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Measurement of radioactivity — Measurement and evaluation of surface contamination —

Part 1:
General principles

Mesurage de la radioactivité — Mesurage et évaluation de la contamination de surface —

Partie 1: Principes généraux

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 85, *Nuclear energy nuclear technologies and radiological protection*, Subcommittee SC 2, *Radiation protection*.

This second edition cancels and replaces the first edition (ISO 7503-1:1988), which has been technically revised.

ISO 7503 consists of the following parts, under the general title *Measurement of radioactivity — Measurement and evaluation of surface contamination*:

— *Part 1: General principles*

— *Part 2: Test method using wipe-test samples*

— *Part 3: Apparatus calibration*

This corrected version of ISO 7503-1:2016 incorporates the following corrections:

— In 3.2, for I(A), replace "(Bq·cm^{-2})/s^{-1}" by "s^{-1}/(Bq·cm^{-2})";

— In Clause 9, replace the first paragraph which has been rephrased.

Introduction

ISO 7503 gives guidance on the measurement of surface contamination. This International Standard is applicable to many situations where radioactive contamination can occur. Contamination arises from the release of radioactivity into the local environment. In most circumstances, the release is inadvertent but, on occasion, may be deliberate. Although the purpose and scope of the investigation may differ, the approaches taken to measure the levels and extent of the contamination are essentially similar.

Radioactive contamination can arise from a number of activities or events such as the following:

— routine laboratory use of radio-chemicals;

— medical treatments;

— industrial applications;

— transport accidents;

— equipment malfunctions;

— malevolent incidents;

— nuclear accidents.

Without process knowledge or documentation, it is not always possible to identify or distinguish the different radionuclides constituting a surface contamination, and the evaluation of such a contamination cannot be made on a quantitative basis. Instead of using instruments with nuclide specific calibrations, it may be necessary to use other instruments which are fit for such a purpose.

However, there may be cases (e.g. a contaminated fuel material transport container) where the radionuclide or the radionuclide mixture can be clearly characterized. A surface contamination evaluation exceeding a pure qualitative assessment of fixed and removable surface contamination may then be needed. Moreover, following requirements laid down in national regulations and in international conventions, a measured surface contamination activity per unit area has to be compared with surface contamination guideline values or surface contamination limits.

Surface contamination guideline values are radionuclide-specific and thus require complex radionuclide-specific calibrations of measurement equipment. Calibration quality assurance is crucial in order to avoid non-detection (i.e. type II decision errors) leading to incorrectly assuming compliance with given surface contamination guideline values or limits. Evaluation of surfaces contaminated by a mixture of radionuclides with known ratios requires respectively proportionated calibration factors.

ISO 7503 is concerned with the measurement and estimation of radioactivity levels. It does not provide advice on decommissioning, planning and surveillance techniques.

Surface contamination is specified in terms of activity per unit area and the limits are based on the recommendations by the International Commission on Radiological Protection (ICRP 103).

This part of ISO 7503 deals with the evaluation of surface contamination by direct measurement using a surface contamination instrument, and in the case of the indirect method, using wipe tests. This part of ISO 7503 is primarily concerned with direct monitoring, practical guidance on measurements, it describes principles to keep an instrument in a fitness-for-purpose state. This part of ISO 7503 also presents instrument calibration principles and compiles the basic uncertainties of both surface contamination evaluation methods.

Measurement of radioactivity — Measurement and evaluation of surface contamination —

Part 1:
General principles

1 Scope

ISO 7503 (all parts) and ISO 8769 are addressed to the people responsible for determining the radioactivity present on solid surfaces. ISO 7503 is published in three parts and can be used jointly or separately according to needs.

This part of ISO 7503 relates to the assessment of surface contamination by direct and indirect measurements and the calibration of the associated instrumentation.

The standard applies to alpha-, beta- and photon emitters and is intended for use by hospitals, universities, police, or industrial establishments. The standard also can be used in the assessment of activity on trucks, containers, parcels, equipment and is applicable in any organization which handles radioactive materials. Generally, it is applicable to well defined flat surfaces where direct methods are applicable, however, it can also be used for surfaces which are not flat and where indirect wipe tests would be appropriate. These investigations may be carried out on containers, inaccessible areas, non-flat areas where wipe tests can be used. This part of ISO 7503 may be useful in emergency situations, i.e. in nuclear accidents where health physics professionals would be involved.

This part of ISO 7503 does not apply to the evaluation of contamination of the skin, of clothing and of loose material such as gravel.

NOTE   The test method using wipe-test samples for the evaluation of radioactive surface contaminations is dealt with in ISO 7503-2. The calibration of instruments for the evaluation of radioactive surface contaminations is dealt with in ISO 7503-3.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8769, *Reference sources — Calibration of surface contamination monitors — Alpha-, beta- and photon emitters*

ISO 11929, *Determination of the characteristic limits (decision threshold, detection limit, and limits of the confidence interval) for measurements of ionizing radiation — Fundamentals and application*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
activity per unit area
ratio between the activity of the radionuclides present on a surface and the area of that surface, expressed in becquerels per square centimetre

3.1.2
surface contamination
radioactive substances deposited on defined surfaces

3.1.3
fixed surface contamination
surface contamination which cannot be removed or transferred by non-destructive means

3.1.4
removable surface contamination
radioactive material that can be removed from surfaces by non-destructive means, including casual contact, wiping, or washing

Note 1 to entry: It should be noted that under the influence of moisture, chemicals, etc., or as a result of corrosion or diffusion, fixed contamination may become removable or *vice versa* without any human action. Furthermore, surface contaminations may decrease due to evaporation and volatilization.

Note 2 to entry: It should be emphasized that the ratio between fixed and removable contamination can vary over time, and that some decisions, such as those related to clearance, should be based on total activity with the potential to become removable over time, not just the amount that is removable at the time of a survey.

3.1.5
direct measurement of surface contamination
measurement of surface contamination by means of a contamination meter or monitor

3.1.6
indirect evaluation of surface contamination
evaluation of the removable surface contamination by means of a wipe test

3.1.7
wipe test
test to determine if removable contamination is present through wiping the surface with a dry or wet material, followed by evaluation of the wipe material for removable contamination

3.1.8
wiping efficiency
ratio of the activity of the radionuclides removed from the surface by one wipe sample to the activity of the radionuclides of the removable surface contamination prior to this sampling

Note 1 to entry: In practice, it is almost impossible to measure the total amount of removable activity on the surface, and in most cases, a value for the wiping efficiency cannot be assessed but can only be estimated.

3.1.9
surface emission rate of a source
number of particles of a given type above a given energy or of photons emerging from the front face of the source per unit time

3.1.10
instrument efficiency
ratio between the instrument net reading and the surface emission rate of a source under given geometrical conditions

3.1.11
emission instrument response
instrument efficiency times detector window area, equals the observed net count rate per surface emission rate per unit area of a calibration source

3.1.12
activity instrument response
instrument efficiency times detector window area times the probability of a particle or photon leaving the source surface, equals the observed net count rate per Bq per unit area of a calibration source

3.1.13
emission calibration factor
reciprocal of instrument efficiency times window area

3.1.14
activity calibration factor
reciprocal of instrument efficiency times window area times probability of a particle leaving the source surface

3.1.15
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

3.1.16
guideline value
value which corresponds to scientific, legal or other requirements for which the measuring procedure is intended to assess

3.2 Symbols and abbreviated terms

For the purposes of this part of ISO 7503, the following symbols apply:

$I(E)$ emission instrument response in $s^{-1}/(s^{-1}\cdot cm^{-2})$

ρ_c observed count rate from the calibration source in s^{-1}

ρ_0 background count rate in s^{-1}

R_c emission rate of the calibration source in s^{-1}

S_c area of the calibration source in cm^2

$I(A)$ activity instrument response in $s^{-1}/(Bq\cdot cm^{-2})$

A_c activity of the calibration source in Bq

P inverse of probability of a particle emerging from the surface, equal ratio of the particle or photon generation rate (activity) and the emission rate from the surface in Bq^{-1}/s^{-1}

S_p effective detector or probe area in cm^2

$C(E)$ emission calibration factor in $(s^{-1}\cdot cm^{-2})/s^{-1}$

$C(A)$ activity calibration factor in $(Bq \cdot cm^{-2})/s^{-1}$

ε instrument efficiency in s^{-1}/s^{-1}

A_s activity per unit area of fixed and removable contamination in $Bq \cdot cm^{-2}$

ρ_g measured total (gross) count rate in s^{-1}

4 Objectives of surface contamination measurements

4.1 General

Initial investigations into possible surface contamination need to assume a worst case scenario. The area, environment or premises need to be approached assuming that there may be significant dose-rates. If the initial investigation establishes that the dose rates do not present a radiological hazard where shielding may be necessary, the issue of contamination needs to be addressed.

If the investigation is routine, then the initial investigation into possible high dose rates does not need to be undertaken. The investigation only needs to proceed into possible surface contamination.

Having established the presence of surface contamination, the question of contamination instrumentation needs to be considered. Factors such as the instrument response to the likely radionuclide contamination and other aspects shall be assessed. The area to be monitored may determine the size of the most suitable detectors.

The bibliography contains publications which provide guidance on suitable instrumentation.

4.2 National and international regulations

It is necessary to comply with current national and international regulations or existing standards and guidance in addition to the customer requirements. National and international regulations provide guidance on averaging areas. In particular, it is essential to establish the areas over which measurements may be averaged for the purposes of demarcating areas on the basis of contamination levels.

4.3 Definition of the measuring programme

The objectives of a surface contamination measurement programme are

— the detection of ionizing particles or photons emitted from a surface contaminated with radioactive material, and

— the evaluation of the instrument readings which can be used to provide an estimate of the quantities and characteristics radioactive contaminants.

In order to achieve these objectives with a reasonable degree of confidence, it is necessary to plan the monitoring procedure. In many organizations, there are standard procedures that state how routine radiation protection monitoring should be done. The monitoring takes place in familiar areas, carried out by an organization's own staff, using its own monitoring equipment and reporting system.

In some circumstances, there may be no standard procedures in place to develop a suitable measurement programme. In these circumstances, information needs to be gathered, which might include the collection and documentation of the following details:

a) identification of the operator;

b) defining the areas or items to be monitored;

c) history of the areas to be monitored to include

     1) radionuclides used in the area and at what times and in what quantities,

    2) refurbishment, repair and maintenance histories, and

    3) previous survey results and possibly trend analysis;

d) the level of detail and levels of accuracy required by the operator;

e) the sampling strategy;

f) the need to distinguish between fixed and removable contamination;

g) the need for any direct or indirect measurements;

h) types and quantities of equipment required for specific measurements and available including status of calibration;

i) details of current dose rate levels around and within the areas to be surveyed;

j) limitations on access;

k) need for personal protective equipment (overalls, breathing apparatus, rubber gloves);

l) facilities for disposal of radioactive waste;

m) liaison with other organizations (e.g. police, national regulatory agencies);

n) environmental conditions (e.g. temperature, humidity);

o) types of surfaces to be monitored (e.g. rough concrete, painted contaminated surfaces).

Having gathered the relevant information listed above, an appropriate measurement programme should be developed and documented. The measurement programme should include the calculations and assumptions used in establishing the action levels. It is recommended that the measurement programme expresses where possible, the action levels in the same units that are displayed on the specified instruments. The measurement programme should include the steps to be taken whenever those levels are exceeded and the designation of those personnel who can authorize the resumption of the measurement programme if action levels have been exceeded.

5 Direct and indirect methods of assessing surface contamination

5.1 General

Contamination on a surface can be assessed either directly or indirectly.

The initial investigation into the contamination of premises should assume the worst case. The premises should be approached assuming that there may be a significant dose rate. This may be applicable to only one laboratory or maybe the whole building. If the initial investigation establishes that the dose rate does not present a shielding problem or radiological hazard, then the issue of contamination can then be addressed.

The applicability and the reliability of direct measurement or indirect evaluation of surface contamination are strongly dependent on the particular circumstances, i.e. the physical and chemical form of the contamination, the adherence of contamination on the surface (fixed or removable), the accessibility of the surface for measurement or the presence of interfering radiation fields.

Direct measurement is used when the surface is readily accessible without

— interfering inactive liquid or solid deposits that cannot be taken into account, or

— interfering radiation fields that cannot be taken into account.

Indirect evaluation of surface contamination is generally more applicable when the surfaces are not readily accessible because of difficult location or configuration, or where interfering radiation fields

adversely affect contamination monitors, or when methods of direct measurement with standard instrumentation are not available. An indirect method cannot assess fixed contamination, and because of the great uncertainty usually related to the wiping efficiency, application of the indirect method usually results in conservative estimations of removable contamination.

Due to the inherent shortcomings of both the direct measurement and the indirect evaluation of surface contamination, in many cases, the use of both methods in tandem can help ensure results which best meet the aims of the evaluation.

5.2   Direct method

The direct method is the best approach whenever possible. In the direct method, the monitor probe is moved over a surface, with the face of the probe at a minimal distance of approximately 3 mm from the surface. The probe shall be kept stationary for a minimum to obtain sufficient accuracy. This measurement can then be used to determine the radiation emitted from the surface.

There are many circumstances where the above measurement might not be possible. A surface may be so convoluted that it is not possible to monitor it directly, or the background radiation may be so high that it is impossible to obtain meaningful results from the measurements; however, these results should be recorded because a calibration could be provided later. In these instances, an indirect measurement has to be made using a wipe test.

5.3   Indirect method (wipe tests)

A test procedure is often carried out using a filter paper or other wipe, typically 20 mm to 60 mm in diameter, which can be placed in commercial holder for measurement. The filter paper should be wiped over the area, usually at least 100 cm^2, or whatever area is locally defined for the surface that may be contaminated with radionuclides. The filter paper can either be placed in a lab counter drawer to assess the level and type of activity, or sent to a radiochemistry laboratory for a full assessment of nuclide type and activity. In both instances, all measurements should be traceable to national standards or governed by local requirements.

Wipe tests can be either "dry wipe" or "wet wipe". In general, it is a senior health physics professional who makes the decision on which to use.

The indirect surface evaluation contamination method is described in detail in ISO 7503-2.

5.4   Wipe test uncertainties

A brief discussion on uncertainties is given in 10.3.

6   Radionuclide identification and spectral analysis

Normally, the radionuclides are known. If not, they need to be identified. Radionuclide identification of contaminants using hand-held instruments is only practicable where the contaminants are gamma emitting nuclides with energies in the range of 50 keV to 1500 keV. If the contaminant does not emit photons in this range, it may not be possible to identify the radionuclide with hand-held instruments. In cases such as an accident or where only one radionuclide is in use, it may not be necessary for it to be determined as the contamination is known. Otherwise, more sophisticated techniques such as beta and alpha spectroscopy are required and these techniques are usually only available in a well-equipped laboratory where samples from the contaminated site can be prepared and analysed.

Small hand-held instruments exist that permit spectroscopic analysis of gamma radiation. In general, the instruments use a small, approximately 40 mm × 40 mm, NaI crystal as the principle detector. The sensitivity of a NaI crystal to gamma radiation makes these instruments particularly useful as "search and locate" devices particularly for finding and identifying lost or hidden gamma sources. However, it is not possible to make an accurate assessment of contamination levels using this type of instrument. A small NaI crystal connected to a multichannel analyser (MCA) permits spectral analysis of the

ambient radiation. The MCA may also contain an electronic library of many common nuclides and their associated photo-peaks.

The instrument shall be properly calibrated before use in a calibration facility that can provide traceability to national standards. The calibration should confirm not only the dose rate accuracy but also that the Multi Channel Analyser (MCA) has been correctly set up. If the MCA is not properly set up, the instrument is not able to perform automatic nuclide identification. The user should understand that automatic nuclide identification is limited to those nuclides in the instrument library. If peaks occur in the gamma spectrum, that are not automatically identified, the photon peak energy should be assessed from the spectrum and the literature consulted to try and identify the parent radionuclide. Alternatively, the user should consult with an experienced health physics professional or radio chemist.

In a situation where there are a number of gamma emitting nuclides present, the instrument may be unable to resolve the individual photo peaks because the resolution of small NaI crystals is poor when compared with germanium crystals. In this situation, germanium detectors can be used instead.

The time taken to collect a spectrum is mainly dependent on the ambient background radiation and the level of contamination. If the background is high or variable, it may be difficult or impossible to collect an adequate spectrum. If the background is particularly high, it may cause a spectrum shift which prevents automatic nuclide identification. Well shielded apparatus is also recommended.

7 Monitoring instruments

7.1 Selection of monitors

NOTE   Dose rate monitors are included in this clause as, prior to any survey to assess surface contamination, it is good practice to measure the ambient dose rates.

The selection of appropriate monitors depends on the following:

— the type(s) of radiation that are expected to be encountered (alpha, beta, photon);

— the levels of contamination that may be expected;

— the detection limits required;

— the accuracy required from the measurements.

The selection should be undertaken under the advice of a suitably qualified expert.

7.2 Introduction to the calibration of surface contamination instruments for direct measurement

For regulatory purposes, the maximum permissible levels for surface contamination are expressed in terms of activity per unit area (Bq·cm^{-2}).

In most situations, it is possible to identify the individual radionuclide which is the major constituent of the surface contamination. For example, in a hospital which only uses ^{99m}Tc for routine diagnostic purposes and no other radionuclides are brought onto the site, the nature of the contamination is obvious. The surfaces which might have become contaminated may also be well-defined in terms of material and surface finish. In this scenario, it would be appropriate to calibrate the contamination monitor(s) directly with the radionuclide concerned by depositing traceable activities to samples of the surfaces that might be affected by contamination. Exposing the monitor to these surfaces, at defined distances, provides a series of calibration factors which, during normal monitoring procedures, can be selected according to the relevant monitoring characteristics such as the nature of the surface, source to detector separation, and contamination area. These calibration factors can be expressed in units of response per unit area (activity per unit area).

In many other situations, this simple scenario does not occur. The worst case situation is that multiple unidentified radionuclides are involved in varying activity concentrations and on a variety of different

surfaces. These could include distributions of activity below the surface up to and beyond the maximum path length of any particulate ionizing radiations. In such a case, the immediate concern is to determine the extent of the spread, and the variation in levels of the contamination. Random sampling combined with spectrometry can provide some estimate of the radionuclide mix and relative activities. Combined with knowledge of the response characteristics of the surface contamination monitor, an estimate can then be made of the surface contamination.

The calibration of individual monitors for every potential scenario is impracticable. The practical alternative is to demonstrate that the monitor is fit for purpose so that users can rely on type test data and other published response data which provide sufficient information to determine the energy-response characteristics for alpha-, beta- and photon emissions. The approach to calibration of individual monitors is to confirm that they comply with type test data. This can be a very simple, rapid, robust and inexpensive exercise. It can be performed with a minimum of high quality reference sources, which do not need to be representative of the surfaces to be monitored in practice. The confirmation of compliance with type test data then allows response factors to be interpolated for all radionuclides based on the known decay data; this interpolation can either be carried out in-house or by third parties.

Calibration is described in detail in ISO 7503-3.

All monitors should be calibrated to standards that meet the legal requirements of the relevant country. All monitors should be recalibrated periodically, in line with national regulations, usually every 12 months, but in many countries, longer than 12 months.

Calibration should be done in calibration laboratories that provide traceability to national standards and meet the quality assurance requirements of ISO/IEC 17025.

The calibration status of the monitor shall not be expired.

New instruments should be thoroughly checked to ensure they meet the manufacturer's specifications. Occasionally, the manufacturer provides this service, but it may also be necessary for the user to have the instrument checked and calibrated by an independent qualified laboratory. This is sometimes known as Test Before First Use (TBFU).

The nature of the calibration programmes for surface contamination and dose monitors are determined by the nature of the contamination scenarios that are expected to be encountered.

7.3 Tests before first use (TBFU)

The **TBFU** should, as appropriate, provide information on the following characteristics of the instrument:

Surface contamination monitors

a) response to the type(s) and energy(s) of ionizing radiation appropriate to the intended use

b) linearity of response with emission rate over the likely range of use

c) relative sensitivity to different types of ionizing radiation

d) sensitivity to light

e) uniformity of response across the entrance window of the detector probe

f) the effects of any special environmental conditions deemed relevant

g) over range indication

h) background specification

i) detection limits

j) alarm threshold

Dose rate meters

k) response to the type(s) and energy(s) of ionizing radiation appropriate to the intended use

l) response to high dose rates

m) linearity of response with dose rate over the likely range of use

n) energy dependence

o) directional dependence

p) response to possible interfering ionizing radiations

q) the effects of any special environmental conditions deemed relevant

r) demonstration of correct operation when used in unusual circumstances, for example instruments used in unusual orientations, such as upside down

It is essential that the instrument is set up in accordance with the manufacturer's specifications and has a current calibration certificate.

7.4 Periodic calibration

Instruments should undergo a periodic calibration. The calibration interval is dependent on relevant national legislation, however, annually is generally accepted as a suitable period. If there is no legislative guidance, the recommended period is annually, and also, following any repair or adjustment which is likely to affect the detection characteristics. The periodic calibration should include checks a) to d) above and a thorough check on the condition of the instrument, for example, the battery state and any physical damage. Specific guidance on the calibration of monitors is given in Annex A (surface contamination monitors) and Annex C (dose meters).

7.5 Function check

It may also be necessary, depending on the way the instrument is used and the conditions of use, to do frequent function checks. Function checks are not calibrations but they give a reasonable degree of confidence that the instrument is still operating correctly and the calibration is still valid. A function check can be as simple as ensuring the instrument is giving the correct response to background or exposing it to a small radioactive source to confirm the reading is normal. Before the test of first use, it is important that the background, alarm threshold, alarm indication and rate meter constant is also checked.

8 Estimation of surface contamination monitor response and calibration factors

8.1 General

When response or calibration factors are not available for the particular combination of radionuclide(s) and surfaces that are being monitored, it is necessary to estimate the appropriate response and calibration factors. The fit for purpose calibration procedure described in Annex A provides characterization data which may be used to make these estimations. The standard method is to measure the calibration factor with traceable sources.

Monitors respond to the emissions which enter their detection volumes, they do not respond directly to activity. The same activity on two different surfaces, which have two different emissions, can produce two different responses from the monitors. The measured quantity is the response of the instrument to the emissions incident on the detector entrance window. In practice, surfaces emit ionizing radiations into 2π. The basic response factor is the response of the instrument either to (a) the emissions per unit area from the surface for a spread source, or (b) the emissions from a point source. In practice, the former is more useful.

The response factors may be expressed in any one of two forms which are linked to each other. The factors are:

$$I\left(E\right), \text{Instrument response}\left(\text{Emission}\right) = \frac{\rho_c - \rho_0}{\left(R_c \,/\, S_c\right)} \tag{1}$$

Units: $s^{-1}/(s^{-1}\,cm^{-2})$

where

ρ_c is the observed count rate from the calibration source, in s^{-1};

ρ_0 is the background count rate, in s^{-1};

R_c is the emission rate of the calibration source, in s^{-1};

S_c is the area of the calibration source, in cm^2.

$$I\left(A\right), \text{Instrument response}\left(\text{Activity}\right) = \frac{\rho_c - \rho_0}{\left(R_c \,/\, S_c\right) \times P} = \frac{\rho_c - \rho_0}{\left(A_c \,/\, S_c\right)} \tag{2}$$

Units: $s^{-1}/(Bq \cdot cm^{-2})$

where

A_c is the activity of the calibration source, in Bq;

P is the ratio of the particle or photon generation rate (activity) and the emission rate from the surface (see ISO 7503-3).

8.2 Relationship between surface emission rate and activity

If the instrument indicates "becquerels per square centimetre", a calibration factor has been stored in the instrument. Conversion of counts per second to becquerels per square centimetre can be complicated. A method to do this can be found in ISO 7503-3. This task requires a comprehensive knowledge of the decay schemes, instrument performance and an estimation of how the local conditions (e.g. surface construction) might affect the observed count rate. Measurements should be made using calibrated reference sources.

A calibration certificate records the instrument's response to a range of ISO 8769 reference sources at a specified distance. These are a set of specialist sources produced for the purpose of calibration. In the case of photon emitters modified by filters, these sources should not be considered as realistic sources of a particular radionuclide. These sources are designed to provide calibration laboratories with a consistent, reproducible method of determining a detector's response to a range of radiation types and energies.

The traceable quantity of a certified calibration source is the surface emission rate or the number of particles/photons emitted from the surface of the source per second.

a) **Instrument response I(E)**, in terms of emissions per unit area:

$$I\left(E\right) = \frac{\rho_c - \rho_0}{\left(R_c \,/\, S_c\right)} \tag{3}$$

where

ρ_c is the observed count rate from the calibration source, in s^{-1};

ρ_0 is the background count rate, in s^{-1};

R_c is the emission rate of the calibration source, in s^{-1};

S_c is the area of the calibration source, in cm^2.

e.g. ^{36}Cl response $= \dfrac{80\,cps}{25\,\beta\,s^{-1}\,cm^{-2}} = 3,2\,cps\,/\left(\beta\,s^{-1}cm^{-2}\right)$

This is the response to beta radiations of maximum energy 708 keV in terms of surface emission rate,

b) **Instrument efficiency** ε in terms of surface emission rate. This is usually expressed as a percentage:

If $S_c \geq S_p$, then

$$\varepsilon = \frac{\rho_c - \rho_0}{\left(R_c\,/\,S_c\right)\cdot S_p} \tag{4}$$

If $S_c < S_p$, then

$$\varepsilon = \frac{\rho_c - \rho_0}{R_c} \tag{5}$$

where

S_p is the effective detector window area (10 cm^2 in this example).

e.g. $^{57}Co\left(filtered\right)$ instrument efficiency $= \dfrac{60\,cps}{30\,\gamma\,s^{-1}\,cm^{-2}\,\times\,10\,cm^2} \times 100 = 20\,\%$

This is the efficiency to gamma radiations of mean energy 124 keV (not to the radionuclide ^{57}Co),

c) **Calibration factor** $C(E)$ in terms of surface emission rate [$C(E)$ is the reciprocal of $I(E)$]:

$$C\left(E\right) = \frac{\left(R_c\,/\,S_c\right)}{\rho_c - \rho_0} \tag{6}$$

e.g. $C\left(E\right)$ for $^{241}Am = \dfrac{25\,\alpha\,s^{-1}\,cm^{-2}}{125\,cps} = 0,2\,\alpha s^{-1}cm^{-2}\,/\,s^{-1}$

This is the calibration factor which is used to multiply the net instrument reading to obtain the number of alpha particles, of mean energy 5,5 MeV, detected,

d) **Instrument response** $I(A)$ in terms of activity:

The calibration laboratory may provide the instrument's response to the source activity in Bq. For the calibration sources involved, in a controlled environment, this is relatively easy to estimate:

$$I\left(A\right) = \frac{\rho_c - \rho_0}{\left(R_c\,/\,S_c\right)\cdot P} \tag{7}$$

e.g. ^{36}Cl response (for an ideal source of ^{36}Cl with no backscatter, P = 2)

$$= \frac{80\,\text{cps}}{25\beta\,\text{s}^{-1}\,\text{cm}^{-2}\cdot 2} = 1,6\,\text{cps} / \left(\text{Bq}\cdot\text{cm}^{-2}\right)$$

This is the response to beta radiations of maximum energy 708 keV in terms of activity.

9 Evaluation of measurement data

Where only one radionuclide is known to be responsible for the contamination and the nature of the contaminated surface is well-characterised, the radioactive contamination per unit area can be estimated from the monitor response as defined in Clause 8. For example, using the relevant activity calibration factor, equal to the reciprocal of the activity instrument response I(A), the activity per unit area is given by:

$$A_s = C(A)\cdot\left(\rho_g - \rho_0\right) = \frac{P}{\varepsilon \cdot S_p}\cdot\left(\rho_g - \rho_0\right)\left[\text{Bq}\cdot\text{cm}^{-2}\right] \tag{8}$$

where

$C(A)$ is the activity calibration factor, in $(\text{Bq}\cdot\text{cm}^{-2})/\text{s}^{-1}$;

ρ_g is the measured total (gross) count rate, in s^{-1};

ρ_0 is the background count rate, in s^{-1};

P is the ratio of the particle or photon generation rate (activity) and the emission rate from the surface (see ISO 7503-3);

ε is the instrument efficiency;

S_p is the effective detector window area, in cm^2.

These evaluations are further discussed in greater detail in ISO 7503-3, Annex C.

10 Uncertainties

10.1 General

Uncertainty analysis is an evolving subject area especially in the area of radiation monitoring. There have been subtle changes in approach over the years and the guidance given below is helpful, but there are many special cases where slightly different rules apply.

Every measurement has an uncertainty associated with it. Generally, the uncertainty in the instrument calibration factor is assessed by an accredited, specialist test house using well-defined sources and measurement facilities and the uncertainty on the calibration factors may be as small, but usually greater than as a few percent. However, the measurement or monitoring process is very much less well-defined and the associated uncertainties are usually at least one order of magnitude greater than the calibration factor uncertainty and may often be much larger. The uncertainty for a radiation survey or contamination survey result includes the uncertainty in the instrument calibration factor, and the uncertainty arising from the monitoring process and these need to be considered separately.

10.2 Assessment of uncertainty in the calibration factor

The assessment of uncertainty and characteristics should be determined in line with the guidance given in ISO 11929 and the GUM.

The assessment of uncertainty in the calibration factor is relatively easy to define.

Contamination monitor instruments include the uncertainty in the surface emission rate delivered to the instrument and the uncertainty in the instrument reading. Surface emission uncertainties may include, but not be limited to the following factors:

— the uncertainty in the surface emission rate from the calibration source usually obtained from the source calibration certificate;

— the uncertainty in the distance that the instrument under calibration is mounted from the source of radiation;

— the horizontal position of the detector relative to the source;

— the uncertainty in the instrument reading arising from the uncertainty in the counting statistics, scale precision and parallax;

— uncertainties in other detector parameters such as the deadtime, voltage and detector uniformity.

Other uncertainties are present, but these are generally insignificant.

Dose rate survey instruments include the uncertainty in the dose rate delivered to the instrument and the uncertainty in the instrument reading. Dose rate instruments are more widely dealt with in ISO 7503-3, but uncertainties may include, but not be limited to the following factors:

— the uncertainty in the calibration factor of the primary or secondary standard instrument used to measure the dose rate usually obtained from the standard instrument certificate;

— the uncertainty in the distance that the instrument under calibration is mounted from the source of radiation;

— the uniformity of the radiation beam across the face of the instrument under calibration;

— the variation in the background dose rate in the test facility;

— variations in environmental conditions;

— any scatter radiation component arising the structure of the test facility and support equipment;

— any directional dependence of the instrument under calibration;

— the uncertainty in the reading of the instrument under calibration.

10.3 Assessment of uncertainty in the measurement

A calibrated instrument has an uncertainty attached to its calibration factor usually obtainable from the calibration certificate (See 10.1). If the instrument is used to make a measurement in identical conditions to those in which it was calibrated then, in addition to the reading uncertainty, only the uncertainty in the calibration factor needs to be considered. However, this is rarely the case and in most instances, measurements are made in conditions vastly different to those in the test facility. This increases the uncertainty in the reading making it difficult to establish an accurate value for the measurement.

For dose rate monitors, most likely, the deviations from calibration conditions are the following:

— the energy of the incident radiation which is unlikely to be mono-energetic or of the same energy as the calibration energy;

— the amount of scattered radiation in the incident radiation;

— the angular distribution of the radiation field incident on the detector;

— the uniformity of the radiation field over the detector volume.

For contamination monitors, most likely, the deviations from calibration conditions are due to the following:

— the energy of the incident radiation which is unlikely to be mono-energetic or of the same energy as the calibration energy and may also be generated by a complicated nuclide mix;

— the condition of the contaminated surface. The type of surface, the amounts of dust, grease and grime covering or mixed in with the contaminant and the shape of the surface;

— the distance the detector or probe was held from the contaminated surface;

— the speed of monitoring, i.e. how fast the detector was moved over the surface being monitored;

— the distribution of contamination, i.e. whether the contaminant is distributed as random points or blobs, or is uniformly spread across the surface;

— the detector surface not being parallel to the surface being measured.

It is these confounding factors that occur in field measurements that make it very difficult to attach an overall uncertainty to any particular reading. For instance, detailed knowledge of the radiation field would be necessary to obtain a truly accurate reading using a dose rate monitor. At a bare minimum, the uncertainty in the instrument energy response, which is frequently ±20 % and sometimes greater, would need to be folded into the uncertainty budget.

In contamination monitoring, particularly alpha and low energy beta monitoring, the assessment of "emergence" factors and the energy of the emergent particulate is extremely difficult to assess and very large uncertainties would need to be applied to any field reading.

10.4 Wipe test uncertainties

The uncertainties in assessing the levels of contamination from wipe tests are great. Reference [1] gives a clear indication of the problems. The wipe efficiency, that is the percentage of contamination removed by a single wipe of the surface, is affected by many factors including, but not limited to the following:

— the type of wipe used;

— the pressure applied by the person when making the wipe;

— the area wiped;

— the contamination distribution;

— accuracy of the background measurement;

— the porosity, chemical composition, texture and cleanliness of the surface.

Reference [1] demonstrates wipe efficiencies can vary enormously and are almost impossible to assess accurately and the uncertainties in the wipe efficiency are an order of magnitude larger than other uncertainties in the measurement. Consequently, it has become common practice to allocate a value of 10 % to the wipe efficiency. This percentage of efficiency was taken as the most likely fraction removed in a single wipe.

11 Test report for a surface contamination instrument

Test report requirements are discussed in detail in ISO 7503-3. In all cases, they should be in compliance with the requirements of ISO/IEC 17025.

As calibration certificates 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 calibration:

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

b) date of calibration or test;

c) calibration certificate number;

d) type and serial number of probe if required. Many contamination monitors comprise a ratemeter and a detachable probe. The two are usually calibrated as one instrument. Hence, calibration labels should be attached to both probe and ratemeter and make reference to the other component.

If an instrument fails to meet the pass/fail criteria of any component of a test, the calibration or test laboratory should label the instrument as failed and make some indication of the nature of the failure on the certificate or test report. It is vital that the test report clearly categorises such an instrument as having failed.

Annex A
(informative)

Calibration of surface contamination instruments

A.1 General

The nature of the calibration programme for surface contamination monitors is determined by the nature of the contamination scenarios that are expected to be encountered. Usually, it is known that only one or two radionuclides are involved and the surfaces that could be contaminated are well characterized; accordingly, it is possible to use direct calibrations in terms of activity.

A.2 Direct calibrations

In certain circumstances, it may be more convenient to generate calibration sources from readily available solutions of known activity concentration. It is important that the activity value is traceable to a national standard. Known aliquots of this solution are then dispensed onto a representative sample of the surface and allowed to dry (care shall be taken to ensure that activity is not lost by volatilization during the drying process as may happen with some elements, such as mercury and iodine). It is advisable that a series of deposits are produced with varying areas. Typically, at least two such areas should be produced. One should have a minimum area (effectively representing a point source) and the other should seek to produce a uniform distribution over an area which is larger than the area of the detector probe entrance window. The detection efficiency for many detectors varies across the surface of the probe entrance window. The use of point and semi-infinite sources allows this variation to be characterized. The calibration factor determined by this method is the activity calibration factor, but this is only relevant for the radionuclide concerned on the defined surface.

A.3 Fit for purpose concept

The objective of the calibration is to confirm that the monitor complies with the performance determined during type testing and is still fit for purpose. These calibration factors may cover a range of individual radionuclides on a range of different surfaces and at different source-to-detector separations. The source-to-detector separation is defined as the distance between the contaminated surface and nearest point of the detector casing. The recommended minimum standard source-to-detector separation is 3 mm usually taken as the surface of the source to the front face of the detector. This confirmation of fitness-for-purpose also allows responses determined by other parties, under the same calibration conditions, to be applied.

The determination of calibration factors is not practicable for all radionuclides, on all surfaces and at all source-to-detector separations. The practical approach is to confirm the calibration factors for a limited range of radionuclides, at a source-to-detector separation of 3 mm using uniformly distributed sources on a surface which exhibits minimum attenuation of the emitted radiations. Ideally, the area of these sources should be larger than that of the probe. These sources should cover a range of energies which are likely to be encountered in normal monitoring situations. Typically, for alpha emissions, one radionuclide may be sufficient; for beta emissions, two radionuclides and; for photon emitters, three or four radionuclides. Provided the calibration process confirms fitness-for-purpose, this allows calibration factors to be interpolated with a reasonable degree of accuracy for all three emission types (alpha, beta, and photon).

Typically, the minimization of source attenuation effects is achieved by using sources which are produced by anodization on an aluminium surface (Other production techniques are acceptable provided that the attenuation is no greater than that produced by the anodization process). The minimum recommended

area of the calibration source is 10 cm × 10 cm and the source-to-detector separation is recommended to be 3 mm. Ideally, the source area should be larger than the probe area.

A typical set of calibration sources, as recommended in ISO 8769, might be:

Alpha: ^{241}Am, ^{238}Pu

Beta: ^{14}C and ^{36}Cl (^{90}Sr may be used as an alternative to ^{36}Cl, but it needs to be noted that a ^{90}Sr source emits betas from the ^{90}Y as well)

Photon: ^{55}Fe, ^{238}Pu, ^{129}I, ^{241}Am, ^{57}Co, ^{137}Cs and ^{60}Co (all filtered to remove alpha and beta emissions, except for ^{55}Fe)

These calibration sources should comply with the specifications in ISO 8769.

If the instruments suitability is confirmed, the calibration factor for any radionuclide can be calculated from a knowledge of the decay characteristics of the radionuclide. These calculations should be treated with caution and should be performed by those with acknowledged expertise in this process. Particular attention should be paid to take into account that radiations that are emitted simultaneously from the same disintegration of a radionuclide only produce one pulse in the monitor (See ISO 7503-3).

All the requirements would be tested by a calibration laboratory or the manufacturer of the instrument. The tests required for instruments suitability are summarized in Table A.1, Table A.2 and Table A.3.

Table A.1 — Requirements for alpha contamination monitors

TEST REQUIRED	COMMENTS	Pass/fail criteria	Tests before first use	Periodic tests
LIGHT LEAKAGE Expose the instrument to an appropriate light source and observe any change in response. Check the instrument response to a small α source, with and without the presence of the light source.	Usually necessary for scintillation and solid state detectors only.	Background count rate should not be elevated and the response to the α source should not be affected by the presence of the light.	Yes	Yes
RESPONSE TO α CONTAMINATION Mount the detector parallel to, and 3 mm above, a source of dimensions at least as large as the detector and determine its response.	—	Responses should agree to within ±30 % of manufacturer's specified performance	Yes	Yes
LINEARITY Determine the instrument's response to a series of α sources. Sources should be chosen to span the range of count rates that the instrument may be expected to measure. At least three point sources should be used, suitable emission rates may be 20, 200, and 2 000 α.s^{-1}. If an instrument could encounter high levels of activity, then it may be necessary to use an additional more active source.	A jig may be used to ensure source and detector positions are reproducible.	Each of the instrument responses should agree to within ±30 % of the mean of all three responses.	Yes	Yes
UNIFORMITY OF RESPONSE Use one of the point sources from the linearity tests to determine the instrument response for each 10 cm^2 area of the detector window. Calculate the mean response over the whole window.	Only instruments with detector areas in excess of 40 cm^2 need be tested.	No more than 25 % of the total detector area should have a response which is less than 35 % of the mean response for the whole detector.	Yes	No

Table A.1 *(continued)*

TEST REQUIRED	COMMENTS	Pass/fail criteria	Tests before first use	Periodic tests
BETA REJECTION Place the instrument 3 mm from a ^{36}Cl or a ^{90}Sr/^{90}Y source and determine its response.	—	Observed response to the β source should be less than 1 % of the instrument's response to an alpha source of similar emission rate.	Yes	Yes
BACKGROUND Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated.	Observed background count rate should be comparable with that stated by the manufacturers.	Yes	Yes

Table A.2 — Requirements for beta contamination monitors

TEST REQUIRED	COMMENTS	Pass/fail criteria	Tests before first use	Periodic tests
LIGHT LEAKAGE Expose the instrument to an appropriate light source, or bright sunlight.	Generally necessary for scintillation and solid state detectors, some end window GM counters and maybe some gas flow counters are also susceptible.	Background count rate should not be affected.	Yes	Yes
RESPONSE TO β CONTAMINATION Use a source with an energy at or below that of the minimum to be monitored in the workplace: ^{14}C is recommended for all wide energy range detectors. If a standard calibration is appropriate, determine the instrument response for the single measurement geometry. Source detector separations of at least 3 mm should be used in both cases.	—	Responses should agree to within ±30 % of manufacturer's specified performance	Yes	Yes
LINEARITY Determine the instrument's response to β sources of known emission rates. Sources should be chosen to span the range of count rates that the instrument may be expected to measure. At least three point sources should be used: suitable emission rates may be 20, 200 and 2 000 β s^{-1}.	A jig may be used to ensure source and detector positions are reproducible.	Each of the instrument responses should agree to within ±30 % of the mean of all three responses.	Yes	Yes
Alternatively, mount the instrument with its reference point at the point of test in the field of a ^{137}Cs source and determine the instrument's gamma dose rate response. Measurements are required for each range or decade of the instrument, up to the maximum dose rate it could encounter in the workplace. Ensure that secondary electron equilibrium exists.	^{60}Co may be used if convenient.	Agreement to within ±30 % of Type Test data.	Yes	Yes

Table A.2 (continued)

TEST REQUIRED	COMMENTS	Pass/fail criteria	Tests before first use	Periodic tests
UNIFORMITY OF RESPONSE Use one of the point sources from the linearity tests to determine the instrument response for each 10 cm² area of the detector window. Calculate the mean response over the whole window.	Only instruments with detector areas in excess of 40 cm² need be tested. The energy of the source used should be equal to or less than the minimum energy to be monitored in the workplace.	No more than 25 % of the total detector area should have a response which is less than 35 % of the mean response for the whole detector.	Yes	No
BACKGROUND COUNT RATE Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated. With no raised background it should be measured with a reasonable degree of accuracy. At least lower than 3 %	Observed background count rate should be comparable with that stated by the manufacturers.	Yes	Yes

Table A.3 — Requirements for photon contamination monitors

TEST REQUIRED	COMMENTS	Pass/fail criteria	Tests before first use	Periodic tests
LIGHT LEAKAGE Expose the instrument to an appropriate light source.	Necessary for scintillation and solid state detectors only.	Background count rate should not be affected.	Yes	Yes
RESPONSE TO PHOTON CONTAMINATION If a standard calibration is appropriate, determine the instrument response with a photon source and a detector separation of at least 3 mm.	—	Responses should agree to within ± 30 % of manufacturer's specified performance.	Yes	Yes
LINEARITY Mount the instrument in the calibration orientation with its reference point at the point of test in the radiation field of a ^{137}Cs source. Measure the instrument's response to the field for each range or decade of the instrument, up to the maximum dose rate it could reasonably encounter in the workplace. Ensure secondary electron equilibrium. If the detector responds reliably to beta radiation, it is acceptable to use a set of beta emitting sources.	^{60}Co may be used if convenient.	Agreement to within ±30 % of Type Test data.	Yes	Yes

Table A.3 *(continued)*

TEST REQUIRED	COMMENTS	Pass/fail criteria	Tests before first use	Periodic tests
UNIFORMITY OF RESPONSE Determine the instrument response for each 10 cm² area of the detector window when it is exposed to a suitable source (see comments). Calculate the mean response over the whole window.	For highly penetrating radiations, it is not easy to determine detector uniformity, as effectively masking the majority of the detector area from those radiations is difficult. A photon source of energy similar to the minimum used in the workplace should be used.	No more than 25 % of the total detector area should have an instrument response which is less than 35 % of the mean response for the whole detector.	Yes	No
BACKGROUND COUNT RATE Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated.	Observed background count rate should be comparable with that stated by the manufacturers.	Yes	Yes

Annex B
(informative)

Example of surface contamination estimation

B.1 General

NOTE   A more complex examination and discussion on the estimation of surface contamination that discusses decay schemes and typical emergence factors is given in ISO 7503-3.

If more than one radionuclide is involved, and the relative activities are unknown, then the estimation of activity for the individual components is a more complex issue. The first step is to identify the radionuclides involved. Often, the history of the facility is sufficient to determine these. In other circumstances, it may be necessary to use gamma spectrometry and radiochemical separation and analysis to identify the radionuclides present. Alternatively, there may be some situations where some simple processes may be applied using a portable contamination monitor, which can provide estimates with uncertainties which are acceptable for the particular investigation. Clearly, each situation needs to be assessed separately.

The example below describes a realistic scenario whereby some relatively simple measurements can be made which allow the determination of the activity of the individual radionuclides.

B.2 Method

The example uses a slightly unusual, but commercially available from a mainstream manufacturer, dual purpose probe which combines a thin aluminized Melinex window with a thin sheet of CsI scintillator. It is intended mainly for life sciences use, where both low energy betas, such as ^{14}C, and low energy X or gamma emitters, such as ^{99m}Tc, are in use. Note that this is very different from conventional beta scintillation probes, which are often incorrectly referred to as "beta/gamma" probes; the latter have a very low gamma detection efficiency.

The probe is supplied with a cover (absorber) that has a thickness of 1 mm plastic. A measurement is first made with no cover and the reading noted. This measures the emissions from both radionuclides. The measurement is then repeated with the cover in place and the reading noted again. The cover absorbs all of the beta particles from ^{14}C. For the ^{99m}Tc, a fraction of the (18 to 21) keV X-rays is absorbed and also, to a much lesser extent, the 140 keV gammas.

For this example, it is assumed that the overall effect of the absorber is to reduce the ^{99m}Tc emissions reaching the detector probe by an amount which equates to a 15 % reduction in the reading. This reduction could either be estimated theoretically or experimentally (the latter being preferred if facilities allow). Hence, we have the following:

— net count rate observed from open window (no cover)   2 000 s^{-1};

— net count rate observed with cover (i.e. due to ^{99m}Tc alone)   1 200 s^{-1}.

Instrument data from the manufacturer for this detector:

— $I(A)$ for ^{14}C (no cover) = 3,5 cps per Bq·cm^{-2};

— $I(A)$ for ^{99m}Tc (no cover) = 12 cycles per second per Bq·cm^{-2};

— $I(A)$ for ^{14}C (with cover) = 0 cps per Bq·cm^{-2};

— $I(A)$ for ^{99m}Tc (with cover) = 0,85 × 12 cps per Bq·cm^{-2} = 10,2 cps per Bq·cm^{-2}.