INTERNATIONAL STANDARD

ISO 7503-3

Second edition
2016-01-15

Corrected version
2018-02-15

Measurement of radioactivity — Measurement and evaluation of surface contamination —

Part 3:
Apparatus calibration

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

Partie 3: Étalonnage de l'appareillage

Reference number
ISO 7503-3:2016(E)

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Foreword

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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, *Radiological protection*.

This second edition cancels and replaces the first edition (ISO 7503-3:1996), 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 7503-3:2016 incorporates the following corrections:

- In E.5, Formulae (E.12) and (E.13) have been modified.

Introduction

ISO 7503 gives guidance on the measurement of surface contamination. ISO 7503 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 should 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 a nuclide specific calibration methodology that incorporates summation corrections. Annex A provides calibration methods which are simplified in respect of radionuclide emission data treatment.

INTERNATIONAL STANDARD **ISO 7503-3:2016(E)**

Measurement of radioactivity — Measurement and evaluation of surface contamination —

Part 3:
Apparatus calibration

1 Scope

ISO 7503 and ISO 8769 are addressed to the people responsible for determining the radioactivity present on solid surfaces.

This part of ISO 7503 applies to the evaluation of contamination on surfaces in terms of activity per unit area by direct and indirect methods of measurement and deals with the complex aspects of instrument calibration.

This part of ISO 7503 is applicable to well-defined surfaces, such as those of equipment and facilities, containers of radioactive materials, sealed sources, and buildings or land.

This part of ISO 7503 can be used for laboratory and equipment/installation control and for remediation and monitoring activities to comply with release criteria.

This part of ISO 7503 also refers to the following:

- calibration laboratories or institutions dealing with radionuclides with complex emission characteristics or radionuclides for which no reference calibration sources are available;
- institutions confronted with the task to evaluate surface contaminations consisting of a radionuclide mixture;
- institutions/authorities controlling nuclear material transports or material/equipment clearance according to national legislation guideline values or international convention limits.

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

NOTE Direct evaluation of surface contamination from alpha-emitters, beta-emitters and photon emitters is dealt with in ISO 7503-1. The test method using wipe-test samples for the evaluation of radioactive surface contaminations is dealt with in ISO 7503-2.

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 7503-1, *Measurement of radioactivity — Measurement and evaluation of surface contamination — Part 1: General principles*

ISO 7503-2, *Measurement of radioactivity — Measurement and evaluation of surface contamination — Part 2: Test method using wipe test samples*

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*

IEC 60325, *Radiation protection instrumentation — Alpha, beta and alpha/beta (beta energy >60 keV) contamination meters and monitors*

3 Terms, definitions, symbols, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7503-1 and ISO 7503-2 and the following apply.

3.1.1
emission probability of a radionuclide
ratio of the number of particles of a given type above a given energy or of photons created per unit time by a given radionuclide to the number of decays of this radionuclide per unit time

3.1.2
emergence factor of a source
ratio of the number of particles of a given type or of photons created or released within the source (for a thin source) or its saturation layer thickness (for a thick source) per unit time and the number of particles of the same type above a given energy or of photons emerging from the front face of a source or its window per unit time (surface emission rate)

3.1.3
source efficiency
ratio of the number of particles of a given type above a given energy or of photons emerging from the front face of a source or its window per unit time (surface emission rate) and the number of particles of the same type or of photons created or released within the source (for a thin source) or its saturation layer thickness (for a thick source) per unit time

3.2 Symbols and abbreviated terms

For the purposes of this part of ISO 7503, the symbols given in ISO 7503-1 and ISO 7503-2 and the following apply.

p_e	probability of a particle emerging from the surface
p_c	probability of a particle emerging from the surface of a calibration source
P	inverse of probability of a particle emerging from the surface
$E_{i,j}$	emergence factor of a source for a given energy or energy region i and for the radiation type j (alpha or beta or photon radiation)
a_i	component i of radionuclide decay path
$\varepsilon_{i,j}$	instrument efficiency for a given energy or energy region i and for the radiation type j (alpha or beta or photon radiation) in $\mathrm{s}^{-1}/\mathrm{s}^{-1}$
k_i	abundance of radionuclide decay path i
$C(A)_n$	direct method activity calibration factor for the radionuclide n in $(\mathrm{Bq \cdot cm^{-2}})/\mathrm{s}^{-1}$
S_G	active calibration source area equal to the averaging area for the surface contamination guideline value in cm^2

$\eta_{i,j}$	summarized emission intensity data for a given energy region and for the radiation type j (alpha or beta or photon radiation)
G_n	radionuclide specific surface contamination guideline value of a radionuclide n in $\text{Bq}\cdot\text{cm}^{-2}$
$r_{G,n}$	instrument net count rate equivalent to the radionuclide specific surface contamination guideline value G_n for a radionuclide n in s^{-1}
$M_{G,n}$	multiple of the surface contamination guideline value G_n
$E_{\beta,\text{max}}$	maximum beta radiation energy in MeV
P_d	probability for a surface contamination monitor to detect a decay cascade of n steps
$A_{s,n}$	activity per unit area of fixed and removable contamination of a radionuclide n in Bq cm^{-2}
$C(A)_m$	direct method activity calibration factor for a given radionuclide mixture m with known radionuclide contribution to the mixture in $(\text{Bq}\cdot\text{cm}^{-2})/\text{s}^{-1}$
G_m	surface contamination guideline value for a given radionuclide mixture m with known radionuclide contribution to the mixture in $\text{Bq}\cdot\text{cm}^{-2}$
f_n	fraction of radionuclide n in the radionuclide mixture
$A_{s,m}$	activity per unit area of fixed and removable contamination of a radionuclide mixture m in Bq cm^{-2}
$r_{G,m}$	instrument net count rate equivalent to the surface contamination guideline value G_m in s^{-1}
$M_{G,m}$	multiple of the surface contamination guideline value G_m
$C(A)_n^\text{ind}$	indirect method activity calibration factor for a given radionuclide n in $(\text{Bq}\cdot\text{cm}^{-2})/\text{s}^{-1}$
L_n	radionuclide specific surface contamination limit in $\text{Bq}\cdot\text{cm}^{-2}$
$r_{L,n}$	instrument net count rate equivalent to the surface contamination limit L_n in s^{-1}
$C(A)_m^\text{ind}$	indirect method activity calibration factor for a given radionuclide mixture m with known radionuclide contribution to the mixture in $(\text{Bq}\cdot\text{cm}^{-2})/\text{s}^{-1}$

4 Surface contamination evaluation methods

The applicability and the reliability of direct measurement or indirect evaluation of surface contamination are strongly dependent on the particular circumstances [e.g. 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, reasonably clean, and when no interfering radiation, such as a high background, is present. Direct measurement is used to establish the presence of both fixed and removable contamination.

Direct surface contamination evaluation is addressed in ISO 7503-1.

Indirect evaluation of surface contamination is more generally applicable when the surfaces are not readily accessible because of difficult location or configuration, where interfering radiation fields adversely affect contamination monitors or when methods of direct measurement with standard instrumentation are not available (e.g. tritium). Also, the indirect method cannot assess fixed contamination, and, due to the uncertainty associated to the wiping efficiency, application of this method results in conservative estimations.

Indirect surface contamination evaluation is addressed in ISO 7503-2.

There are many inherent shortcomings in both the direct measurement and the indirect evaluation of surface contamination, so in many cases the use of both methods in tandem may help to obtain results which best meet the aims of the evaluation.

5 Principal direct calibration methodology including summation correction

5.1 General

The aim of Clause 5 is to clarify the interpretation of measurements using surface contamination instruments. Despite the simplicity of such measurements, a confusing array of terms is used in national and international standards and manufacturers' brochures. Misinterpretation of the terminology can lead to errors in reported measurements or the selection of an inappropriate instrument.

5.2 starts from first calibration principles, identifies any assumptions made and uses this approach to show the differences between parameters used to describe instrument response.

The *P*-factor, which reflects the nature of the surface being monitored, is introduced in 5.3 and discussed in 5.4.

The calibrations using ISO 8769 calibration sources allow the energy-dependent instrument response, in terms of response per emission, to be characterized over a wide energy range (5.5.1). This in turn allows responses to be interpolated for the various emissions associated with a particular radionuclide. If each of these emission responses is then modified by the *P*-factor (5.4), they can be combined to provide an instrument response factor for that radionuclide/surface combination in terms of response per Bq cm^{-2} (5.5.3).

5.2 Calibration for radionuclides with single emission decay schemes

For the following, it is assumed that the considered radionuclide emits a single particle per decay (e.g. a pure beta-emitter that decays directly to the ground state of the daughter radionuclide).

If an infinitely thin detector of an ideal monitor with an effective probe area S_p is placed directly on the surface being monitored, the detector would only detect particles from the surface directly under the instrument (i.e. no edge effects). The probability of a particle emerging from the surface is given by p_e and each particle hitting the instrument is detected with an efficiency ε, which for simplification of the presented discussion is assumed to be independent of the particle energy.

To calibrate the ideal monitor, it is placed on a calibration source of known surface emission rate R_c and active area S_c (larger in area than the detector window). Assuming zero background count rate, the observed count rate is:

$$\rho_\mathrm{c} = \varepsilon \cdot \frac{R_\mathrm{c}}{S_\mathrm{c}} \cdot S_\mathrm{p} \tag{1}$$

If the activity of the calibration source is A_c, it can be seen that $R_\mathrm{c} = A_\mathrm{c} \cdot p_\mathrm{c}$ and the formula becomes

$$\rho_\mathrm{c} = \varepsilon \cdot \frac{A_\mathrm{c} \cdot p_\mathrm{c}}{S_\mathrm{c}} \cdot S_\mathrm{p} \tag{2}$$

If the instrument is now placed on a surface which is uniformly contaminated (larger in area than the detector) with the same radionuclide as the calibration source, the observed count rate is:

$$\rho' = \varepsilon \cdot \frac{R'}{S'} \cdot S_\mathrm{p} \tag{3}$$

where the primed terms relate to the contaminated surface.

The emission rate per unit area of the contaminated surface is given by:

$$\frac{R'}{S'} = \rho' \cdot \left(\frac{A_{\text{c}}}{S_{\text{c}}}\right) \cdot \left(\frac{p_{\text{c}}}{\rho_{\text{c}}}\right) \tag{4}$$

Assuming that the activity on the contaminated surface is related to its measured emission rate by the relationship $R' = A_{\text{s}}' \cdot p_{\text{e}}'$, it is evident that

$$\frac{A_{\text{s}}'}{S'} = \rho' \cdot \frac{1}{p_{\text{e}}'} \cdot \left(\frac{A_{\text{c}}}{S_{\text{c}}}\right) \cdot \left(\frac{p_{\text{c}}}{\rho_{\text{c}}}\right) \tag{5}$$

It can be seen that the formulae above comprise terms that describe the instrument (ε and S_{p}) (see Table 1) and that which describes the surface being monitored (p_{e}) (see Table 2). The latter term is related to the "*P*-factor" (see 5.3).

The quantities in the above formulae can be combined to give one parameter that describes the instrument, the instrument response factor, and one parameter that describes the surface being monitored. Instrument response factors have been defined in various ways over time and these are shown in Table 1 below.

Three of the definitions are independent of the surface nature of the calibration source on condition that the response factors are determined using calibration sources emitting a single particle per decay. However, the activity related instrument response $I(A)$ and the activity related calibration factor $C(A)$ depend on both the instrument characteristics and the nature of the surface of the calibration source (described by p_{c}).

Table 1 — Quantities that describe the instrument

Definition	Symbol	Formula	Description
Instrument efficiency	ε	$\varepsilon = \rho_{\text{c}} \cdot \left(\frac{S_{\text{c}}}{R_{\text{c}}}\right) \cdot \left(\frac{1}{S_{\text{p}}}\right)$	Instrument efficiency = observed count rate per surface emission rate under the detector window
Instrument response (Emission)	$I(E)$	$I(E) = \varepsilon \cdot S_{\text{p}} = \rho_{\text{c}} \cdot \left(\frac{S_{\text{c}}}{R_{\text{c}}}\right)$	Instrument efficiency times window area = observed count rate per surface emission rate per unit area
Instrument response (Activity)	$I(A)$	$I(A) = \varepsilon \cdot S_{\text{p}} \cdot p_{\text{c}} = \rho_{\text{c}} \cdot \left(\frac{S_{\text{c}}}{R_{\text{c}}}\right) \cdot p_{\text{c}}$	Instrument efficiency times window area times probability of a particle or photon leaving the source surface = observed count rate per Bq per unit area
Calibration factor (Emission)	$C(E)$	$C(E) = \frac{1}{\varepsilon \cdot S_{\text{p}}} = \frac{1}{\rho_{\text{c}}} \cdot \left(\frac{R_{\text{c}}}{S_{\text{c}}}\right)$	Reciprocal of instrument efficiency times window area
Calibration factor (Activity)	$C(A)$	$C(A) = \frac{1}{\varepsilon \cdot S_{\text{p}} \cdot p_{\text{c}}} = \frac{1}{\rho_{\text{c}}} \cdot \left(\frac{R_{\text{c}}}{S_{\text{c}}}\right) \cdot \frac{1}{p_{\text{c}}}$	Reciprocal of instrument efficiency times window area times probability of a particle leaving the source surface

Table 2 — Quantities that describe the surface

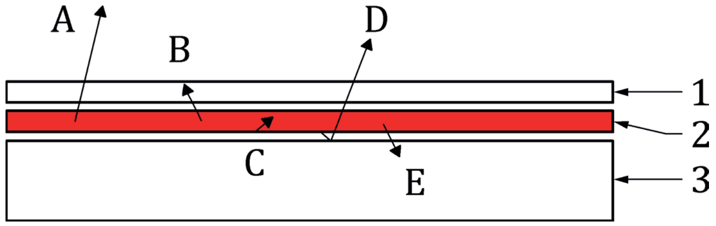
Quantity	Symbol	Description
Surface emission rate of calibration source	R_{c}	Surface emission rate of particles or photons
P-factor	$P \left(= \frac{1}{p_{\text{e}}}\right)$	Inverse of probability of particle emission

5.3 *P*-factor for radionuclides with uncomplex decay schemes

The concept of the *P*-factor was initially introduced in the development of Reference [3].

NOTE The *P*-factor was designed in Reference [3] to convert a measurement of emission rate from a monoenergetic conform calibration source (ISO 8769) into a measure of activity. Because such calibration sources are single radionuclides with essentially a single emission which has a 100 % emission probability, the *P*-factor could be used very simply to achieve this conversion. The *P*-factor is essentially just the reciprocal of p_e (Table 2). The original definition, “A *P*-factor is the ratio between the activity per unit area of a source and its surface emission rate per unit area” was correct, but only for the single emission ISO 8769 calibration sources.

To estimate the *P*-factor, the illustration in Figure 1 shows the various emission processes from a contaminated surface.



Key

A	particle/photon emitted from surface
B	particle/photon absorbed in surface grime (see Tables 3 and 4)
C	particle/photon absorbed in active layer (see Tables 3 and 4)
D	particle/photon back scattered from substrate (see Tables 3 and 4)
E	particle/photon absorbed in substrate
1	surface grime
2	active layer
3	substrate

Figure 1 — Schematic of emission processes from the surface of a source

The magnitude of effect of the *P*-Factor components B, C and D is indicated in Tables 3 and 4. Reference for Tables 3 and 4 is Reference [4].

Table 3 — Variation of attenuation effects with emission type and energy (illustrative only)

Effect	*P*-Factor component	Particle type affected	Magnitude of effect
Backscatter	D	High energy betas	Increases surface emission by 10 % to 20 % for high energy beta particles on high atomic number backings (e.g. steel)
Self-absorption	C	Alphas	Decreases surface emission by a factor 2 or more
		Low energy betas (0,15 to 0,4) MeV	Even very thin deposits produce a considerable reduction in surface emission rates
		High energy betas	Surface emission unaffected for thin deposits (<1 mg cm^{-2})
Surface coatings	B (see Table 4)	Alphas	Layer 5 mg cm^{-2} thick: totally absorbs α radiation
		Low energy betas	Layer 5 mg cm^{-2} thick: decreases surface emission by a factor of 2 or more
		High energy betas	Layer 5 mg cm^{-2} thick: decreases surface emission by 30 %
Interfering radiation			Some gamma interference possible, effect normally small (typically 1 % for ^{137}Cs/^{60}Co)

Table 4 — Percentage transmission factors for surface coatings (illustrative only)

Surface coating	Mass per unit area mg cm^{-2}	Typical radionuclide and radiation type				
		^{238}Pu Alpha	^{14}C Soft beta	^{36}Cl Medium beta	^{90}Sr/^{90}Y Medium + hard beta	^{55}Fe 5,9 keV photon
		Percentage transmission factor				
Car paint	2,6	10	50	90	95	30
Anti-rust paint	4,0	0	30	90	95	35
Lacquer	2,4	10	50	90	95	50
Wood varnish	1,4	30	60	95	100	70
Furniture polish	0,1	90	95	100	100	95
Oil as applied	1,3	30	70	95	100	70
Oil wiped off	0,14	90	95	100	100	95
Grease as applied	1,8	20	60	95	100	60

NOTE The paints are one coat only, the polish is two coats. All are applied according to the manufacturers' instructions.

The ideal situation assumes contamination is in an infinitely thin layer and there is no scattering. For these assumptions, exactly half of the emissions resulting from a radioactive disintegration will emerge and have the potential to enter the detector. For those cases where there is only one emission per decay, the *P*-factor has a value of 2 and the activity per unit area is twice the emission rate per unit area provided by the detector response.

5.4 concentrates on calculating the *P*-factor for radionuclides with complex decay schemes.

5.4 *P*-factors for radionuclides with complex decay schemes

The majority of radionuclides do not exhibit simple decay schemes and may have multiple branches from the parent to the ground state, including the emission of photon(s), conversion electrons and secondary emissions such as X-rays and Auger electrons. For any single decay event, it is possible also that more than one emission may be produced, for example, a beta particle followed by a gamma ray.

The instrument may detect any or all of the emissions arising from a single decay but only one event is registered as the emissions occur at the same time. This is the key reason why interpreting readings from surface contamination instruments is complex, as it means that it is incorrect to sum the detection probabilities for all the emissions without correction for the summation.

In estimating the appropriate calibration factor (in Bq·cm^{-2}/s^{-1}) for a particular radionuclide, it is necessary to take into account the probabilities of the various emissions, the effect of the surface on each separate emission, and the probability of detecting in coincidence any or all of the emissions from a single decay. The estimation of an appropriate instrument response factor for most radionuclides therefore is a complex issue because it is not possible to apply the same *P*-factor for each emission involved in the decay and indeed the simplistic definition of the *P*-factor is not appropriate here.

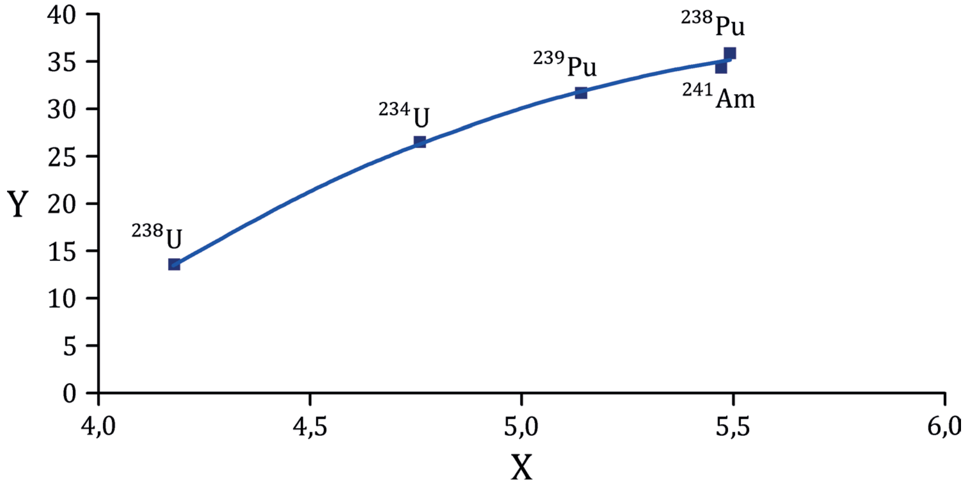
In practice, high uncertainties (tens of percent) in measurement can normally be tolerated as the measurements may be for screening or re-assurance purposes only. However, it is still necessary to understand the underlying physical processes and the estimation algorithms to check that gross errors are not being made. The following discussion is intended to provide a generic approach which puts these estimations on a sound footing.

An additional factor, the "emergence factor", shall be introduced which characterizes the ratio of the generation of individual emissions to the fraction of those emissions which emerge from the surface. Let this factor be defined as $E_{i,j}$ for the relevant energy i and for emission of alpha-, beta- or gamma-radiation j. Each emission can then be taken in turn, the appropriate value for $E_{i,j}$ estimated, this combined with the emission probability per decay and then the effects combined of all emissions in the decay taking into account the potential for coincident detections.

5.5 Generic estimation of instrument response

5.5.1 Determination of the energy response of the instrument

The first step is to determine the instrument efficiency (5.2) as a function of energy for the emission types (alpha, beta and photon). Examples of instrument efficiency values are shown in Figures 2, 3, and 4.

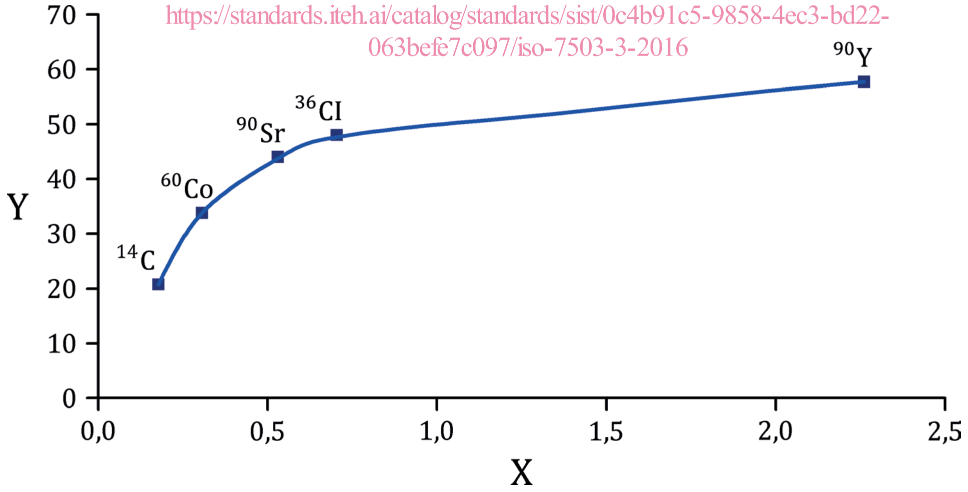


Key

X alpha energy (MeV)

Y instrument efficiency (%)

Figure 2 — Alpha energy vs. instrument efficiency (illustrative only)

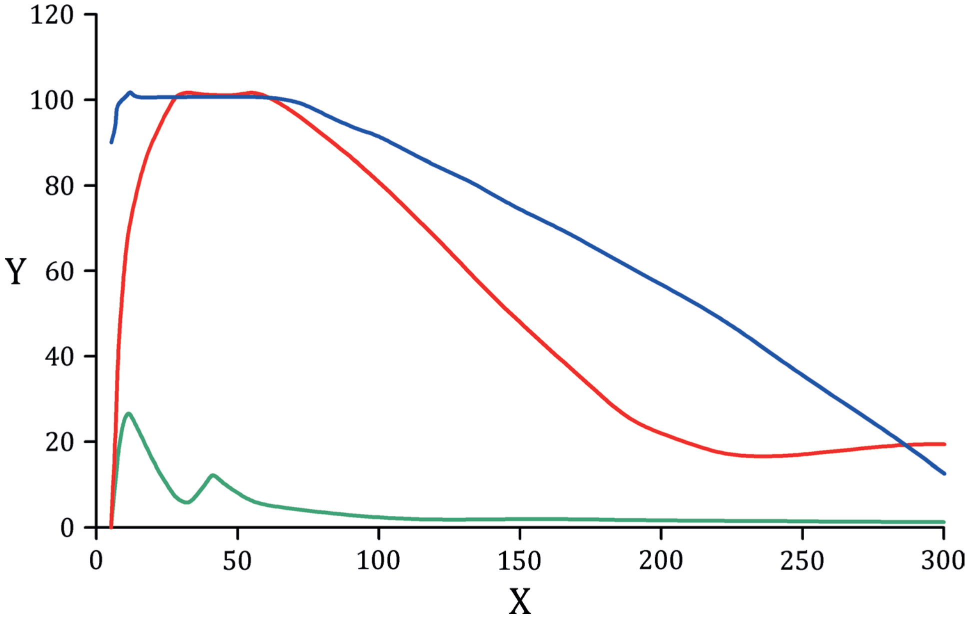


Key

X beta energy E_{max} (MeV)

Y instrument efficiency (%)

Figure 3 — Beta energy vs. instrument efficiency (illustrative only)



Key

X	photon energy (keV)
Y	instrument efficiency (%)
🟦	NaI detector 3 mm thick, Be window 47 mg cm^{-2}
🟥	NaI detector 2 mm thick, Al window 14 mg cm^{-2}
🟩	Xe gas detector 20 mm thick, Ti window 5 mg cm^{-2}

Figure 4 — Photon energy vs. instrument efficiency (illustrative only)

5.5.2 Modelling of the decay paths of the radionuclide of interest

For each complete decay path, more than one emission may occur but these are normally emitted simultaneously (in cascade) and the detector only produces one pulse even though more than one of the emissions may have been detected. It is necessary to ensure in the calculations that double (or even multiple) counting is not included.

In this step, each decay path (cascade) of the radionuclide is therefore treated separately. For example, ^{60}Co has one cascade (beta decay followed by two gammas), whereas ^{131}I has six beta branches with each of these branches being followed by the emission of various combinations of photons, conversion electrons, Auger electrons and X-rays. The latter case produces tens of individual decay paths and, within each path, various values of $E_{i,j}$ need to be applied for the various emissions. However, given the relatively coarse levels of accuracy required for radiation monitoring, the task can be simplified by appropriate groupings and thresholds as shown obviously below.

In general, the process to follow is:

a) identify each complete sequential decay path for the radionuclide and determine its abundance;

b) estimate the inherent detector efficiency for each emission (alpha, beta, gamma) in that decay path;

c) estimate the relevant E-factor for each emission from a knowledge of the nature of the contaminated surface;

d) calculate the overall efficiency for each complete sequential decay path.

For example, consider a typical decay scheme (Figure 5) which includes the complexity typical of many radionuclide decays. The initial decay shown here is beta decay but the method applies equally to those