can be significantly greater or less than half the activity of the source. Thus, calculating the detection efficiency by dividing the measured signal count rate by the activity of the reference source would give a misleading value that may be significantly higher or lower than the true detection efficiency.

A1.5 Source construction

Several types of source are available.

Anodised Aluminium

Alpha and beta sources made by incorporating the activity in a thin anodized layer on the surface of an aluminium foil are recommended as they are robust and meet the requirements of ISO8769. They are the only beta sources whose emissions are known to be isotropic (see below). However, some are sealed with protective foils and are unsuitable for accurate measurements (see below).

Electroplated and vacuum-deposited sources

Electroplated and vacuum-deposited alpha sources are high quality sources which, by virtue of their minimal self-absorption and narrow line widths, are suitable for calibrating alpha spectrometers. At one time, card-mounted air-monitor alpha sources were made by vacuum deposition but they were liable to loss of activity from careless handling and have been superseded by the more robust anodized-aluminium types.

Activity incorporated in silver foils

At one time, most of the beta sources available in the United Kingdom were made by incorporating the activity in a rolled silver foil; however, self absorption and scattering within the source causes beta rays to be emitted anisotropically with more emitted at angles close to the normal and less emitted at oblique angles than would be the case from a thin source or sample that emits beta rays uniformly in all directions. In effect, the beta radiation is collimated and therefore the beta efficiency measured with these sources is always an overestimate, sometimes by as much as a factor of 2. This type of source gives highly inaccurate results even when the total surface emission into 2π is accurately calibrated. Early card-mounted beta sources for air monitors were of this type.

Sources with a protective seal

Some beta sources are made by sealing the activity under, or between, protective foils. These also suffer from anisotropic emissions and give overestimated beta efficiencies. Examples of beta sources that suffer from this problem are:

Some older beta sources for air monitors which were made by sealing the activity under a trefoil imprinted protective foil;

Some beta sources, currently available from French and US suppliers, which are made by sealing the activity between protective foils;

Some of the more active anodized aluminium sources that otherwise emit betas isotropically and which are sealed by a protective red or yellow plastic layer. Although the anisotropy introduced by this seal is less severe than with the other types, it is still sufficient to give apparent air-monitor efficiencies about 15% higher than the true value.

If there is reason to suspect that there is a problem with any sources, contact NPL for advice.

A1.6 Source geometry

Ideally, the reference source should reproduce the geometry of the filter sample; that is, it should be located with its active surface at the same distance from the detector and have the same active diameter.

The first requirement is mandatory but in practice the second may be relaxed, providing account is properly taken of the effect of using a source whose diameter does not match that of the sample.

Card-mounted sources for air monitors

Reference sources mounted on stainless steel are available for routine checks on those air monitors that use card-mounted filters.

To allow air sampling to continue operating with the source in place, the original Harwell card was designed with a concentric ring of holes around the active area of the source whose diameter is only 19 mm compared with 25 mm for the filter. It has been established by calculation, and verified by measurement[17], that the efficiency of detecting radiations from a 25 mm source located at 5 mm ± 0.5 mm from a 450 mm^2 detector is 85 % of that for a 19 mm diameter source. This difference is allowed for when the instrument calculates activity.

To achieve the same end, the Laboratory Impex card has a hole in the centre of the active area of the source whose overall diameter matches that of the filter. The correction required to take account of the inactive area at the centre of the source is negligible.

Sources for laboratory equipment

Sources to test laboratory equipment come in a range of formats. If the instrument is required to measure radiations from a range of radionuclides on samples of different diameters, then ideally it should be tested with a full set of reference sources covering that full range of nuclides and sample diameters; however, to reduce cost, a limited selection of diameters may have to be made.

Geometrical Detection Efficiency

The ideal 4π geometrical efficiency, E_G, of detecting radiation from a point source located on the axis of a disc detector is easily calculated using the standard equation:

$$E_G = \frac{1}{2}\left(1 - \frac{h}{\sqrt{1+h^2}}\right) \qquad \text{...equation 1}$$

in which 'h' (the normalised detector distance) is given by:

$$h = \frac{z}{R_D} \qquad \text{...equation 2}$$

where

R_D is the detector radius

z is the distance between the source and the detector

It is much more difficult to calculate efficiencies for other geometries. Different methods for disc sources and disc detectors have been described[13, 18 - 20]. The following chart and table show how the 4π geometrical detection efficiency depends on the normalised source radius and the normalised detector distance.

The normalised source radius, r, is given by:

$$r = \frac{R_S}{R_D} \qquad \text{...equation 3}$$

where

R_S is the source radius.

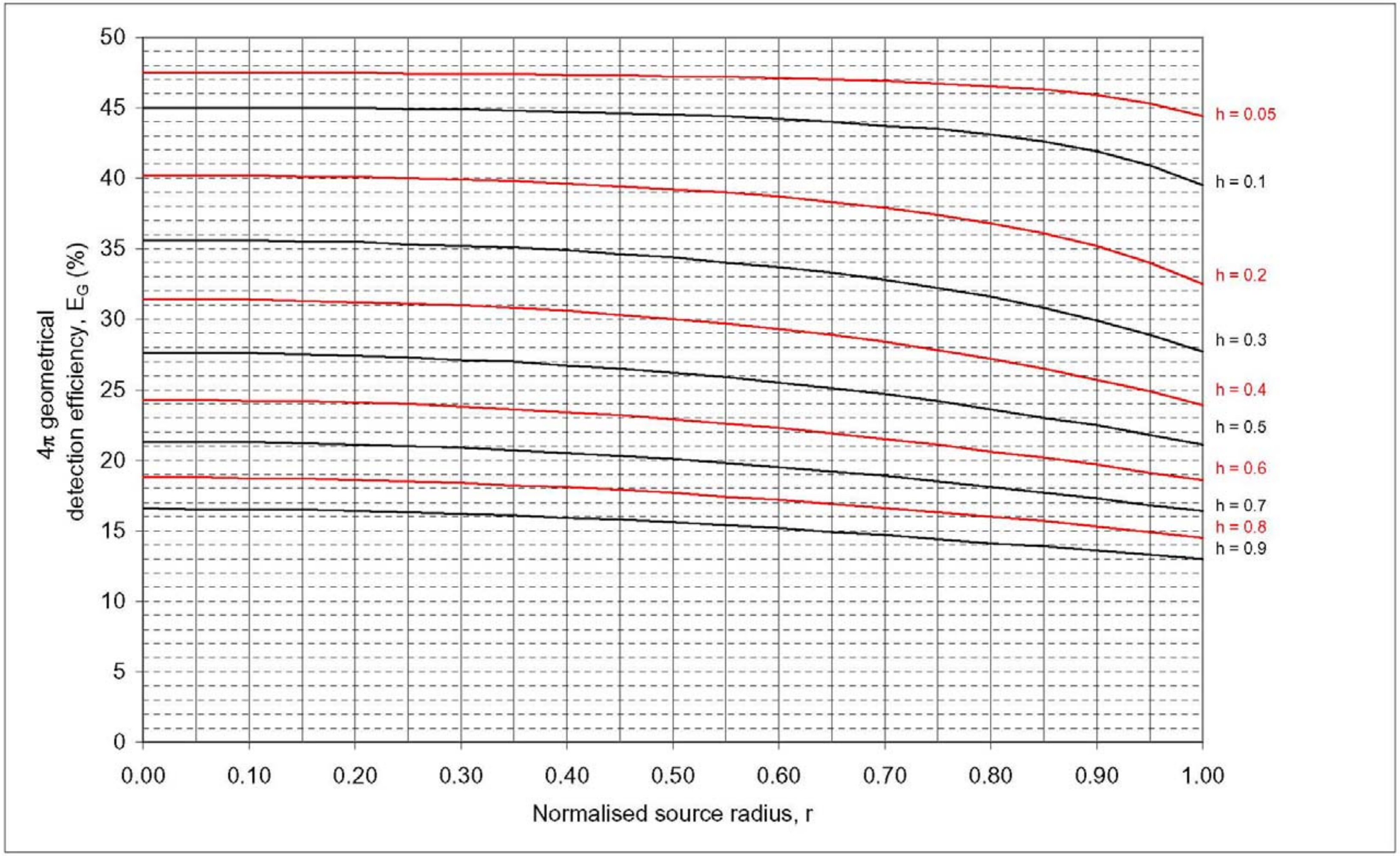


Figure 1. **Variation of 4π geometrical detection efficiency (E_G) with normalised source radius (r) for various values of the normalised detector distance (h)**

	Normalised detector distance, h									
Normalised source radius, r	h=0.05	h=0.1	h=0.2	h=0.3	h=0.4	h=0.5	h=0.6	h=0.7	h=0.8	h=0.9
0.00	47.5%	45.0%	40.2%	35.6%	31.4%	27.6%	24.3%	21.3%	18.8%	16.6%
0.05	47.5%	45.0%	40.2%	35.6%	31.4%	27.6%	24.3%	21.3%	18.8%	16.5%
0.10	47.5%	45.0%	40.2%	35.6%	31.4%	27.6%	24.2%	21.3%	18.7%	16.5%
0.15	47.5%	45.0%	40.1%	35.5%	31.3%	27.5%	24.2%	21.2%	18.7%	16.5%
0.20	47.5%	45.0%	40.1%	35.5%	31.2%	27.4%	24.1%	21.1%	18.6%	16.4%
0.25	47.4%	44.9%	40.0%	35.3%	31.1%	27.3%	24.0%	21.0%	18.5%	16.3%
0.30	47.4%	44.9%	39.9%	35.2%	31.0%	27.1%	23.8%	20.9%	18.4%	16.2%
0.35	47.4%	44.8%	39.8%	35.1%	30.8%	27.0%	23.6%	20.7%	18.2%	16.1%
0.40	47.3%	44.7%	39.6%	34.9%	30.6%	26.7%	23.4%	20.5%	18.1%	15.9%
0.45	47.3%	44.6%	39.4%	34.6%	30.3%	26.5%	23.2%	20.3%	17.9%	15.8%
0.50	47.2%	44.5%	39.2%	34.4%	30.0%	26.2%	22.9%	20.1%	17.7%	15.6%
0.55	47.2%	44.4%	39.0%	34.0%	29.7%	25.9%	22.6%	19.8%	17.4%	15.4%
0.60	47.1%	44.2%	38.7%	33.7%	29.3%	25.5%	22.3%	19.5%	17.2%	15.2%
0.65	47.0%	44.0%	38.3%	33.3%	28.9%	25.1%	21.9%	19.2%	16.9%	14.9%
0.70	46.9%	43.7%	37.9%	32.8%	28.4%	24.7%	21.5%	18.9%	16.6%	14.7%
0.75	46.7%	43.5%	37.4%	32.2%	27.8%	24.2%	21.1%	18.5%	16.3%	14.4%
0.80	46.5%	43.1%	36.8%	31.6%	27.2%	23.6%	20.6%	18.1%	16.0%	14.1%
0.85	46.3%	42.6%	36.1%	30.8%	26.5%	23.0%	20.2%	17.7%	15.7%	13.9%
0.90	45.9%	41.9%	35.2%	29.9%	25.7%	22.5%	19.7%	17.3%	15.3%	13.6%
0.95	45.3%	40.9%	34.0%	28.9%	24.9%	21.8%	19.1%	16.8%	14.9%	13.3%
1.00	44.4%	39.5%	32.5%	27.7%	23.9%	21.1%	18.6%	16.4%	14.5%	13.0%

Table 5. Variation of 4π geometrical detection efficiency (E_G) with normalised source radius (r) for various values of the normalised detector distance (h)

Consider the example given on page 36. The detector area is 450 mm^2, corresponding to a radius of 12.0 mm. The detector is 5 mm from the source, so the normalised detector distance, *h*, is 5/12, or approximately 0.417.

Now consider a source with a diameter of 19 mm. The normalised source radius, *r*, is 9.5/12, or approximately 0.79. Using the data in Table 5 above, this corresponds to a value for E_G of 26.7 %. Changing to a 25 mm diameter source means that *r* becomes 12.5/12, or approximately 1.04, corresponding to a value for E_G of 23.0 %.

The ratio of the two values is approximately 0.86. Given that the value of *r* has been extrapolated beyond the limits of Table 5, this is in good agreement with the stated value of 0.85 referred to earlier[17].

The calculations assume that all those particles that are emitted in a direction in line with part of the detector surface reach the detector with sufficient energy to produce a response. No account is taken of energy losses in air and/or the detector window. Alpha particles of interest have ranges in air of only a few tens of millimetres and so efficiencies observed with larger-diameter detectors will fall below the ideal geometric efficiency.

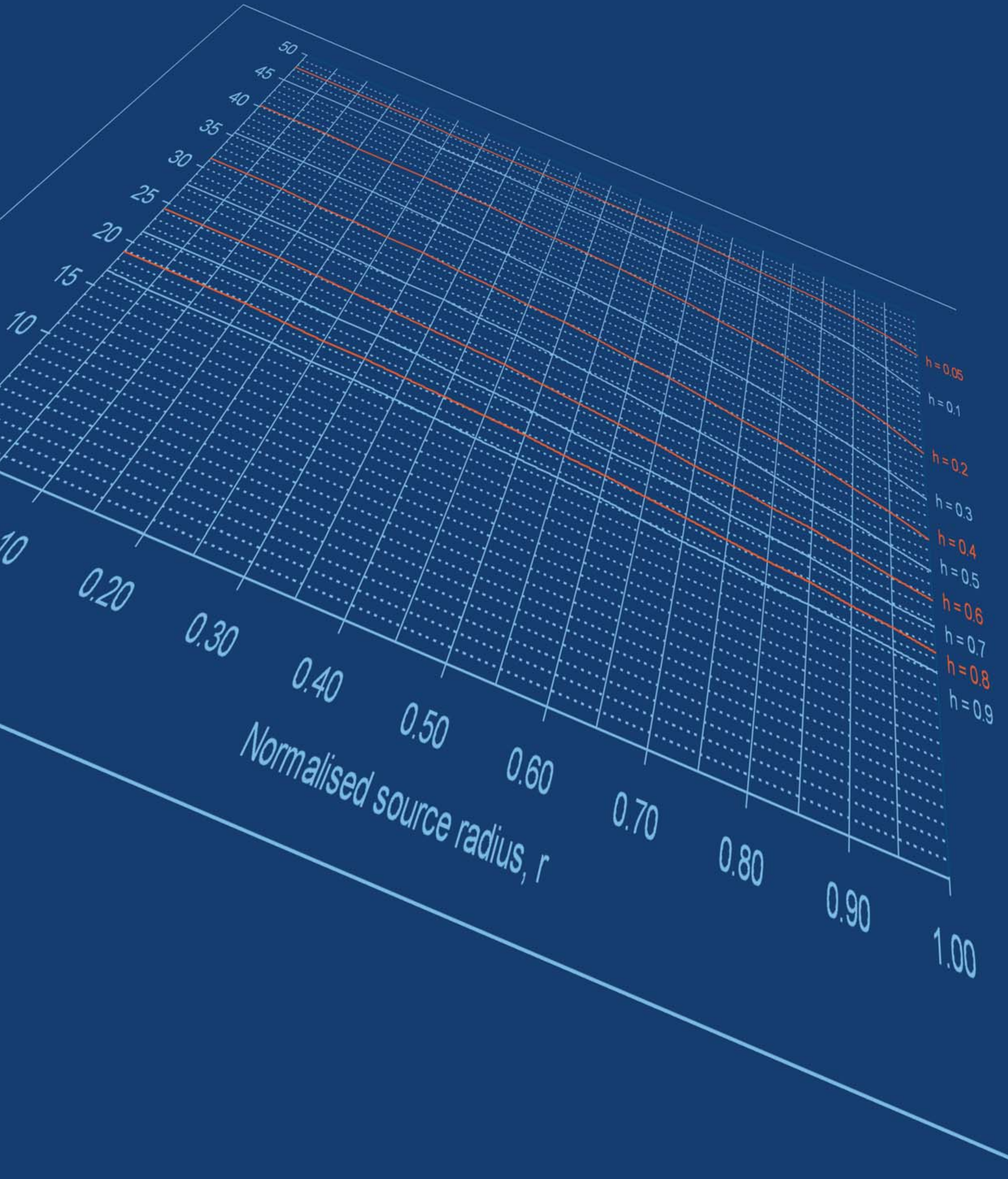
Alpha-particle energy (MeV)	Range in air (mm)
4.0	26
4.5	31
5.0	36
5.5	42
6.0	47

Table 6. Variation of alpha particle range in air with particle energy

GLOSSARY

AMAD	Activity Median Aerodynamic Diameter. The diameter in an aerodynamic particle size distribution for which the total activities above and below the diameter are equal. A log-normal particle size distribution is assumed.
DAC	Derived Air Concentration in units of $Bq.m^{-3}$. This is the concentration of radioactive particulate in air, which if inhaled for a working year (typically 2000 hours) would result in an inhalation committed dose of 20 mSv[1].
DAC.h	The DAC integrated over the sampling time.
Employer	The person or establishment who is legally responsible for the maintenance of the equipment.
Geometrical Detection Efficiency	The solid angle subtended by the detector (averaged over the surface of the source or sample) divided by 4π steradians. It represents the fraction of radiations emitted isotropically from a source or sample emitted in a direction to be intercepted by the detector. It is, therefore, the maximum theoretically possible efficiency with which observed efficiencies can be compared.
Qualified Person (QP)	A person who possesses the necessary expertise in instrumentation, theory and practice appropriate to the instrumentation to be tested. This person may have responsibility for developing test protocols, taking account of the intended use of the instrumentation, as stated by the employer.

Radon and Thoron	Radon (^{222}Rn) is a gaseous daughter of ^{226}Ra, a member of the naturally occurring ^{238}U series. Radon itself is not collected by the filter. Radon's short-lived progeny will be deposited on the filter paper and will emit alpha and beta particles. The major alpha emissions in these progeny are from ^{218}Po and ^{214}Po (with alpha energies of approximately 6.0 and 7.7 MeV respectively) and the major beta emissions lie in the approximate range 600 – 3300 keV, arising from ^{214}Pb and ^{214}Bi. Thoron (^{220}Rn) is part of the ^{232}Th series. Thoron itself is not deposited on the filter. Thoron's short-lived progeny will be deposited on the filter paper and emit alpha and beta radiation. The major alpha emissions in these progeny are from ^{212}Po and ^{212}Bi (with alpha energies of approximately 8.8 and 6.1 MeV respectively) and the major beta emissions lie in the approximate range 300 – 2300 keV, arising from ^{212}Pb, ^{212}Bi and ^{208}Tl.
Test House	This is the organisation undertaking the testing of the instrument. This may be an independent calibration laboratory, a contract company who undertake the instrument testing in the workplace, or a department under direct management control of the employer that undertakes testing in the laboratory or in the workplace. Ideally, the Test House should hold UKAS accreditation for all the testing that it undertakes.
Detection Efficiency	The ratio between the observed count rate and the surface emission rate of the source, expressed as a percentage.
4π Efficiency	For alpha- and beta-emitting particulate-in-air monitoring, the 4π Efficiency is conventionally taken to be the Detection Efficiency divided by 2.



50
45
40
35
30
25
20
15
10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Normalised source radius, r
h = 0.05
h = 0.1
h = 0.2
h = 0.3
h = 0.4
h = 0.5
h = 0.6
h = 0.7
h = 0.8
h = 0.9