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Evaluation of surface contamination —

Part 3:
Isomeric transition and electron capture emitters, low energy beta-emitters ($E_{\beta\text{max}} < 0{,}15$ MeV)

Évaluation de la contamination de surface —
Partie 3: Émetteurs à transition isomérique et capture électronique, émetteurs bêta basse énergie ($E_{\beta\text{max}} < 0{,}15$ MeV)

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Contents

Page

Annexes

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 7503-3 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

ISO 7503 consists of the following parts, under the general title *Evaluation of surface contamination*:

— *Part 1: Beta-emitters (maximum beta energy greater than 0,15 MeV) and alpha-emitters*

— *Part 2: Tritium surface contamination*

— *Part 3: Isomeric transition and electron capture emitters, low energy beta-emitters* ($E_{\beta\max} < 0{,}15$ MeV)

Annexes A to D form an integral part of this part of ISO 7503. Annexes E and F are for information only.

Introduction

This part of ISO 7503 provides recommendations for surface contamination measurements for two groups of radionuclides.

a) Radionuclides which can only be detected and measured with the aid of the following emissions:

- gamma radiation and X-rays from isomeric transitions and electron capture processes,
- electrons from internal conversion processes and Auger-electrons,
- Low-energy beta radiation ($E_{\beta\text{max}} < 0{,}15$ MeV) from classical beta decay.

b) Beta-emitters which do not emit one electron per decay.

Widespread application and involvement of such radionuclides in nuclear medicine, industrial processes and research, under conditions which do not allow full control of the radionuclide spread, have led to the necessity to view critically surface contamination problems in connection with unconfined use. Health and sanitation problems may occur due to the fact that the possible existence and/or extent of surface contamination remains undetected because measurements are made with an instrument not suited to the purpose. Such problems may arise due to the low energy and complexity of the characteristic emissions of the nuclides.

The wide range of particle types and energies makes it necessary to select an instrument appropriate to the radionuclide, if satisfactory health and safety information is to be obtained. It is the purpose of this document to provide the necessary information for the selection of measurement and calibration methods.

Evaluation of surface contamination —

Part 3:
Isomeric transition and electron capture emitters, low energy beta-emitters ($E\beta_{max} < 0{,}15$ MeV)

1 Scope

This part of ISO 7503 applies to the evaluation of contamination on surfaces of facilities and equipment, containers of radioactive materials and sealed sources in terms of activity per unit area. It does not apply to the evaluation of contamination of skin or clothing.

It is restricted to the direct measurement by portable probes and to the indirect measurement of the radionuclides mentioned in the Introduction and listed in table A.1 of annex A.

For each radionuclide, the energy spectrum as well as the intensity of each type of emitted particle or photon is unique. This type of information can be found in the bibliographic references given in annex F.

For the purpose of this part of ISO 7503, the term "beta energy" refers to the maximum energy of particles from classical beta decay.

NOTE — Evaluation of surface contamination by beta-emitters (beta energy greater than 0,15 MeV) and alpha-emitters is dealt with in ISO 7503-1. Evaluation of tritium surface contamination is dealt with in ISO 7503-2.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 7503. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 7503 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7503-1:1988, *Evaluation of surface contamination — Part 1: Beta-emitters (maximum beta energy greater than 0,15 MeV) and alpha-emitters.*

ISO 8769-2:—[1], *Reference sources for the calibration of surface contamination monitors — Part 2: Electrons of energy less than 0,15 MeV and photons.*

IEC 248:1984, *Dimensions of planchets used in nuclear electronic instruments.*

IEC 325:1981, *Alpha, beta and alpha-beta contamination meters and monitors.*

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[1] To be published.

3 Definitions

For the purposes of this part of ISO 7503, the following definitions apply.

3.1 decay efficiency of a radionuclide, ε_d: Ratio of the number of photons or electrons of a given energy created per unit time by a given radionuclide to the number of decays of this radionuclide per unit time.

3.2 efficiency of a source, ε_s: Ratio of the surface emission rate of a source to the respective production rate in the source.

NOTE — The term "source" includes any structural material in which the activity is dispersed or that may be covering the front surface of the active layer.

3.3 production rate: Number of electrons produced by the decay process(es) in the source, or the number of photons of given energy(ies) produced by decay in the source, per unit time.

3.4 surface emission rate: Number of electrons above a certain energy, or number of photons whose origin is as described for production rate, emerging from the surface of the source per unit time.

3.5 instrument efficiency, ε_i: Ratio of the instrument net reading to the surface emission rate of a source for photons or electrons of a given energy under given geometric conditions.

For a given instrument, the instrument efficiency depends on the energy of the radiations emitted by the source. The instrument efficiency is also influenced by absorbers (including air where appropriate) between source and detector.

4 Measurement techniques

4.1 General

For the measurement of radionuclides listed in table A.1 of annex A, various measurement techniques exist. Where direct measurement is not suitable, indirect methods shall be used.

Basic requirements and guidelines for direct and indirect measurements, including the use of smears for sampling, are dealt with in ISO 7503-1.

The detector types listed in table 1 are also suitable for indirect measurements if they are adequately equipped (see annex D).

4.2 Direct measurements

4.2.1 General

Direct measurements are used for the following purposes:

a) to evaluate the total amount of contamination on a surface (fixed and movable);

b) to determine whether a subsequent indirect measurement is necessary;

c) when indirect measurements are unsuitable due to long delays and possible loss of activity between sampling and measurement.

Detector size should be chosen in relation to the contaminated area, in order to complete the survey in a reasonable time. For practical purposes a detector with a minimum area of 100 cm^2 is recommended, though smaller detectors may be necessary in circumstances of restricted geometry and can also be useful in locating active spots. The surface area on which a detector receives photons is dependent on the distance from the surface contaminated and the emission energies of the radionuclides. This is of special importance for the quality of the measurement results, when the detector is not in contact with the surface or the detector is equipped with a collimator.

4.2.2 Instruments for direct measurement

Information on the application of different detector types is presented in table 1. The properties of these detectors are described in annex C.

4.3 Indirect measurements

4.3.1 General

For indirect measurements, i.e. the measurement of the amount of activity of a sample removed from the contaminated surface, a stationary well-shielded instrument offers great advantages. Such instruments can normally be operated for long counting times. Also, in some situations the background contribution may be reduced by the use of pulse-height discrimination. The user can, therefore, compensate for low instrument efficiencies by the use of long counting periods at a low background level.

However, the indirect method is restricted to the measurement of removable activity, and has a low accuracy due to uncertainties of the sampling efficiency and possible losses of activity between obtaining the smear sample and the subsequent measurement.

Indirect measurements are used for one or more of the following purposes:

a) to evaluate the amount of removable contamination on a surface;

b) to evaluate radionuclides that are difficult to measure by direct measurement due to their radiation characteristics;

c) to obtain information about the radionuclides present and the composition of mixtures;

d) to measure contamination of a surface when the surface shape does not allow direct measurement;

e) to measure contamination of surfaces which are located in radiation fields which interfere with direct measurement;

f) to detect contamination on surfaces which have overlying material that reduces the intensity of radiation available for direct measurement (wiping can remove a layer of dirt of substantial thickness; as a result, activity covered by or distributed in this layer may become better exposed on the surface of the wiped sample).

4.3.2 Instruments for indirect measurement

Information on the application of different detector types is presented in table 2. The properties of these detectors are described in annex D.

5 Suitability of various types of measuring instruments

Tables 1 and 2 indicate the suitability of different instruments for the detection of some important radionuclides included in this part of ISO 7503.

In table 1 the instruments are divided into different classes on the basis of the time t_n necessary to detect a contamination of 3,7 Bq·cm^{-2} (averaged over an area of no more than 200 cm^2) as follows:

Necessary detection time

$0 < t_n \leqslant 20$ s	Adequate
$20 \text{ s} < t_n \leqslant 60$ s	Poor
$t_n > 60$ s	Not recommended

Instruments which cannot detect a radionuclide even with counting times of 1 000 s are represented by a barred code number followed by the sign §.

Table 1 — Types of hand-held surface-contamination measuring instruments and their suitability for the direct detection of important low-energy emitters at 3,7 Bq·cm^{-2} (background measuring time: 1 000 s)

Type of instrument	Code
Windowless argon-methane gas flow proportional detector	1
Butane-propane gas-filled, large-area proportional detector	2
Argon-methane gas flow, large-area proportional detector	3
Xenon-filled large-area proportional detector	4
Windowless plastic scintillation detector	5
Organic crystal/plastic scintillation detector	6
NaI thin-layer scintillation detector	7
Geiger-Müller detector, large area type (window Ø 46 mm)	8

Instrument characterization in terms of detection ability

Radionuclide	Instrument Adequate	Poor	Not recommended
^{7}Be		**7***	**1**§ **2**§ **3**§ **4**§ 5 6 **7**§ **8**§
^{51}Cr	**1** **3** **4** 5 **7***	**2** **8**	6 **7**
^{54}Mn	**1** **2** **3** **4** 5 **7** **8**		6
^{55}Fe	**1** **3** **4** 5 **7***		**2** 6 **7**§ 8
^{57}Co	**1** **2** **3** **4** 5 **7** **8**		6
^{63}Ni	**1** **2** **3** 5	2	**4** 6 **7**§ **8**
^{65}Zn	**1** 2 **3** **4** **7*** **8**	7	
^{67}Ga	**1** **2** **3** **4** 5 **7**	6 **8**	
^{73}As	**1** **2** **3** **4** 5 **7** **8**		6
^{75}Se	**1** **2** **3** **4** 5 **7** **8**		6
^{85}Sr	**1** **2** **3** **4** 5 **7** **8**		6
^{88}Y	**1** **2** **3** **4** 5 **7** **8**		6
^{99m}Tc	**4** 5 **7**	**1** **2** **3** 6	**8**
^{111}In	**1** **2** **3** **4** 5 6 **7** **8**		
^{113}Sn/^{113m}In	**1** **2** **3** **4** 5 6 **7***	7 8	
^{123}I	**1** **2** **3** **4** 5 6 **7**	**8**	
^{125}I	**1** **2** **3** **4** 5 **7**	**8**	6
^{133}Ba	**1** **2** **3** **4** 5 **7** **8**		6
^{139}Ce	**1** **3** **4** **7**	**2** **8**	
^{191}Os	**1** **2** **3** **4** **7**	**8**	
^{195}Au	**1** **2** **3** **4** 5 7	**8**	6
^{197}Hg	**1** **2** **3** **4** 5 7	6 **8**	
^{199}Au	**1** **3** **4** 7	**2**	**8**
^{201}Tl	1 **2** **3** **4** 5 7	6 **8**	
^{203}Hg	**3** **4** 7	**2**	**8**
^{207}Bi	**1** **2** **3** **4** 5 6 7 8		
^{210}Pb	**1** **2** **3** **4** 5 7 8		6

NOTES

1 The code numbers for instrument types are listed in numerical order. Numbers in bold typeface denote CHAOSCAL calibrations (underlined) or experimental evidence as basis for instrument characterization data.

2 The asterisk (*) indicates large-area detector is necessary (window of more than 100 cm^{2} area).

3 The sign § indicates detector cannot detect the radionuclide in less than 1 000 s.

Table 2 — Types of instruments for indirect measurements under laboratory conditions and their suitability for the detection of important low-energy emitters at 3,7 Bq·cm^{-2}, (averaged over 100 cm^2)

Type of instrument	**Code**
Installed gas-flow large-area proportional counters[1] with thin window	A
Installed gas-flow large-area proportional counters[1] with sample inside detector	B
Liquid scintillation counters	C
Thick crystal NaI (Tl)-scintillational counters	D
Semiconductor spectrometers	E
Installed Geiger-Müller counters	F

Instrument characterization in terms of detection ability

Radionuclide		**Instrument**	
	Adequate	**Poor**	**Not recommended**
^{7}Be	D E	C	A B F
^{51}Cr	C D E		A B F
^{54}Mn	C D E	F	A B
^{55}Fe	B C E	A	D F
^{57}Co	B C D E	A F	
^{63}Ni	B C E	A	D F
^{65}Zn	A B C D E	F	
^{67}Ga	A B C D E	F	
^{73}As	B C D E	F	A
^{75}Se	B C D E F	A	
^{85}Sr	B C D E F	A	
^{88}Y	B C D E F	A	
^{99m}Tc	C D E		A B F
^{111}In	A B C D E	F	
^{113}Sn/^{113m}In	A B C D E	F	
^{123}I	A B C D E		F
^{125}I	A B C D E		F
^{133}Ba	A B C D E F		
^{139}Ce	B C D E		F
^{191}Os	B C D E		F
^{195}Au	A B C D E		F
^{197}Hg	A B C D E	F	
^{199}Au	A B C D E	F	
^{201}Tl	A B C D E		F
^{207}Bi	A B C D E F		
^{210}Pb	A B C D E F		

NOTES

1 The code letters for instrument types are listed in alphabetical order.

2 Hand-held instruments can also be used for indirect measurements. Guidelines and restrictions for this purpose are given in table 1 and annex D.

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[1] For optimal detection of low-energy photons, the use of an argon-based gas mixture is necessary.

The combinations of instruments and radionuclides described as "adequate" are the recommended combinations. The combinations described as "poor" should be used only after thorough evaluation since it may not be possible to meet requirements of national regulations. The combinations described as "not recommended" should not be used unless careful calibration with that combination has shown that it is possible to detect the radionuclide according to relevant national regulations.

The information compiled in tables 1 and 2 is based on an uncertainty level as allowed by IEC 325, on instrument efficiency data obtained by measurements or CHAOSCAL calibrations (see 6.2), on plausible theoretical estimates and comparisons of radionuclides using their decay data.

The tables were compiled assuming that a given type of instrument is used under the most favourable conditions, i.e. covered with a window material of minimum available thickness, positioned as close as practicable to the surface examined and handled under background radiation conditions as stated in the manufacturer's specifications.

In the case of thin-layer NaI-scintillation detectors, a distinction is made between the normal small-area type (8 cm^2) and the less common large-area type (more than 100 cm^2).

The listing of instrument types in the lower part of the tables is in numerical order of code and not in order of preference.

Instruments which primarily measure electrons are not suitable for calibration or measurements with an absorber between the source and the detector. Use of an absorber is part of a recommended calibration techniques for many radionuclides in this part of ISO 7503 (MSA-, SSA-methods: see 6.2/6.3, table A.1, annex A). When the code numbers in table 1 are based on CHAOSCAL calibrations without absorber, the response of the instruments to electrons was not taken into account. Therefore, the actual total response to photons plus electrons may be somewhat higher than that used as basis for the classification.

6 Calibration

6.1 General

The principal considerations concerned with calibration and reference sources are covered in ISO 7503-1 and ISO 8769-2, respectively.

However, since the types of radiation and the energy distributions of the radionuclides considered in this part of ISO 7503 are quite different to those relating to pure higher-energy beta-emitters, the actual calibration methods cannot be the same. The diversity of the emission characteristics of the radionuclides under consideration makes it necessary to determine specific calibration factors for each of these radionuclides. This can be done in two principal ways:

a) The instrument efficiency is measured versus radiation energy using sources emitting monoenergetic radiation. Instrument efficiency values for the radionuclides under consideration are then calculated individually, using the energy and emission probability data relating to the monoenergetic components of the radiation.

   Most of the radionuclides under consideration emit monoenergetic photons and electrons, both of which may contribute to the response of a measuring instrument. A full calibration for both types of radiation would, therefore, need separate measurements of the instrument efficiency as a function of energy for both photons and electrons.

   For detectors that are capable of responding to the low-energy electron radiation that is emitted by the radionuclides under consideration, the response of the instrument will be very dependent upon the construction of the calibration and contamination sources. Also, the response of the instrument can be very dependent on the geometric conditions of the measurement (e.g. air-path attenuation). Therefore, in order to minimize errors and provide consistency of measurement, it is recommended that the assessment of surface contamination be generally made from the measurement of photon emissions. In addition, since sources for monoenergetic electrons in the energy range under consideration are not available, the calibration has to be restricted to the photon emissions.

b) For each of the radionuclides to be measured, a specific calibration source made from the same radionuclide is used.

For some of the radionuclides with sufficiently long half-lives (e.g. ^{55}Fe and ^{63}Ni), large-area calibration sources are commercially available. In the case of radionuclides with shorter half-lives, a rough calibration of measuring instruments can be done using working sources produced periodically from calibrated radionuclide solutions.

6.2 Multisource calibration with respect to photon emissions

This method is based on the measurement of photon emissions of a group of pseudo monoenergetic calibration sources with the help of the detector to be calibrated. The calibration sources are defined in ISO 8769-2 and cover a photon energy range from 5,9 keV to 1 250 keV. They are designed to filter out other interfering surface emissions of electrons, alpha particles and lower-energy photons by the radionuclide. For measurements of the calibration source, no additional absorber is used between source and detector.

In applying the method, it is assumed that electron emissions from the actual contamination sources do not contribute to the response of the measuring instrument. This can be ensured by using detectors not sensitive to electrons in the energy range being considered. The detector can either be insensitive to electrons by virtue of its construction (sensitive window of sufficient thickness) or it can be made insensitive by covering the sensitive window with a filter foil of sufficient thickness.

For radionuclides emitting both detectable electrons and photons, the calibration shall take into account that, in order to filter the electrons, the measurements on actual contamination sources are done with a 46 mg·cm^{-2} (0,5 mm thick) polyethylene (PE) absorber foil in front of the sensitive window of the detector. (This thickness was considered to be sufficient for electron absorption up to 200 keV energy without serious attenuation of the photons to be measured.) This mean that calculated factors have to be applied to correct for the attenuation effects of the 46 mg·cm^{-2} absorber foil.

The measurements of the calibration sources as well as necessary background measurements shall be done with such counting times (pulse counting) or time constants (ratemeters) that a relative standard deviation of the corrected count rate of not greater than 5 % is obtained.

Evaluation of the measured data can be done by help of the computer program CHAOSCAL[2] developed for the application of this part of ISO 7503. Principally, the use of this part of ISO 7503 is not tied to the use of this software. However, the program CHAOSCAL facilitates a substantial range of calculations which otherwise would require a prohibitive effort. The program is described in annex E, which also gives an example printout of calibration results.

In the case of nonideal contamination sources, the source efficiency, the instrument efficiency and the decay efficiency are different for each of the m photon energies, and the activity per unit area, A_s, has to be calculated using the following equation:

$$A_s = \frac{n - n_b}{W \sum_{j=1}^{m} \left(\varepsilon_i^j \varepsilon_d^j \varepsilon_s^j \right)} \qquad \text{. . . (1)}$$

where

n is the measured count rate, in counts per second;

n_b is the background count rate, in counts per second;

W is the area of the source seen by the sensitive window of the detector, in square centimetres.

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[2] Available as public domain program. Information on this program can be obtained from the Secretariat of ISO/TC 85 Subcommittee 2.

For an ideal contamination source (no self-absorption, no backscattering) the source efficiency for each of the m discrete photon energies is $\varepsilon_{\mathrm{s}}^{j} = 0{,}5$ and only the instrument efficiencies $\varepsilon_{\mathrm{i}}^{j}$ and the decay efficiencies $\varepsilon_{\mathrm{d}}^{j}$ remain as variables.

The equation for the calculation of the activity per unit area, A_{s}, would then be:

$$A_{\mathrm{s}} = \frac{n - n_{\mathrm{b}}}{W \times 0{,}5 \sum_{j=1}^{m} \left(\varepsilon_{\mathrm{i}}^{j} \varepsilon_{\mathrm{d}}^{j}\right)} \qquad \ldots (2)$$

If the detector is calibrated and used at a distance from the source greater than the smallest practicable distance, the calibration distance and the area from which the sensitive window of the detector receives photons shall be specified by the manufacturer or be derived by the calibrator.

For both ideal and nonideal sources, the measurement of a single radionuclide by an instrument cannot be characterized by two independent values of ε_{i} and ε_{s} as can be done for pure beta-emitters of the "one electron per decay-type" (see ISO 7503-1:1988 4.2.3.2). Instead, the simple calibration factor $1/W\varepsilon_{\mathrm{i}}\varepsilon_{\mathrm{s}}$ is replaced by the more complex calibration factors:

$$C_{\mathrm{ni}} = \frac{1}{W \sum_{j=1}^{m} \left(\varepsilon_{\mathrm{i}}^{j} \varepsilon_{\mathrm{d}}^{j} \varepsilon_{\mathrm{s}}^{j}\right)} \qquad \ldots (3)$$

or

$$C_{\mathrm{i}} = \frac{1}{W \times 0{,}5 \sum_{j=1}^{m} \left(\varepsilon_{\mathrm{i}}^{j} \varepsilon_{\mathrm{d}}^{j}\right)} \qquad \ldots (4)$$

where

C_{ni} is the calibration factor for nonideal contamination sources;

C_{i} is the calibration factor for ideal contamination sources.

In the case of nonideal contamination sources this calibration factor depends on the thickness of absorbing material, including the source and the distribution of the activity in this material.

6.3 Single-source calibration

The method of direct calibration of an instrument with respect to a specific radionuclide using a working or calibration source made from the same radionuclide can be applied to all radionuclides for which either calibration sources or calibrated solutions that allow the production of sufficiently stable working sources are available.

In principle, all types of radiation emitted can be utilized for such a calibration and the measurements based on it.

However, for nuclides with both photon and electron emissions, a 46 mg·cm^{-2} PE absorber foil in front of the detector shall be used for filtering out electrons, provided that the photon transmission remains acceptable. This will help to reduce errors caused by differences between the calibration and actual measurement conditions (backscatter, self-absorption, geometry).

In cases where filtering out electrons cannot be achieved by the 46 mg·cm^{-2} PE absorber, it is recommended that working sources for single-source calibration be prepared so as to provide the same source efficiency as the contamination source. This is also valid for ^{63}Ni.

The single-source calibration factor is defined as:

$$C_{\text{ss}} = \frac{A_{\text{cs}}}{n - n_{\text{b}}} \qquad \text{. . . (5)}$$

where A_{cs} is the activity of the working or calibration source seen by the sensitive window of the detector.

7 Evaluation of measurements

7.1 Evaluation based on multisource calibration data

The activity per unit area, A_{s}, is calculated by use of equation (6):

$$A_{\text{s}} = C(n - n_{\text{b}}) \qquad \text{. . . (6)}$$

where C is the calibration factor according to equation (3) or (4).

For the selection of the relevant value of C from the CHAOSCAL printout, see annex E.

7.2 Evaluation based on single-source calibration data

The activity per unit area, A_{s}, is calculated using equation (7):

$$A_{\text{s}} = \frac{C_{\text{corr}} C_{\text{ss}} (n - n_{\text{b}})}{W} \qquad \text{. . . (7)}$$

where

C_{ss} is the single-source calibration factor according to equation (5);

C_{corr} is the factor correcting for the difference in efficiencies of the calibration and the contamination sources;

W is the area of the source seen by the sensitive window of the detector, in square centimetres.

If the detector is calibrated and used at a distance from the source greater than the smallest practicable distance, the calibration distance and the area from which the sensitive window of the detector receives electrons and/or photons shall be specified by the manufacturer or be derived by the calibrator.

Where the calibration and the contamination sources have approximately the same source efficiency C_{corr} has the value 1.

If instruments are calibrated using near-ideal working or calibration sources with high source efficiency and are then used for the measurement of contamination sources with low source efficiency, the surface activity will be underestimated.

When the contamination source is thicker than the calibration source or if it is covered by absorbing material and thus has a reduced source efficiency, calculated values of C_{corr} (see table 3) can be applied **if electron emissions from the source do not contribute to the count rate.**

The appropriate value of C_{corr} is selected from

- column 2 of table 3, if no PE absorber foil was used in front of the detector;
- column 3 of table 3, if a 46 $\text{mg} \cdot \text{cm}^{-2}$ PE absorber foil was used in front of the detector.

The C_{corr} values from table 3 shall always be used if the measurement of low-energy photons (energy < 10 keV) is essential for adequate detector performance and reliable data on source efficiencies is not available.

7.3 Evaluation for beta-emitters that do not emit one electron per decay[3)]

Instrument calibrations and measurements shall be performed as described in ISO 7503-1 for normal beta-emitters.

The activity per unit area, A_s, is calculated by use of equation (8):

$$A_s = \frac{n - n_b}{W \varepsilon_d^e \varepsilon_s \varepsilon_i} \qquad \ldots (8)$$

where ε_d^e is the number of monoenergetic electrons above 20 keV energy plus beta-particles emitted per decay (see table A.1).

In the absence of more precisely known values, the following values for ε_s should be used:

$\varepsilon_s = 0,5$ (if $E_{\beta\max} \geqslant 0,4$ MeV)

$\varepsilon_s = 0,25$ (if $0,15$ MeV $< E_{\beta\max} < 0,4$ MeV)

Table 3 — Correction factors C_{corr}, for source/absorber combinations and some important radionuclides

Radionuclide	Correction factor, C_{corr} No absorber foil in front of the detector	46 mg·cm^{-2} PE absorber foil in front of the detector
^{7}Be	1,00	1,00
^{51}Cr	1,28	1,12
^{54}Mn	1,22	1,10
^{55}Fe	1,18	1,08
^{57}Co	1,11	1,05
^{58}Co	1,15	1,07
^{67}Ga	1,07	1,03
^{73}As	1,05	1,03
^{75}Se	1,04	1,02
^{85}Sr	1,03	1,01
^{88}Y	1,02	1,01
^{99m}Tc	1,01	1,01
^{111}In	1,01	1,01
^{113}Sn/^{113m}In	1,01	1,01
^{123}I	1,01	1,01
^{125}I	1,01	1,01
^{133}Ba	1,01	1,01
^{139}Ce	1,02	1,01
^{195}Au	1,04	1,02
^{197}Hg	1,04	1,02
^{201}Tl	1,04	1,02
^{207}Bi	1,03	1,02
^{210}Pb	1,04	1,02
Calibration source: ideal Contamination: a source of 10 mg·cm^{-2} thickness, homogeneous depth distribution of the activity		

[3)] See also B.4 and paragraph b) in the Introduction.

Annex A
(normative)

Radionuclides appropriate to the evaluation methods given in this part of ISO 7503

The radionuclides to which the evaluation methods specified in this part of ISO 7503 apply are given in table A.1.

Table A.1 — Radionuclides

Nuclide	Half-life	Important emission types					Emissions and calibration methods used	$E_{\beta\,\max}$ keV	$\varepsilon_{\mathrm{d}}^{\mathrm{e}}$
		β^+	β^-	leph	heph	mee			
^{7}Be	53 d				X		CALI/heph		
^{22}Na	2,6 a	X			X		P1/β, CALIh	546	0,90
^{26}Al	$7,2 \times 10^{5}$ a	X			X		P1/β, CALIh	1 174	0,82
^{40}K	$1,3 \times 10^{9}$ a		X		X		P1/β	1 312	0,89
^{45}Ti	3,1 h	X					P1/β	1 041	0,85
^{44}Ti/^{44}Sc	47,3 a	X		X	X		P1/β	1 476	0,53
^{49}V	330 d			X			MSNA		
^{51}Cr	28 d			X	X		MSNA/SSNA CALIh		
^{52}Mn	5,6 d	X		X	X		P1/β, CALIh	575	0,29
^{53}Mn	$3,7 \times 10^{6}$ a			X			MSNA		
^{54}Mn	313 d			X	X		MSNA/SSNA CALIh		
^{55}Fe	2,7 a			X			MSNA		
^{56}Co	79 d	X			X		P1/β, CALIh	1 460	0,20
^{56}Ni	6,1 d			X	X		CALIh		
^{57}Co	271 d			X			MSA		
^{58}Co	71 d	X		X	X		P1/β, CALIh	475	0,15
^{59}Ni	$7,5 \times 10^{4}$ a			X			MSNA		
^{61}Cu	3,4 h	X			X		P1/β, CALIh	1 216	0,62
^{62}Zn/^{62}Cu	9,26 h	X		X	X	X	P1/β mee	2 927	0,62
^{63}Ni	100 a		X				SSNA, CALIβ	66	1,00
^{64}Cu	12,7 h	X	X	X			P1/β	653	0,55
^{65}Zn	244 d			X	X		MSA		
^{66}Ga	9,4 h	X			X		P1/β, CALIh	4 153	0,55
^{67}Ga	3,3 d			X	X	X	MSA/SSA		
^{68}Ge/^{68}Ga	288 d	X		X			P1/β	1 899	0,44
^{69m}Zn/^{69}Zn	13,8 h		X		X		P1/β, CALIh	321	0,50
^{71}Ge	11,8d			X			MSA		
^{72}As	26,0 h	X			X		P1/β	3 329	0,89
^{73}As	80,3 d			X		X	MSA		
^{73}Se	7,15 h	X		X	X	X	P1/β, CALIh	1 651	0,89
^{74}As	17,8 d	X	X		X		P1/β, CALIh	1 553	0,64

Nuclide	Half-life	Important emission types					Emissions and calibration methods used	$E_{\beta\,\max}$ keV	ε_d^e
		β^+	β^-	leph	heph	mee			
^{75}Se	120 d			X	X		MSA		
^{77}Br	57,0 h			X	X		MSA, CALIh		
^{80m}Br/^{80}Br	4,42 h		X	X		X	P1/βmee	2 006	1,26
^{81}Rb	4,58 h	X		X	X	X	P1/βmee CALIh	1 050	0,65
^{82}Sr/^{82}Rb	25,0 d	X		X			P1/β	3 356	0,48
^{84}Rb	32,9 d	X	X	X	X		P1/β	1 658	0,31
^{85}Sr	64,8 d			X	X		MSA, CALIh		
^{86}Y	14,7 h	X		X	X		P1/β	3 174	0,33
^{87}Y/^{87m}Sr	80,3 h			X	X	X	MSA, CALIh		
^{88}Y	107 d			X	X		MSA, CALIh		
^{89}Zr	78,4 h	X		X	X		P1/β, CALIh	905	0,23
^{90}Nb	14,6 h	X		X	X	X	P1/β mee CALIh	1 500	0,87
^{91m}Nb	61 d			X		X	MSA		
^{91}Nb	1×10^4 a			X			MSA		
^{92m}Nb	10,2 d			X	X		MSA, CALIh		
^{92}Nb	$3{,}6 \times 10^7$ a			X	X		MSA, CALIh		
^{93}Nb	14,6 a			X		X	MSA		
^{95m}Tc	61 d			X	X		MSA, CALIh		
^{95}Tc	20,0 h			X	X		MSA, CALIh		
^{96}Tc	4,28 d			X	X		MSA, CALIh		
^{97}Tc	$2{,}6 \times 10^6$ a			X			MSA		
^{97m}Tc	89 d			X		X	MSA		
^{97}Ru	2,9 d			X	X		MSA, CALIh		
^{99m}Tc	6,02 h			X	X	X	MSA, CALIh		
^{103}Pd/^{103m}Rh	17 d			X		X	MSA		
^{106}Ag	8,46 d			X	X		MSA, CALIh		
^{108m}Ag/^{108}Ag	127 a		X	X	X		MSA, CALIh		
^{109}Cd/^{109m}Ag	464 d			X		X	MSA		
^{111}In	2,83 d			X	X	X	MSA, CALIh		
^{113}Sn/^{113m}In	115 d			X	X	X	MSA, CALIh		
^{114m}In/^{114}In	49,5 d		X	X	X	X	P1/β mee	1 985	0,90
^{115m}In	4,36 h			X	X	X	CALIh		
^{117m}Sn	13,6 d			X	X	X	MSA, CALIh		
^{117}Sb	2,80 h			X	X	X	MSA, CALIh		
^{119m}Sn	293 d			X		X	MSA		
^{121m}Te/^{121}Te	154 d			X	X	X	MSA, CALIh		
^{123m}Te	120 d			X	X	X	MSA, CALIh		
^{123}I	13,1 h			X	X	X	MSA, CALIh		
^{124}I	4,18 d	X		X	X	X	P1/β mee	2 135	0,32
^{125m}Te	58 d			X		X	MSA		
^{125}I	60,1 d			X		X	MSA		
^{126}I	12,9 d		X	X	X		P1/β	1 251	0,40
^{126}Sn/^{126m}Sb	1×10^5 a		X	X	X	X	P1/β mee	1 810	1,30
^{127m}Te/^{127}Te	109 d		X	X		X	P1/β	694	1,02
^{129}Te	1,16 h		X			X	P1/β mee	1 470	1,82

Nuclide	Half-life	Important emission types					Emissions and calibration methods used	$E_{\beta\,\max}$ keV	$\varepsilon_\mathrm{d}^\mathrm{e}$
		β^+	β^-	leph	heph	mee			
^{129}I	$1{,}6 \times 10^7$ a		X	X		X	P1/β mee MSA	152	1,22
^{129}Cs	32,1 h			X	X	X	MSA, CALIh		
^{131}Cs	9,69 d			X			MSA		
^{132}Cs	6,47 d			X	X		MSA, CALIh		
^{133}Ba	10,5 a			X	X	X	MSA, CALIh		
^{133m}Ba	38,9 h			X	X	X	CALIh		
^{134m}Cs	2,90 h			X		X	MSA		
^{135m}Ba	28,7 h			X	X	X	MSA, CALIh		
^{136}Cs	13,2 d		X	X	X	X	P1/β mee	681	1,29
^{139}Ce	138 d			X	X	X	MSA, CALIh		
^{140}Ba/^{140}La	12,8 d		X	X	X	X	P1/β mee	2 164	1,41
^{141}Ce	32,5 d		X			X	P1/β mee	580	1,24
^{143}Pm	265 d			X	X		MSA, CALIh		
^{144}Pm	363 d			X	X		MSA, CALIh		
^{145}Pm	17,7 a			X			MSA		
^{146}Pm	2 020 d		X	X	X		P1/β	795	0,40
^{152m1}Eu	9,32 h		X	X	X	X	P1/β mee	1 865	0,82
^{152}Eu	13,6 a		X	X	X	X	P1/β mee	1 475	0,68
^{153}Sm	46,7 h		X	X		X	P1/β mee	805	1,82
^{153}Gd	242 d			X		X	MSA		
^{154}Eu	8,8 a		X	X	X	X	P1/β mee	1 844	1,51
^{156}Eu	15,2 d		X		X	X	P1/β mee	2 453	1,37
^{157}Tb	150 a			X			MSA		
^{157}Dy	8,06 h			X	X		MSA, CALIh		
^{160}Tb	72,3 d		X	X	X	X	P1/β mee	1 747	1,65
^{166}Dy	81,6 h		X	X		X	P1/β mee	484	1,89
^{166m}Ho	$1{,}2 \times 10^3$ a		X	X	X	X	P1/β mee	1 314	2,18
^{166}Ho	26,8 h		X			X	P1/β mee	1 854	1,43
^{169}Yb	32,0 d			X	X	X	MSA, CALIh		
^{171}Er	7,52 h		X	X	X	X	P1/β mee	1 485	1,68
^{181}Hf	42,4 d		X	X	X	X	P1/β mee	407	1,67
^{181}W	121 d			X			MSA		
^{182}Ta	115 d		X	X	X	X	P1/β mee	590	1,91
^{182}Re	12,7 h			X	X	X	MSA, CALIh		
^{182}Re	64,0 h			X	X	X	MSA, CALIh		
^{183}Re	70 d			X	X	X	MSA, CALIh		
^{184}Re	38,0 d			X	X	X	MSA, CALIh		
^{185}Os	93,6 d			X	X		MSA, CALIh		
^{187}W	23,8 h		X	X	X	X	P1/β mee	1 313	1,27
^{190}Ir	11,8 d			X	X	X	MSA, CALIh		
^{191}Os	15,4 d		X	X		X	P1/β mee MSA	139	2,76
^{191}Pt	2,71 d			X	X	X	MSA, CALIh		
^{193}Os	30 h		X	X		X	P1/β mee	1 132	1,38
^{193}Pt	50 a			X			MSA		
^{193m}Pt	4,33 d			X		X	MSA		

Nuclide	Half-life	Important emission types					Emissions and calibration methods used	$E_{\beta\,\max}$ keV	$\varepsilon_{\mathrm{d}}^{\mathrm{e}}$
		β^+	β^-	leph	heph	mee			
^{194}Ir	171 d		X		X	X	P1/β mee	253	1,46
^{194}Au	39,5 h			X	X		MSA, CALIh		
^{195}Pt	4,02 d			X		X	MSA		
^{195}Au	183 d			X		X	MSA/SSA		
^{196}Au	6,2 d			X	X	X	MSA/SSA		
^{197}Pt	18,3 h		X	X		X	P1/β mee	719	1,76
^{197}Hg	64,1 h			X		X	MSA/SSA		
^{199}Au	3,1 d		X	X		X	P1/β mee MSA	453	1,46
^{200}Tl	26,1 h			X	X		MSA, CALIh		
^{201}Tl	73,1 h			X		X	MSA		
^{202}Tl	12,2 d			X	X		MSA, CALIh		
^{203}Hg	46,6 d		X	X	X	X	P1/β mee MSA, CALIh	212	1,23
^{203}Pb	52,0 h			X	X	X	MSA, CALIh		
^{204}Pb	1,12 h				X	X	CALIh		
^{206}Bi	6,2 d			X	X	X	CALIh		
^{207}Bi	33,4 a			X	X	X	SSA, CALIh		
^{208}Bi	$3,6 \times 10^5$ a			X	X		MSA, CALIh		

Key

MSA	Multisource calibration with 46 mg·cm^{-2} PE absorber
MSNA	Multisource calibration without absorber
SSA	Single-source calibration with absorber
SSNA	Single-source calibration without absorber
P1/β	Calibration according ISO 7503-1
CALIh/CALIβ	Accepted instrument calibration method for the indirect measurement (wipe sample) of high-energy photons or beta-particles
heph	High-energy photon emissions (energy > 130 keV)
leph	Low-energy photon emissions (energy ≤ 130 keV)
mee	Monoenergetic electron emissions (energy > 20 keV)
β^-, β^+	Beta-particle emissions

Annex B

(normative)

Explanation of basic terms and data for calibration and measurement procedures

B.1 General

Whilst surface contamination is normally referred to in terms of activity per unit area, the count rate measured by an instrument is related directly to the radiation emitted from the surface rather than the activity upon or contained within the surface. For a given activity per unit area, the intensity of the radiation emerging from the surface depends on the amount of self-absorption in the source and the amount of backscatter from the source and its backing material. The former will decrease the number of emerging particles and the latter will increase it. Due to variations in the absorptive and scattering properties of a real surface it cannot be assumed, in general, that there is a simple, known relationship between emission rate and activity. There thus appears a clear need for calibrating contamination meters in terms of instrument efficiency, i.e. on the basis of emission rate of a source, and for specifying calibration sources in terms of both activity and emission rate.

It has been common practice to calibrate contamination meters by determining the response of the instrument to a known activity (or activity per unit area) of a calibration source.

NOTE — This method was proposed in IEC 325, where the response to the activity per unit area of the calibration source was defined as "surface activity response".

For this procedure to yield a unique calibration factor, the sources are required to be ideal thin sources, i.e. sources with no self-absorption and no backscatter. However, in practice the sources can be far from ideal, especially when low-energy photon-emitters (photon energy lower than 10 keV) and low-energy beta-emitters (maximum beta energy lower than approximately 0,4 MeV) are concerned. The calibration based on activity will, therefore, yield a calibration factor which is not unique but depends critically on the source construction: a wide range of values may be obtained using calibration sources containing the same activity of a given radionuclide but having a different construction.

The calibration factor based on the emission rate of the source is much less dependent on the source construction. Therefore, calibrating surface contamination meters on the basis of emission rate rather than on activity allows the comparison of instruments with respect to sensitivity. It also enables a traceability chain to national standards to be established.

In this annex the various terms related to the measurement of surface contamination and to the calibration of surface contamination meters are illustrated, in order to avoid confusion and to ensure a clear understanding of the difference between the two approaches to calibration. The terms instrument efficiency (ε_i) and source efficiency (ε_s) are considered in more detail.

B.2 Illustration of terms

The various terms, some of which are defined in clause 3, are illustrated in figure B.1. The symbols beginning with the letter q refer to the rates of production of the types of beta, electron or photon radiation (including scattered photons or secondary electrons) defined below:

$q1$ Radiation emitted towards the detector and reaching the detector, under the following conditions:

- $q1$a Direct with no interaction before the interaction in the detector

- q1b After interaction with the detector window
- q1c After interaction with the detector casing
- q1d After interaction with air (or other surrounding material)
- q1e After interaction in the source
- q1f Passing the detector without interaction with the detector (including radiations which have interacted before reaching the detector)

q2 Radiation reaching the detector as a result of backscattering from the source or holder

q3 Radiation leaving the source into the upper solid angle of 2π sr, but not reaching the detector due to absorption or scattering including:

- q3a Absorption or scattering in air
- q3b Absorption or scattering in the detector window

q4 Radiation emitted into the upper solid angle of 2π sr, but not leaving the source due to self-absorption or scattering

q5 Radiation leaving the source into the upper solid angle of 2π sr, but missing the detector due to geometric reasons

q6 All radiation emitted into the lower solid angle of 2π sr, including backscattered radiation with the exception of q2 radiation

q7 Radiation from the surface outside the area that is being measured, reaching the detector and interacting in the detector

q8 Radiation that is not coming from the surface that is measured, reaching the detector and interacting in the detector, including:

- q8a Background and other interfering radiation
- q8b After scatter in the source or in material surrounding the detector

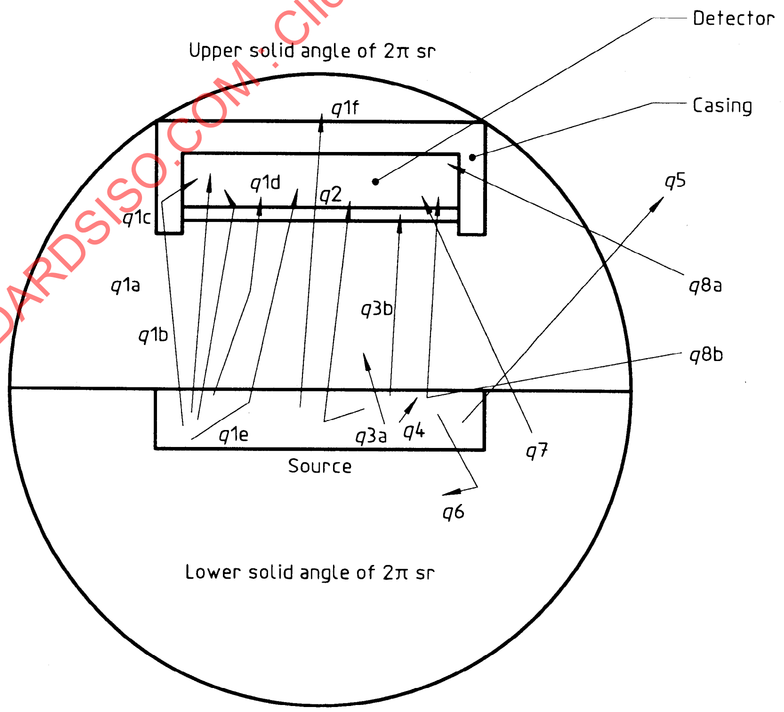

Figure B.1 — Cross-section of a source-detector combination

Table B.1 — Definition of terms (see also figure B.1)

Term	Symbol	Unit	Definition
Activity of a source	A	Bq	$A = \frac{1}{\varepsilon_d}(q_1 + q_2 + q_3 + q_4 + q_5 + q_6)$
Surface emission rate of a source	$q_{2\pi}$	s^{-1}	$q_{2\pi} = q_1 + q_2 + q_3 + q_5$
Efficiency of a source	ε_s		$\varepsilon_s = \frac{q_1 + q_2 + q_3 + q_5}{q_1 + q_2 + q_3 + q_4 + q_5 + q_6} = \frac{q_{2\pi}}{A\varepsilon_d}$
Instrument efficiency	ε_i		$\varepsilon_i = \frac{n}{q_1 + q_2 + q_3 + q_5}$
Intrinsic instrument efficiency	I_i		$I_i = \frac{n}{q_1 + q_2}$
Decay efficiency	ε_d		$\varepsilon_d = \frac{q_1 + q_2 + q_3 + q_4 + q_5 + q_6}{A}$
Response of the instrument to an activity A	R_i		$R_i = \varepsilon_i \varepsilon_s \varepsilon_d = \frac{n}{A}$
NOTE — n is the net count rate induced in the measuring instrument by radiation of types 1 to 3.			

The terms illustrated in figure B.1 are defined in table B.1. The additional term "intrinsic instrument efficiency", I_i, is sometimes needed and is defined as the quotient of the count rate induced in the detector and the number of photons and electrons incident on the detector per unit time.

The maximum values of I_i and ε_i are 1,0.

For an ideal source (no self-absorption, no backscatter), the value of ε_s is 0,5. For a real source, the value of ε_s is usually less than 0,5, but it may also be greater than 0,5 depending on the relative importance of self-absorption and backscatter processes.

Generally, the term ε_d (decay efficiency) used in the definition of activity is the number of photons plus electrons emitted per decay. However, within the context of this part of ISO 7503, this term, as well as ε_i and ε_s, refer to either pure photon emissions or to pure electron emissions. In the case of ^{63}Ni, $\varepsilon_d = 1$ and refers to pure beta emissions, but many of the radionuclides considered are mixed photon/electron-emitters and are treated as pure photon-emitters after discrimination against electrons by a 46 mg·cm^{-2} PE absorber foil.

Values for the number of photons emitted per decay can be found in reference [1] to [3]. For the more important radionuclides, these values are also stored in the relevant file of the computer program CHAOSCAL.

All the efficiencies are dimensionless.

According to the definitions in table 1, the response of the instrument (R_i) to an activity used as calibration source can be written as:

$$R_i = \varepsilon_i \varepsilon_s \varepsilon_d$$

In other words, the response R_i can be split up into instrument efficiency ε_i (reflecting instrument characteristics and counting geometry), efficiency of the source ε_s (reflecting the structural properties of the source) and decay efficiency ε_d (reflecting the decay properties of the radionuclide). The calibration factor $1/R_i$, obtained when the calibration is based on the activity of the source, is, therefore, a combination of the characteristics of the detector, the calibration source structure and the radionuclide to be measured.

B.3 Comments on instrument efficiency and source efficiency

The instrument efficiency, ε_i, is dependent on the actual energy distribution of the emitted radiation, i.e. on the energy spectrum of the source. In other words, two sources with the same surface emission rate but different energy spectra may induce different count rates in the same detector. This is because the intrinsic instrument efficiency is generally energy-dependent, and also because the number of photons or electrons incident on the detector per unit time may be reduced by energy-dependent processes of absorption in air.

The efficiency of a calibration source, ε_{sc}, is known whenever the source is specified in terms of both activity and surface emission rate [$\varepsilon_s = q_{2\pi} / A \varepsilon_d$ (see table B.1 in annex B)]. However, this information is not normally available for sources consisting of nuclides emitting a mixture of photons and electrons of discrete energies. The series of pseudo-monoenergetic calibration sources recommended in ISO 8769-2 are defined only in terms of their monoenergetic photon emission rate. They are designed to allow the determination of instrument efficiencies with respect to monoenergetic photon radiations. The use of these measured instrument efficiencies, of specific values for ε_d and of plausible assumptions concerning the contamination source structure make it possible to calculate values for the complex calibration factors described in 6.2 (program CHAOSCAL).

The table of calibration factors obtained by CHAOSCAL lists values for two types of contamination sources:

a) ideal sources (no self-absorption, no backscattering);

b) sources with a homogeneous distribution of the activity in a depth of 10 mg·cm^{-2} (thickness of normal wipe test filter-paper).

The user of this part of ISO 7503 has to decide which type is nearest to the actual structure of the contamination source. If no information concerning this structure is available, calibration factors for type b) sources shall be used.

CHAOSCAL also allows a recalculation of its basic data files, so that the determination of calibration factors for other structures of contamination sources is possible.

This means that this part of ISO 7503 does not recommend separate ε_s values to be applied by the user of the multisource calibration method, since source efficiency aspects are already considered during the calculation of the calibration factors.

In the case of single-source calibration, this part of ISO 7503 offers calculated correction factors to compensate for the reduced source efficiency of non-ideal contamination sources (see table 3).

B.4 Other comments

B.4.1 ^{63}Ni emissions

This radionuclide is the only pure beta-emitter considered in this part of ISO 7503. It emits one low-energy beta particle per decay ($\varepsilon_d = 1$). The beta particles lose a large portion of their energy between the origin and the detector. Hence the lower limit of detection depends strongly on the source thickness and the distance between the source and the detector. It is necessary to use detectors without a window or with a very thin window positioned close to the source.

Self-absorption can be very different in calibrated sources, in-house working sources and contaminated surfaces that are to be measured.

Detectors for the measurement of ^{63}Ni are normally calibrated using the single source calibration method.

B.4.2 Low-energy photon emissions

The utilization of photon emissions in the energy range 3 keV to 130 keV is the recommended method for the measurement of many radionuclides considered in this part of ISO 7503. All applications of the multisource calibration method and some applications of the single-source calibration method are based on the measurement of such emissions.

The detection of low-energy photon emissions is reduced by absorption and scattering within the source, in air and in the detector window, and it is kept high by good absorptive properties of the detector medium.

Absorption edges of the window materials and the detector medium materials are of special importance in this energy range.

For photon emission of energy less than 10 keV, the absorption can be different in calibration sources, in working sources and in the contaminated surface to be measured.

B.4.3 High-energy photon emissions

The detection depends especially on the absorption properties of the detector medium. For low density material such as e.g. methane in the detector, the detection probability is low.

As photons have a longer path range than electrons, the detectors are more sensitive to radiation not coming directly from the surface under the detector. Detectors for high-energy photons are also very sensitive to background and other interfering radiation, hence they should be shielded from radiation from other directions.

B.4.4 Monoenergetic electron emissions

Many of the radionuclides considered emit monoenergetic electrons at different energy levels. The electron emissions are always accompanied by monoenergetic photon emissions.

The only basis for measurements using monoenergetic electrons with a calibrated instrument is the single-source calibration (see 6.3) with the assumption that the calibration source and the contamination source have the same efficiency.

In all other cases, the importance of monoenergetic electron emissions can be seen in their contribution to the detection sensitivity rather than the measurement ability of the detectors.

B.4.5 Beta and monoenergetic electron emissions at a rate of other than one particle per decay ($\varepsilon_\mathrm{d}^\mathrm{e} < 1$ or > 1)

B.4.5.1 A number of radionuclides decay only partially by beta-decay. Examples are ^{48}V, ^{56}Co, ^{64}Cu and ^{74}As, with $\varepsilon_\mathrm{d}^\mathrm{e}$ values between 0,20 and 0,64. In cases where these beta emissions are the only easily detectable emissions, the radionuclides are measured like normal beta-emitters (see ISO 7503-1), however, the result according to equation (1) of ISO 7503-1:1988 has again to be divided by $\varepsilon_\mathrm{d}^\mathrm{e}$ to yield the corrected activity value.

B.4.5.2 Another group of radionuclides (e.g. ^{181}Hf, ^{191}Os, ^{210}Pb) emit about one beta article per decay, but in addition emit monoenergetic electrons of different energies. In order to avoid underestimation of surface activities, it is recommended to consider only the detectable[4)] monoenergetic electrons (energy > 20 keV) and to add their production rate to the beta-particle production rate. This leads to a new $\varepsilon_\mathrm{d}^\mathrm{e}$ value, which is then used in the same way as described in B.4.5.1.

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4) Detectable by detectors with a sensitive window of 0,3 mg/cm^2 thickness. Windowless detectors may detect electrons with energies below 20 keV. Therefore, for such detectors the $\varepsilon_\mathrm{d}^\mathrm{e}$ values may be higher than those listed in table A.1.

B.4.5.3 For some of the radionuclides specified in B.4.5.2, measurement of the low energy photons with a 46 mg/cm^2 PE absorber in front of the detector is also possible (e.g. ^{191}Os, ^{199}Au, ^{203}Hg). Calibration of the detector is then performed using the multisource calibration method and evaluation of the results is performed according to 7.1.

Annex C

(normative)

Instruments for direct measurement

C.1 Proportional detectors

C.1.1 Xenon-filled sealed proportional detectors

C.1.1.1 General

The most frequently used window material is titanium foil of thickness approximately 5 mg/cm^2 from which large-area detectors can be made. Other materials such as beryllium or aluminium can also be used, but owing to the porosity of these metals there are restrictions with respect to the minimum thickness and size of the windows produced.

C.1.1.2 Advantages

a) High instrument efficiency for X-rays in the energy range from 3 keV to 50 keV.

b) Sensitivity to electrons of energies greater than 60 keV.

c) Large-area detectors with window areas typically between 100 cm^2 and 500 cm^2 are available.

d) No counting-gas consumption.

e) Not affected by normal changes in ambient conditions.

C.1.1.3 Disadvantages

a) Low instrument efficiency for photons with energies greater than 50 keV and low-energy electrons.

b) Electrons of less than 60 keV energy are not detected.

c) Detector irreparable if the window material is damaged.

C.1.2 Gas-flow proportional detectors

C.1.2.1 General

Normal window material is an aluminized polyester foil 0,3 mg/cm^2 to 0,9 mg/cm^2 in thickness, covering sensitive detector areas up to 1 000 cm^2. These windows are not gas-tight, and therefore continuous gas flow or a periodic replenishment is required.

C.1.2.2 Advantages

a) High instrument efficiency for electrons of energies down to 30 keV.

b) Damage to window can be repaired.

c) Low relative response to interfering gamma radiation (above 30 keV).

d) Large-area detectors with window areas typically between 100 cm^2 and 1 000 cm^2 are available.

C.1.2.3 Disadvantages

a) Low instrument efficiency for photons if butane or methane is used as counting gas.

b) Efficiency values for low-energy photons are increased by use of argon-methane mixtures.

c) Butane and methane are flammable gases.

C.1.3 Windowless gas-flow proportional detectors

C.1.3.1 General

This type of instrument was developed for the detection of low-energy electrons and is available with sensitive areas from 10 cm^2 and 50 cm^2. For larger-area detectors, the sensitive area may be fitted with a cathode grid to reduce electrical interference from the surface to be measured. Counting gases like argon-methane or argon-CO$_2$ are commonly used, with a gas flowrate of 2 l/min through the entrance window.

C.1.3.2 Advantages

High efficiency for both low-energy electrons and beta radiation down to 1 keV under favourable conditions.

C.1.3.3 Disadvantages

Possible electrostatic interference by the measured surface, especially surfaces with low electrical conductivity.

C.2 Geiger-Müller detectors

Normal window material is mica of about 2 mg/cm^2 thickness, and window areas up to 20 cm^2 are available. Geiger-Müller detectors are not suitable for general use in measuring the radionuclides with low emission energies considered in this part of ISO 7503 due to the low instrument efficiency for photons. They have the advantages of low cost and simplicity, and can be used in certain carefully considered applications where a sufficient number of conversion electrons with energies > 60 keV are emitted.

C.3 Thin scintillator detectors

C.3.1 Organic scintillators covered by a window

Typical window materials are aluminized polymer foils (≈ 1 mg/cm^2). Typical scintillators are either plastic or anthracene. Anthracene may be used as a single crystal or a thin layer of powder affixed to a transparent base material. Plastic scintillators have the advantage of being available in large-area sheets of highly reproducible light output. However, for the measurement of lower-energy electron radiation, anthracene scintillators have the advantages of a higher intrinsic light conversion efficiency than plastic scintillators. Thin (≈ 12 mg/cm^2) scintillators have a low relative response to interfering gamma background.

This type of detector is unsuitable for the measurement of the characteristic X-rays and gamma radiations considered in this part of ISO 7503 due to the low detection efficiency (typically < 1 %).

Electron detection is possible at energies above approximately 40 keV. Although large-area detectors can be produced, the reduced efficiency of light collection is likely to result in a nonuniform detection efficiency across the window of the detector, and an increase in the threshold energy of detection and hence a greater variability between instruments of the same type. However, this type of probe can be considered in certain applications where a significant number of high-energy conversion electrons are emitted.

C.3.2 Windowless organic scintillation detectors

C.3.2.1 General

Light from the excitation of an organic scintillator is detected by two photomultipliers operating in coincidence mode. As the detection is windowless, an essential requirement is the exclusion of ambient light. This is achieved by means of an opaque rubber gasket between the detector and the surface to be measured. A secondary function of the gasket is to ensure the correct geometry for measuring weak emissions. If a partial vacuum is created in the light-tight chamber so formed, the instrument efficiency for low-energy electrons is increased.

C.3.2.2 Advantages

a) Detects all emissions referred to in this part of ISO 7503.

b) Detected light is proportional to the energy deposited in the scintillation, therefore energy discrimination can be used in some cases to assist identification of radionuclides.

c) Detectors with 100 cm^2 sensitive area are available.

d) Wipes of surfaces can be measured for indirect assay of surface contamination.

C.3.2.3 Disadvantages

a) Light seal becomes contaminated and in high activity areas needs replacing frequently.

b) Background is affected by high ambient light.

c) Can only be used on smooth, flat, opaque surfaces.

C.3.3 Inorganic scintillators

C.3.3.1 General

Typical window materials are aluminium (from approx. 7 mg/cm^2 to 30 mg/cm^2) and beryllium (from approx. 40 mg/cm^2 to 100 mg/cm^2), for sodium iodide detectors. The latter is used to improve instrument efficiency for X-ray energies below 20 keV. Caesium iodide detectors can use windows of aluminized plastic sheet of thickness less than 1 mg/cm^2. Inorganic crystals with thicknesses of 1 mm to 3 mm and sensitive areas of 30 cm^2 to 127 cm^2 are used as scintillators in order to reduce background and the response to other interfering high-energy gamma radiation. Collimated types are available.

C.3.3.2 Advantages

Intrinsic instrument efficiency of more than 10 % for photons in the range of 7 keV to 500 keV and more than 70 % in the range of 15 keV to 85 keV.

C.3.3.3 Disadvantages of sodium iodide detectors

Will not detect beta particles with energies below:

84 keV (14 mg/cm^2 Al windows),

127 keV (28 mg/cm^2 Al window),

280 keV (94 mg/cm^2 Be window).

C.4 Semiconductor detectors

Semiconductor detectors are not recommended for general use in direct measurement of radionuclides considered in this part of ISO 7503. This is due to the fact that detectors with large surfaces and high detection efficiency will be difficult to operate with a reproducible response due to the complicated electronics and support systems that are needed.

Annex D
(normative)

Instruments for indirect measurement

D.1 Liquid scintillation counters

Liquid scintillation counting is a method of detecting radioactivity introduced into a scintillation solution. The energy of the primary emission from the radioactive material is converted to light. A photomultiplier (or two photomultipliers operating in coincidence mode) responds to this light and produces a pulse which is amplified and counted by a scaling circuit. In certain cases emissions of differing energies can be counted differentially.

Emission of X-rays or Auger electrons from the radionuclides covered by this part of ISO 7503 can be detected by liquid scintillation counting with varying degrees of efficiency depending on

- the type and energy of emission (X-rays and gamma photons may escape from the scintillator without interacting),
- whether the sample is dissolved in the scintillator or is in the form of particles or retained in the wipe material,
- the effect of chemicals on the scintillator,
- absorption of the emitted light by colour or opacity of the sample before it reaches the photomultiplier(s),
- the orientation of the wipe in the sample vial.

NOTES

1 Because of the variable geometry of wipes introduced into the sample vial, care is necessary to achieve accurate measurement unless the wipe is made with a material which can be dissolved in the scintillator (e.g. expanded polystyrene).

2 The subject is covered in more detail in the literature (see references [4] and [5]).

D.2 Semiconductor instruments

D.2.1 Photon measurement

For indirect measurements of radionuclides emitting photons with energies above 3 keV, semiconductor instruments can be used with great advantage as they can identify the radionuclides in the sample.

D.2.2 Beta and electron radiation measurement

For the measurement of low-energy beta and electron radiation, special semiconductor detectors with very thin windows are available.

When measurements of low-energy beta or electron emitters are made, only dry smears should be used.

D.3 Installed sodium iodide scintillation detectors

For indirect measurement of radionuclides emitting photons with energies above 15 keV, sodium iodide (T1) detectors can be used with advantage because of their high efficiency. This type of detector can also be helpful for the identification of the radionuclides in the sample.