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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
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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*

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.

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 $(\mathrm{Bq}\cdot\mathrm{cm}^{-2})/\mathrm{s}^{-1}$
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 Bq·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
$E_{\beta,\mathrm{max}}$	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 (Bq·cm^{-2})/s^{-1}
G_m	surface contamination guideline value for a given radionuclide mixture m with known radionuclide contribution to the mixture in Bq·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
$C(A)_n^{\mathrm{ind}}$	indirect method activity calibration factor for a given radionuclide n in (Bq·cm^{-2})/s^{-1}
L_n	radionuclide specific surface contamination limit in Bq·cm^{-2}
$r_{L,n}$	instrument net count rate equivalent to the surface contamination limit L_n in s^{-1}
$C(A)_m^{\mathrm{ind}}$	indirect method activity calibration factor for a given radionuclide mixture m with known radionuclide contribution to the mixture in (Bq·cm^{-2})/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:

$$\frac{R'}{S'} = \rho' \cdot \left(\frac{A_c}{S_c}\right) \cdot \left(\frac{p_c}{\rho_c}\right) \tag{4}$$

Assuming that the activity on the contaminated surface is related to its measured emission rate by the relationship $R' = A_s' \cdot p_e'$, it is evident that

$$\frac{A_s{}'}{S'} = \rho' \cdot \frac{1}{p_e{}'} \cdot \left(\frac{A_c}{S_c}\right) \cdot \left(\frac{p_c}{\rho_c}\right) \tag{5}$$

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	$\varepsilon = \rho_c \cdot \left(\frac{S_c}{R_c}\right) \cdot \left(\frac{1}{S_p}\right)$	Instrument efficiency = observed count rate per surface emission rate under the detector window
Instrument response (Emission)	$I(E)$	$I(E) = \varepsilon \cdot S_p = \rho_c \cdot \left(\frac{S_c}{R_c}\right)$	Instrument efficiency times window area = observed count rate per surface emission rate per unit area
Instrument response (Activity)	$I(A)$	$I(A) = \varepsilon \cdot S_p \cdot p_c = \rho_c \cdot \left(\frac{S_c}{R_c}\right) \cdot p_c$	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)	$C(E)$	$C(E) = \frac{1}{\varepsilon \cdot S_p} = \frac{1}{\rho_c} \cdot \left(\frac{R_c}{S_c}\right)$	Reciprocal of instrument efficiency times window area
Calibration factor (Activity)	$C(A)$	$C(A) = \frac{1}{\varepsilon \cdot S_p \cdot p_c} = \frac{1}{\rho_c} \cdot \left(\frac{R_c}{S_c}\right) \cdot \frac{1}{p_c}$	Reciprocal of instrument efficiency times window area times probability of a particle leaving the source surface

Table 2 — Quantities that describe the surface

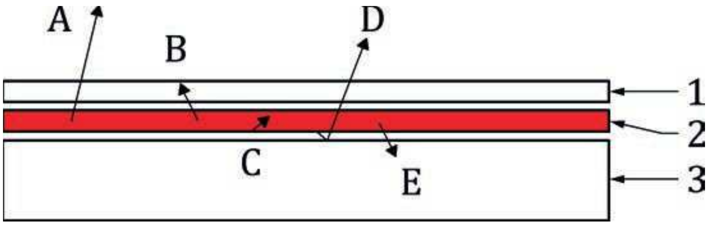
Quantity	Symbol	Description
Surface emission rate of calibration source	R_c	Surface emission rate of particles or photons
P-factor	$P \left(= \frac{1}{p_e}\right)$	Inverse of probability of particle emission

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.

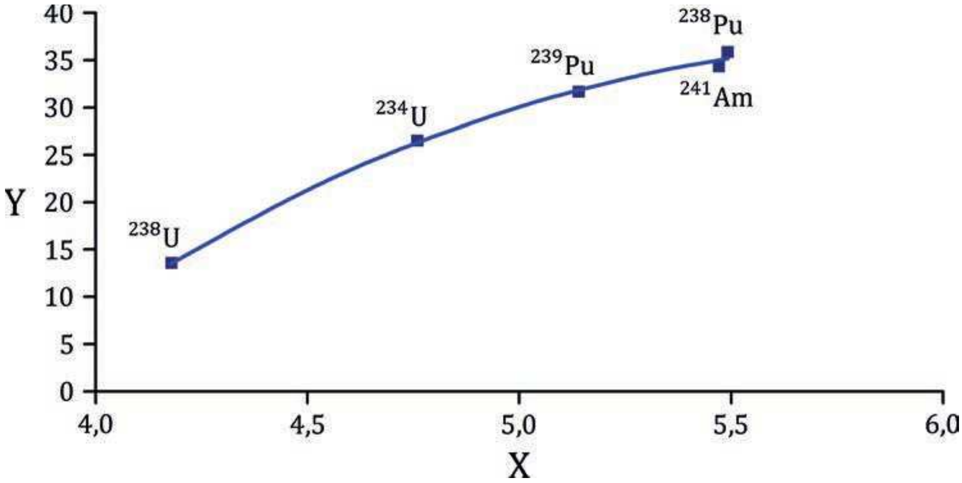
In practice, high uncertainties (tens of percent) in measurement can normally be tolerated as the measurements may be for screening or re-assurance purposes only. However, it is still necessary to understand the underlying physical processes and the estimation algorithms to check that gross errors are 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.

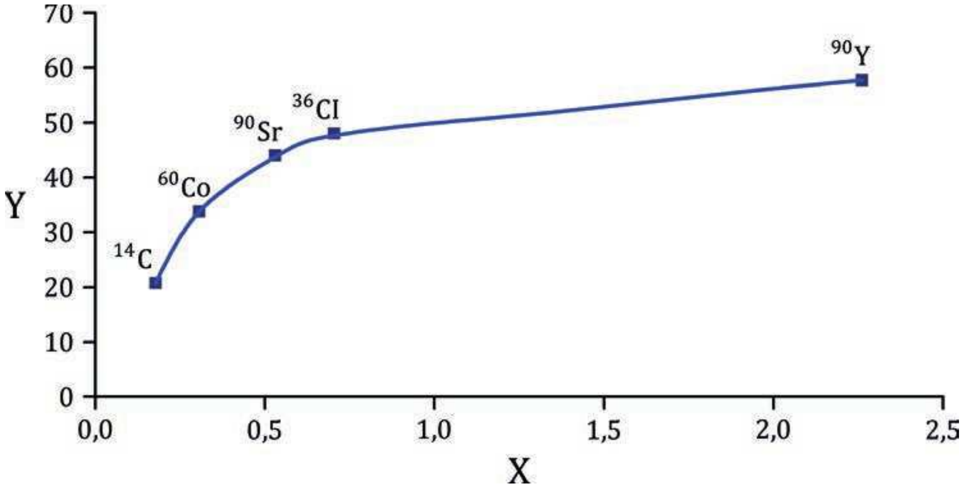


Key

X alpha energy (MeV)

Y instrument efficiency (%)

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

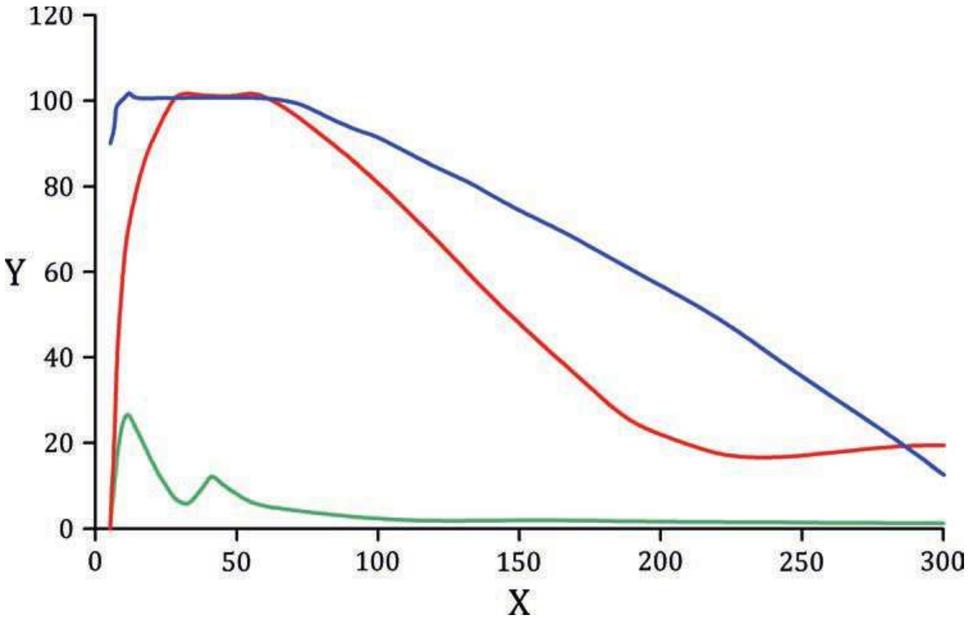


Key

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 radionuclides where the initial decay from the parent ground state is by alpha particle emission or by electron capture.

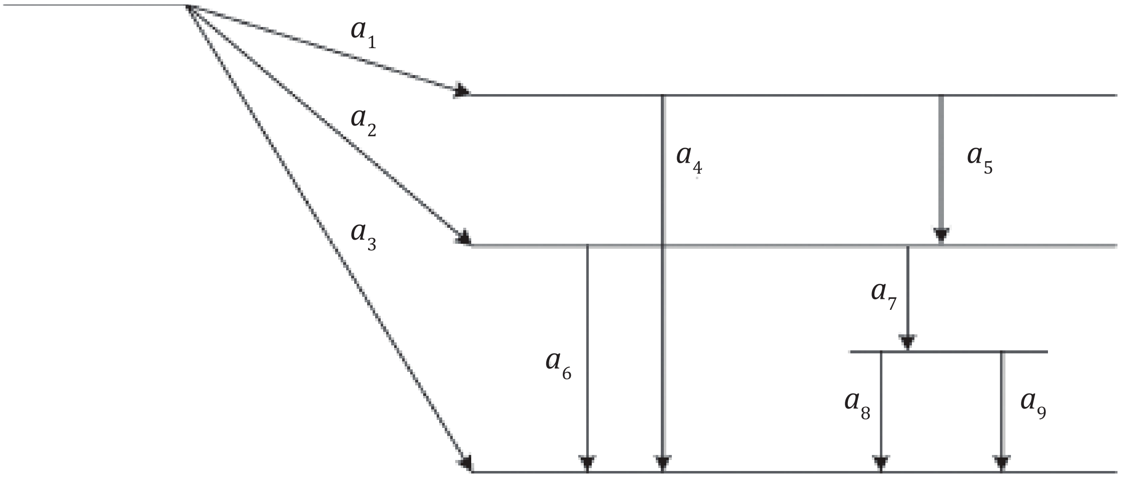


Figure 5 — Typical decay scheme

If, for the relevant emission i which has an energy e, $\varepsilon_{i,j}$ and $E_{i,j}$ are defined as the energy specific instrument efficiency and the appropriate emergence factor, respectively, the decay scheme can be summarized in tabular form as shown in Table 5, where the decay path abundance is the fraction of decays from a particular state.

Table 5 — Decay scheme in tabular form

Components of path	Nature of decay	Inherent detector efficiency	Emergence factor
a_1	Low energy beta	ε_1	$E_{1,\beta}$
a_2	Medium energy beta	ε_2	$E_{2,\beta}$
a_3	High energy beta	ε_3	$E_{3,\beta}$
a_4	High energy gamma	ε_4	$E_{4,\gamma}$
a_5	Medium energy gamma	ε_5	$E_{5,\gamma}$
a_6	Medium energy gamma	ε_6	$E_{6,\gamma}$
a_7	Internal conversion	ε_7	$E_{7,\gamma}$
a_8	K-X-ray	ε_8	$E_{8,\gamma}$
a_9	L, M, N...X-rays and K, L, M, N...Augers	ε_9	$E_{9,\gamma}$

There are 8 complete paths to the ground state and if each complete decay path abundance is defined as k_i these are given in Table 6:

Table 6 — Notional example of probabilities associated with each decay path

Decay path abundance	Components of path	
k_1	$a_1 \cdot a_4$	Σk_i equal decay probability
k_2	$a_1 \cdot a_5 \cdot a_6$	
k_3	$a_1 \cdot a_5 \cdot a_7 \cdot a_8$	
k_4	$a_1 \cdot a_5 \cdot a_7 \cdot a_9$	
k_5	$a_2 \cdot a_6$	
k_6	$a_2 \cdot a_7 \cdot a_8$	
k_7	$a_2 \cdot a_7 \cdot a_9$	
k_8	a_3	

Consider just two of these decay path abundances, k_8 and k_4.

For path component a_3, the instrument response factor in respect of activity is given by:

$$I(A) = \frac{k_8 \cdot \varepsilon_3 \cdot S_\mathrm{p}}{E_{3,\beta}} \tag{6}$$

where S_p is the effective probe area.

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

This is analogous to the situation with a pure beta emitter (e.g. $^{14}\mathrm{C}$). In that case, assuming no attenuation of the source, $k_8 = 1$ and $E_{3,\beta} = 2$, and the formula simplifies to:

$$I(A)_\mathrm{C\text{-}14} = \frac{\varepsilon_3 \cdot S_\mathrm{p}}{2} \tag{7}$$

For path k_4, the situation is more complicated. The $I(A)$ for each part of the path may be expressed in the same way as above but a cascade effect is now considered. If any one of the four different emissions is detected, a pulse is registered (the instrument may detect other emissions in the cascade as well, but only one pulse is registered). The detection efficiency is therefore given by one minus the probability of not detecting any of the emissions, which is the same as the product of the probabilities of not detecting each individual emission. The relevant E-factors shall also be included and the probability of registering a pulse for that path may be expressed as:

$$1 - \left(1 - \frac{\varepsilon_1}{E_{1,\beta}}\right) \cdot \left(1 - \frac{\varepsilon_5}{E_{5,\gamma}}\right) \cdot \left(1 - \frac{\varepsilon_7}{E_{7,\gamma}}\right) \cdot \left(1 - \frac{\varepsilon_9}{E_{9,\gamma}}\right) \tag{8}$$

In most practical cases, the above formula may be simplified by taking one of the terms (corresponding to the emission in the cascade with the highest detection probability). This underestimates the detection efficiency, resulting in an over-estimate of the activity on the surface but for radiation protection/clearance purposes conservative results are acceptable.

5.5.3 Determination of the overall instrument response

For the whole radionuclide decay the probabilities of detecting at least one emission from each complete path are then added and these are combined with the complete path abundances. The activity instrument response can then be expressed generally as:

$$I(A) = S_\mathrm{p} \cdot \sum_{l=1}^{n} k_l \cdot \left\{ 1 - \prod \left(1 - \frac{\varepsilon_{i,j}}{E_{i,j}} \right) \right\} \qquad (9)$$

where *l* represents the different complete path abundances and *i* represents the individual emissions in each complete path.

Some typical radionuclides have been examined and, for each, two different surface scenarios are considered. The detailed analyses are shown in Annex B.

5.5.4 Alternative determination of the overall instrument response

The identification of each complete sequential decay path for the radionuclide of interest and the determination of its abundance is complex, and it is best done by a well-trained specialist. Calibration laboratories confronted with the task to calibrate instruments for a variety of radionuclides in a time as short as possible may have the need for an easier applicable calibration method.

A simplified calibration method is therefore presented in Annex A. It is based on the classification of particle and/or photon emission intensity data of the radionuclide of interest into specific emission energy regions.[5] Radionuclide emission intensity data is tabulated in most radionuclide decay data bases and can therefore easily be imported for calculation purposes. A comparison of numeric calibration examples performed according to 5.5.2 and Annex A is given in Annex B.

5.6 Conclusion

It is evident, from the discussions above and the examples given in Annex B, that the use of a *P*-factor as originally defined is not applicable for radionuclides which have complex decay schemes. Attempting to redefine the factor would only cause confusion and the discussions here have sought to resolve the problem by showing how to determine instrument response factors from fundamental principles.

In Clause 5, formulae have been derived to enable the count rate observed on a surface contamination monitor to be converted from counts per second to Bq cm^{-2}, assuming the identity of the radionuclide on the surface is known; the energy response of the monitor can be estimated; and there is some knowledge of the surface and depth distribution of the radionuclide.

Surface contamination measurements are subject to high uncertainties and are probably best regarded as qualitative rather than quantitative. The formulae in Clause 5 should enable the reader to check whether measurements are fit-for-purpose.

6 Test report

Any test reports issued should be in compliance with the requirements of ISO/IEC 17025 and contain the following:

a) a title such as “Calibration Certificate” or “Test Certificate”;

b) name and address of customer;

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

NOTE Many contamination monitors are comprised of a rate meter and a detachable probe. The two are usually calibrated as one. Hence, the certificate should refer to both probe and rate meter.

d) date of receipt of the instrument;

e) type of tests (e.g. tests before first use, periodic calibration, periodic test or retest after repair);

f) basic description of the test (e.g. geometrical condition used for the determination of the instrument efficiency), any specific instrument settings used which are available externally to the user, and any adjustments or repairs performed;

g) limitations of the calibration performed including identification of the ranges not tested;

h) results of the tests including instrument response or calibration factor for specific radiations or radionuclides, and a statement of the uncertainty with the confidence level at which the uncertainty is quoted;

i) name and signature of the person responsible for the test;

j) name and address of the laboratory at which test was performed and the date of test;

k) units in which the results are expressed;

l) test result with the associated coverage value k.

In addition, the following information should be included for the benefit of the instrument user:

- record of the background dose rate or count rate and any relevant environmental conditions during the calibrations;
- the value of any conversion coefficient applied to the results;
- statement that the test was carried out for the purpose of the regulations and was successful (or unsuccessful);
- where appropriate, the indication produced by any check source supplied with the instrument or from a generic check source if a similar source is available to the end user.

Since calibration certificates are usually filed away for quality assurance purposes, it is recommended to label instruments with the following information:

- description of the instrument (including type and serial no.);
- date of calibration or test;
- calibration certificate number;
- type and serial number of probe if required;
- guideline value count rate(s) (see A.6) for the calibrated radionuclide(s).

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 and obviously identifies such an instrument as having failed.

Annex A
(normative)

Alternative calibration methodology

A.1 General

The calibration methodology presented in this Annex neglects the summation correction as outlined in Clause 5. It is based only on the radionuclide emission intensity data and knowledge of the radionuclide decay path abundance is not necessary. This leads to a more simplified and therefore easier performable radionuclide emission data treatment.

A.2 Overview

This Annex especially refers to accredited calibration laboratories or institutions dealing with radionuclides with complex emission characteristics or radionuclides for which no calibration sources are available, or to institutions/authorities controlling nuclear material transports or material/equipment clearance according to national legislation guideline values or international convention limits.

The calibration procedure for direct measurement outlined in this Annex refers to instruments [surface contamination monitors (SCM)] with a preferably effective detector window area of 100 cm^2 (see A.3.2). Instrument detection principles include

- Xe-filled sealed proportional counters,
- gas-flow proportional counters,
- plastic/Zn(Ag)S scintillators, and
- Zn(Ag)S scintillators.

A presentation of the energy dependence for beta and photon radiation and the sensitivity for alpha radiation of these detector types is given in Reference [5].

Characteristics and performance of the measuring instruments shall comply with IEC 60325 and be adapted to the measurement objectives.

The instruments shall be capable of measuring activities below the levels of the (radionuclide specific) surface contamination guideline values or limits set by national legislations or international conventions, to which the results of the contamination measurements are to be compared.

A.3 Basic method

A.3.1 General

Principally, instrument calibration should be done by means of reference radiations provided by reference sources of certified surface emission rate in accordance with ISO 8769.

For the evaluation of surface contaminations consisting of a known radionuclide, a calibration procedure can be applied using a specific calibration source made from the same radionuclide.

The method of direct calibration of an instrument with respect to a specific radionuclide using a *single calibration source* made from the same radionuclide can be applied to all radionuclides for which calibration sources are available. In principle, all types of radiation emitted can be utilized for such a calibration.

NOTE If the direct calibration is performed by means of a beta and photon radiation emitting calibration source for which only the beta surface emission rate is certified (e.g. a ^{60}Co or a ^{137}Cs source), an underestimated surface activity determination will result from a measurement with an instrument of high photon radiation sensitivity calibrated in this way.

In case of radionuclides with complex emission characteristics or of radionuclides for which no calibration sources are available, a multisource calibration procedure can be applied. The instrument efficiency is measured versus radiation energy using sources emitting mono-energetic radiation. Instrument efficiency values for the radionuclides under consideration are then calculated individually, using the energy and emission probability data relating to the mono-energetic components of the radiation.

For the application of this multisource calibration procedure, calibration can be performed by a set of basic radionuclide reference sources with certified alpha, beta, or photon emission rate (Table A.1). Respective uncertainties of the surface emission rate as stated in the individual certificate lie in the range given in Table A.1. These calibration reference sources are used as emitters of alpha particles, electrons, or photons of a particular energy range. They are not perceived as sources of particular radionuclides.

The calibration sources for the photon energy regions are where necessary covered with filters according to ISO 8769 to suppress the beta radiation (Table A.1).

Table A.1 — Reference sources for the determination of the instrument efficiency

Radio-nuclide	**Emission type**	**Relative emission probability**	**Surface emission rate uncertainty** [%, coverage factor k = 2]	**Emission energy** keV			
				Energy region for all alpha emitters			
^{241}Am	alpha	1,0	5	5 400 to 5 640			
				Energy regions for beta emitters (mean energy)			
				40 to 70	70 to 140	140 to 400	>400
^{14}C	beta	1,0	3	50 [157][b]			
^{99}Tc	beta	1,0	3		95 [294]		
^{36}Cl	beta	0,98	3			250 [709]	
^{90}Sr/^{90}Y	beta	1,0 each	3			195 [546]	925 [2 280]
				Energy regions for photon emitters			
				5 to 15	15 to 90	90 to 300	>300
^{55}Fe	photon	0,29	9	6			
^{129}I	photon[a]	0,74	9		39		
^{57}Co	photon[a]	0,96	7			124	
^{137}Cs	photon[a]	0,85	10				662
^{60}Co	photon[a]	2,0	12				1 250

[a] Supression of electron emission by means of filters according to ISO 8769.

[b] End-point energy $E_{\beta,\mathrm{max}}$.

If available as class 2 reference sources with certified surface emission rates in the same energy regions, sources with basic radionuclides other than those given in Table A.1 may be used.

If a maximum usability of an instrument is required without being restricted by the emission characteristics of a radionuclide, efficiency determination using all the sources indicated in Table A.1 is recommended.

When calibration is required, calibration sources can be chosen from Table A.1 based on emission type and energy range. For example, $^{99\mathrm{m}}$Tc emits electrons in the beta energy region (70 to 140) keV and photons in the photon energy regions (15 to 90) keV and (90 to 300) keV. The sources to be used for calibration in this case are the sources designated for these energy regions (Table A.1).

A.3.2 Area of calibration sources

For surface contaminations evaluations, the area of the calibration source should be sufficient to cover the effective detector area, especially when not averaging the instrument reading.

Surface contamination guideline values according to national legislations (e.g. MARSSIM[1]) or surface contamination limits according to international conventions (e.g. IAEA Safety Standard No. SSR-6[2]) are expressed in activity per unit area (Bq·cm^{-2}) with an additional requirement for averaging the reading over a given area, i.e. 100 cm^2 and 300 cm^2, respectively. The dimension of the calibration source area should then correspond to the averaging area, i.e. 100 cm^2 for effective detector window areas of 100 cm^2 or larger and 300 cm^2 for effective detector window areas of 300 cm^2 or larger (see A.9).

A.4 Determination of the instrument efficiency

Instrument efficiency shall be determined under geometrical conditions which shall be as close as practicable to the conditions met during the measurement.

The area of the calibration source should be sufficient to cover the active or working area of the detector. Where the detector is larger than the calibration source sequential measurements shall be carried out with the calibration source moved across the surface of the detector. These measurements shall cover the whole of the window area of the probe and give an average value for the instrument efficiency.

The calibration source type may be adapted to the expected homogenous or heterogeneous contamination distribution. It is generally understood that contamination is frequently found in random locations rather than a uniform distribution. This fact should be taken into account when assessing the level of contamination from the probe efficiency data. This is done by averaging the assessed contamination preferably over 1 000 cm^2. For small-sized surface contaminations, calibration with point sources may sometimes be appropriate.

Probes that are capable of measuring alpha radiation shall be calibrated using alpha reference sources. The calibration provides instrument efficiency and demonstrates the instrument is operating correctly.

However, the instrument efficiency for alpha radiation derived from calibration should be applied with great caution in assessing the level of surface contamination because radiation from alpha contamination in the field is subject to severe attenuation from surface coatings (e.g. dust, grease, and moisture) and surface conditions (e.g. rough surfaces such as scrabbled concrete).

For the definition of the instrument efficiency, see Table 1 in 5.2.

The instrument efficiency $\varepsilon_{i,j}$ for a given radionuclide with radiation type j (alpha, beta or photon radiation) or for a given energy range represented by radiation type j is calculated according to:

$$\varepsilon_{i,j} = \frac{\rho_\mathrm{c} - \rho_0}{R_\mathrm{c}} \qquad \text{(A.1)}$$

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 surface emission rate for radiation type *j* (alpha, beta or photon radiation) of the calibration source in s^{-1}.

Calculation of the efficiency for the >400 keV beta energy region

The calibration source for the beta energy region >400 keV consists of the radionuclide pair $^{90}Sr/^{90}Y$ (Table A.1). Beside the emission of ^{90}Y in the >400 keV region, there is also the ^{90}Sr emission in the energy region (140 to 400) keV (Table A.1). Therefore, the efficiency for the region >400 keV ($\varepsilon_{i,400}$) has to be calculated using the efficiency for the (140 to 400) keV plus >400 keV region obtained for $^{90}Sr/^{90}Y$ ($\varepsilon_{i,\mathrm{SrY}}$) and the efficiency for the beta energy region (140 to 400) keV determined with ^{36}Cl ($\varepsilon_{i,\mathrm{Cl}}$). This is done as follows[5]:

$$\varepsilon_{i,400} = 2 \cdot \left(\varepsilon_{i,\mathrm{SrY}} - \frac{1}{2} \varepsilon_{i,\mathrm{Cl}} \right) \tag{A.2}$$

Calculation of the efficiency for the >300 keV photon energy region

The instrument efficiency for the >300 keV photon energy region can be determined by means of two different basic radionuclide reference sources. If both sources are available for measurements, a mean instrument efficiency is preferably calculated from calibration results for the photon energy region >300 keV obtained with both prescribed reference sources (Table A.1).

A.5 Examples of instrument efficiency determinations

Figure A.1 shows the results of instrument efficiency determinations according to A.4 for a high instrument efficiency SCM and a low instrument efficiency SCM.

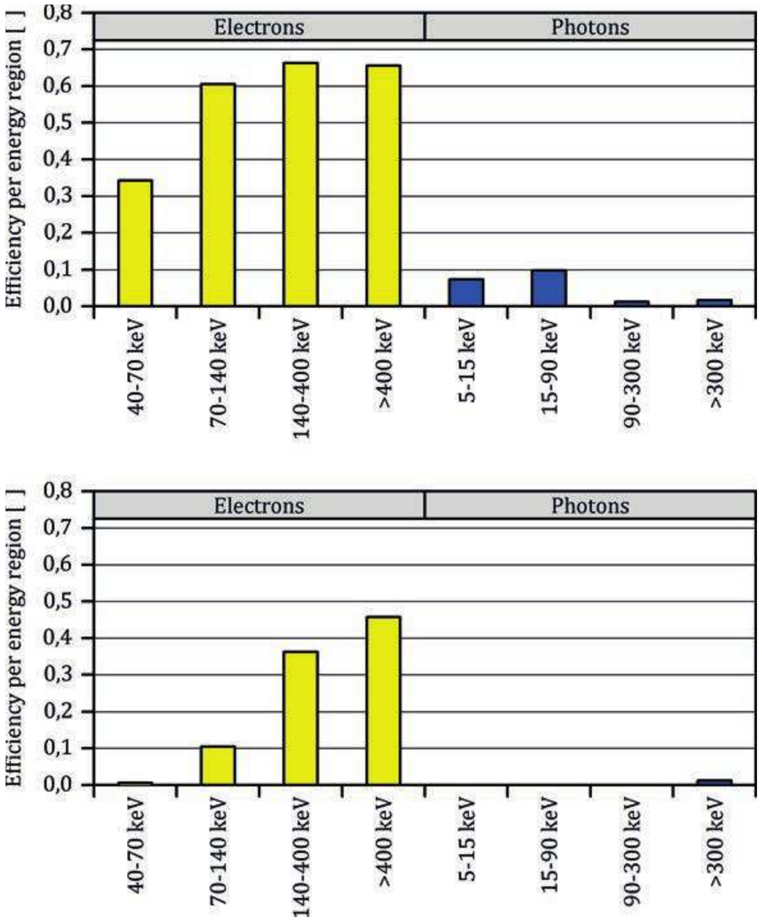


Figure A.1 — Instrument efficiency determinations for a high efficiency SCM (top) and a low efficiency SCM (bottom) (illustrative only)

A.6 Calculation of activity calibration factor and activity instrument response

For the definition of activity calibration factor and activity instrument response, see Table 1 in 5.2.

The activity calibration factor $C(A)_n$ [$= 1/I(A)$] for a given radionuclide n is calculated[5] according to:

$$C(A)_n = \frac{1}{S \cdot \sum_{i,j} \left(\varepsilon_{i,j} \cdot \eta_{i,j} \cdot E_{i,j}^{-1} \right)} \tag{A.3}$$

where

in case of no requirement for averaging, the instrument reading:

$S = S_\mathrm{p}$ is the effective detector window area in cm^2;

in case of a requirement for averaging, the instrument reading:

$S = S_G$ is the active calibration source area equal to the averaging area for the surface contamination guideline value in cm^2;

$\varepsilon_{i,j}$ is the instrument efficiency for a given energy or energy region i and for the radiation type j (alpha or beta or photon radiation);

$\eta_{i,j}$ is the summarized emission intensity data for a given energy region i and for the radiation type j (alpha or beta or photon radiation);

$E_{i,j}^{-1}$ is the reciprocal of the emergence factor of a surface contamination for a given energy or energy region i and for the radiation type j (alpha or beta or photon radiation).

The summation index refers to the radiation type and its specific energy regions.

The instrument net count rate $r_{G,n}$ in s^{-1} equivalent to the radionuclide specific surface contamination guideline value G_n[5] for a single radionuclide n can be expressed by:

$$r_{G,n} = \frac{G_n}{C(A)_n} = G_n \cdot I(A)_n \tag{A.4}$$

where

$S = S_G$ in Formula (A.3)

The activity of fixed and removable contamination of a radionuclide n on the surface being checked can be calculated using the multiple, $M_{G,n}$, of the surface contamination guideline value. The multiple $M_{G,n}$ of the surface contamination guideline value G_n[5] is calculated according to:

$$M_{G,n} = \frac{\left(\rho_{\text{g}} - \rho_0\right)}{r_{G,n}} \tag{A.5}$$

where

ρ_{g} is the measured total count rate from the surface contamination in s^{-1};

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

NOTE Numerical example demonstrating the use of the quantity $M_{G,n}$:

Let the guideline value count rate for ^{60}Co, $r_{G,\text{Co-60}}$, of a calibrated SCM, calculated according to Formula (A.4), be 44 s^{-1}. Assume a measurement of a surface contamination with this instrument results in a net count rate of 132 s^{-1}. The multiple of the guideline value $G_{\text{Co-60}}$, $M_{G,\text{Co-60}}$, calculated according to Formula (A.5), is then 132 s^{-1}/44 s^{-1} = 3. With a guideline value $G_{\text{Co-60}}$ = 3 Bq cm^{-2}, the activity per unit area of the measured surface contamination corresponds to 3 times 3 Bq·cm^{-2} = 9 Bq cm^{-2}.

An example for a SCM calibration for the radionuclide ^{131}I is given in B.6.

A.7 Source efficiency of contamination sources

The correct application of the emergence factor E is treated in Clause 5. For this quantity, a conservative approach is discussed in the following.

This approach should be used only with great precaution, if no or insufficient information is available concerning the nature, specific properties, and condition of a contaminated surface.

The efficiency of an actual contamination source, represented by the reciprocal of the emergence factor E, is difficult to estimate and may vary by an order of magnitude due to structural differences of the real sources. Only self-absorption in the source has to be considered here, since back-scattering increases the count rate and its omission provides an additional margin of safety by yielding a conservative (higher) value for the activity per unit area.

Values of E for beta-emitters are derived by considering the following types of contamination sources:

— thin layers of beta-emitters covered by about 2,5 mg cm^{-2} of inactive material;

— homogeneous beta sources of the thickness of a wipe test filter paper (~10 mg·cm^{-2}).

The first type of contamination sources may occur during direct measurements, the second one mainly during the application of the indirect measuring method.

In both cases, source efficiency losses by absorption in the source are considered to be negligible ($E = 2$) for beta emitters with $E_{\beta,\max} \geq 0{,}4$ MeV. Sources of beta-emitters with 0,15 MeV < $E_{\beta,\max}$ < 0,4 MeV are assumed to have a mean emergence factor E of about 4 under the same conditions.

Application of $E = 4$ can lead to an underestimation of beta activity covered by more absorbing material than specified above. It should, however, be noted that the contributions of such radioactive material to the risks of incorporation, inhalation and external radiation are reduced in parallel.

In the case of alpha-emitters, the assessment of plausible and conservative values for E is more difficult because E for practical contamination sources can easily reach very high numbers. A theoretical value for a saturation layer source is $E = 4$, and for the majority of alpha-emitters the saturation layer thickness is only about 5 mg cm^{-2}. The use of value $E = 4$ covers two important types of possible alpha contamination: layers up to saturation thickness homogeneously contaminated by alpha-emitters in the case of direct measurement, and sources produced and homogenized in the process of collecting a wipe test sample.

The value $E = 4$, however, underestimates activity per unit area when alpha-emitters are in a depth of more than saturation thickness or when thin layers of alpha-emitters are covered by inactive material of more than 50 % of the saturation thickness. This confirms the importance of wipe tests.

A.8 Consequences of coincidence summing effect on the instrument detection efficiency

Radioactive decay typically yields nearly simultaneous emissions of particles and photons. For example a nucleus after beta decay usually is in an excited energy level, which is reduced to ground state by the emission of photon energy in one or several steps. Another example is conversion electrons in combination with photon emissions.

These combined emissions cannot be counted separately, if the detector response time is larger than the time difference between emissions (coincidence summing effect).

For an approximation of the maximum impact of the coincidence summing effect it is assumed, that all detected combined emissions of particles and photons are summed. The summation effect is correlated to the instrument efficiency per decay instead to the instrument efficiency per surface emission. The probability P_d for a surface contamination monitor to detect a cascade of n steps can be expressed in terms of the decay based detection efficiency $\left(\varepsilon_{i,j} \cdot E_{i,j}^{-1} \cdot \eta_{i,j}\right)$ for the radiation type j as:

$$P_\mathrm{d} = 1 - \prod_{i=1}^{n}\left(1 - \left(\varepsilon_{i,j} \cdot E_{i,j}^{-1} \cdot \eta_{i,j}\right)\right) \quad \text{(A.6)}$$

For a cascade consisting of one beta decay followed by one photon decay with $\eta_{i,j} = 1$:

$$P_\mathrm{d} = 1 - \left(1 - \left(\varepsilon_{i,\beta} \cdot E_{i,\beta}^{-1}\right)\right)\left(1 - \left(\varepsilon_{i,\gamma} \cdot E_{i,\gamma}^{-1}\right)\right) = \left(\varepsilon_{i,\beta} \cdot E_{i,\beta}^{-1}\right) + \left(\varepsilon_{i,\gamma} \cdot E_{i,\gamma}^{-1}\right) - \left(\varepsilon_{i,\beta} \cdot E_{i,\beta}^{-1}\right)\left(\varepsilon_{i,\gamma} \cdot E_{i,\gamma}^{-1}\right)$$

Thus, P_d is not exactly the sum of beta and photon detection efficiency, but the sum reduced by the product of the respective detection efficiencies.

For the calculation of the calibration factor (A.3), instrument efficiencies for beta and photon radiation multiplied by the respective radionuclide decay efficiencies are added. So, the coincidence summing effect has to be assessed.

This assessment assumes that summation of different photon emissions can be neglected. The detection efficiencies derived above are added (“Sum” in Table A.2 and Table A.3). An analogue summation is separately made for the beta and photon radiation energy regions and the product of the two sums is calculated ("Product" in Table A.2 and Table A.3). By comparison of "sum" and "product", the relative extent of the coincidence summing effect for a given radionuclide can be derived.

The above described analysis was performed for a total of 158 radionuclides from a decay efficiency database for a high instrument efficiency SCM and for a total of 105 radionuclides for a low instrument efficiency SCM (compare Figure A.1)[5].

The analysis of the extent of the coincidence summing effect on the detection efficiency shows, that this effect does not exceed 7 % (Table A.2 and Table A.3). For the SCM having high instrument efficiencies, the mean coincidence summing effect amounts to (1,5 ± 0,1) % (68 % confidence level) and for the SCM having low instrument efficiencies to (0,8 ± 0,1) % (68 % confidence level)[5].

Table A.2 — Example of summation effect for high instrument efficiency SCM (radionuclide ^{169}Yb)

	Electrons				Photons				Sum	Product	Product
	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV	$\sum\left(\varepsilon_{i,j}\cdot E_{i,j}^{-1}\right)\cdot\eta_{i,j}$	$\sum\left(\left(\varepsilon_{i,\beta}\cdot E_{i,\beta}^{-1}\right)\cdot\eta_{i,\beta}\right)\cdot\sum\left(\left(\varepsilon_{i,\gamma}\cdot E_{i,\gamma}^{-1}\right)\cdot\eta_{i,\gamma}\right)$	as percent of sum
$\left(\varepsilon_{i,j}\cdot E_{i,j}^{-1}\right)$	0,085	0,151	0,331	0,329	0,035	0,048	0,005	0,008			
$\left(\eta_{i,j}\right)_{\text{Yb}-169}$	0,560	0,470	0,060	0,000	0,510	2,320	0,930	0,100			
$\left(\varepsilon_{i,j}\cdot E_{i,j}^{-1}\right)\cdot\eta_{i,j}$	0,047	0,071	0,019	0,000	0,018	0,110	0,004	0,001	0,272	0,018	6,8 %

Table A.3 — Example of summation effect for low instrument efficiency SCM (radionuclide ^{134}I)

	Electrons				Photons				Sum	Product	Product
	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV	$\sum\left(\varepsilon_{i,j}\cdot E_{i,j}^{-1}\right)\cdot\eta_{i,j}$	$\sum\left(\left(\varepsilon_{i,\beta}\cdot E_{i,\beta}^{-1}\right)\cdot\eta_{i,\beta}\right)\cdot\sum\left(\left(\varepsilon_{i,\gamma}\cdot E_{i,\gamma}^{-1}\right)\cdot\eta_{i,\gamma}\right)$	as percent of sum
$\left(\varepsilon_{i,j}\cdot E_{i,j}^{-1}\right)$	0,001	0,026	0,183	0,229	0,000	0,000	0,000	0,008			
$\left(\eta_{i,j}\right)_{\mathrm{I-134}}$	0,000	0,010	0,050	0,960	0,000	0,020	0,090	2,920			
$\left(\varepsilon_{i,j}\cdot E_{i,j}^{-1}\right)\cdot\eta_{i,j}$	0,000	0,000	0,010	0,220	0,000	0,000	0,000	0,022	0,253	0,005	2,0 %

A.9 Applicability of the different activity calibration factor types

If surface contamination guideline values (national legislations) or surface contamination limits (international conventions) have to be followed, the correct calibration factor shall be chosen in order to avoid an underestimating of the measuring results. Table A.4 presents the following: a case differentiation in relation to calibration factor type; effective detector window area; calibration source area and averaging area.

Table A.4 — Case differentiation for consequences of calibration factor type on the measuring result

Calibration factor type	Effective detector window area cm^2	Calibration source area cm^2	Averaging area cm^2	Measuring result		
				under-estimated	accurate	conservative
$C(A)_n$ with	100	100	100		+	
$S = S_p$	150	150	100	+		
	300	300	100	+		
	100	100	300			+
	150	150	300			+
	300	300	300		+	
$C(A)_n$ with	100	100	100		+	
$S = S_G$	150	100	100			+
	300	100	100			+
	100	100	300			+
	150	100	300			+
	300	100	300			+

It follows from Table A.4 that accurate or conservative measuring results are achieved if an instrument is used with a calibration factor type relating to an effective detector window area or a calibration source area not larger than the required averaging area.

A.10 Calculation of the activity per unit area for surface contaminations of a radionuclide

The activity per unit area, $A_{s,n,}$ of fixed and removable contamination of a radionuclide n, in relation to the measured count rate, is expressed in $\text{Bq}\cdot\text{cm}^{-2}$, and is given by Formula (A.7):

$$A_{s,n} = C(A)_n \cdot \left(\rho_\text{g} - \rho_0\right) \qquad \text{(A.7)}$$

where

$C(A)_n$ is the activity calibration factor for a given radionuclide n in $(\text{Bq}\cdot\text{cm}^{-2})/\text{s}^{-1}$;

ρ_g is the measured total count rate from the surface contamination in s^{-1};

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

A.11 Determination of characteristic limits according to ISO 11929

The calculation of the characteristic limits (decision threshold, detection limit and limits of the confidence interval) according to ISO 11929 is given in Annex E.

Annex B
(informative)

Direct surface contamination evaluation: Numeric calibration examples

B.1 General

Numeric calibration examples 1 to 4 given in this Annex are based on the principal calibration methodology including summation correction (Clause 5) and example 5 serves to illustrate the application of the calibration method outlined in Annex A.

B.2 Example 1: Calibration for the radionuclide ^{125}I

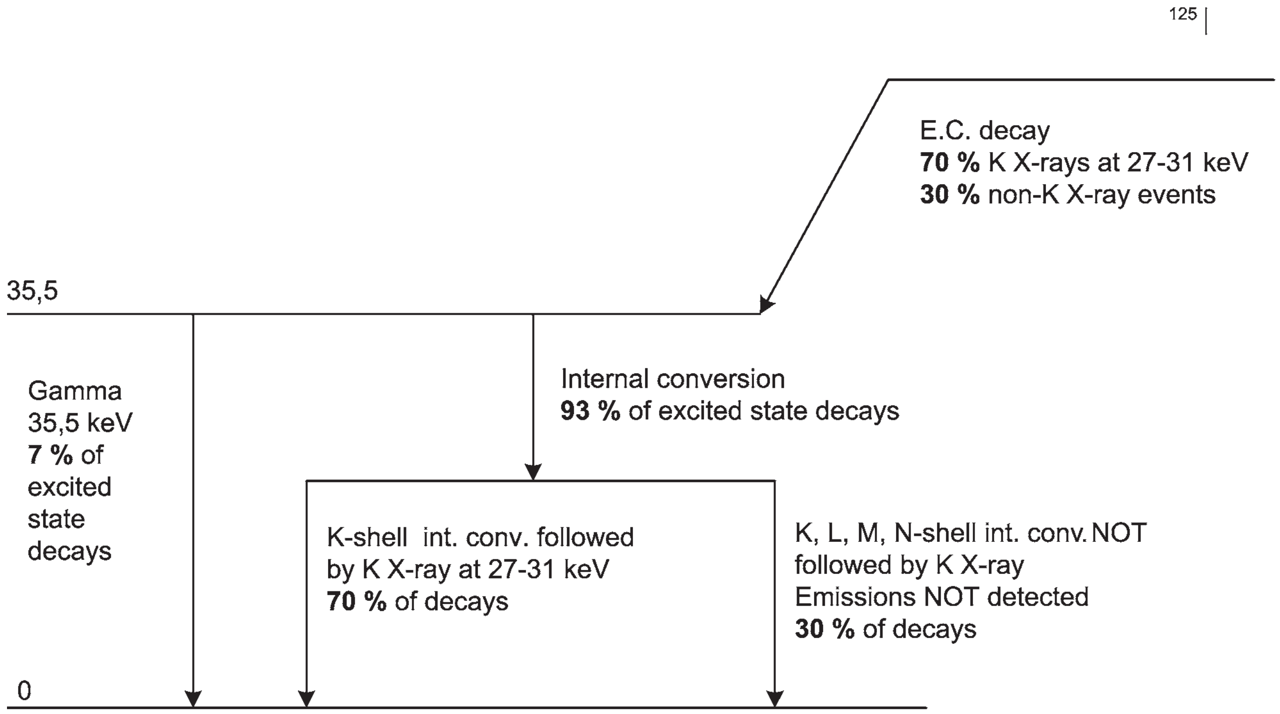


Figure B.1 — Decay scheme of ^{125}I

Assumptions made:

Conversions electrons (~30 keV) and non K X-rays are absorbed by the source and/or the detector window and are not detected.

Instrument efficiencies for the gamma and the K X-rays are approximately the same, ε_{30}.

E-factors for the gamma and the K X-rays are approximately the same, $E_{30,\gamma}$.

Table B.1 — Decay path abundances and products for ^{125}I

Components of paths	Decay path abundance	Product, k_i
ec K X-ray, gamma	0,7 × 0,07	0,049
ec K X-ray, int. conv. K X-ray	0,7 × 0,93 × 0,7	0,456
ec K X-ray, int. conv non K X-ray	0,7 × 0,93 × 0,3	0,195
ec non K X-ray, gamma	0,3 × 0,07	0,021
ec non K X-ray, int. conv. K X-ray	0,3 × 0,93 × 0,7	0,195
ec non K X-ray, int. conv. non K X-ray	0,3 × 0,93 × 0,3	0,084 (no detections)

It should be noted that for the last path (ec non K X-ray, int. conv. non K X-ray), the detection efficiency is zero, i.e. none of the emissions is detected.

Therefore

$I(A)_{\text{I-125}} = S_p$ times probability of registering a detection

$$I(A)_{\text{I-125}} = S_{\text{p}} \cdot \begin{array}{l} 0,049 \cdot \left\{1 - \left(1 - \dfrac{\varepsilon_{30}}{E_{30,\gamma}}\right)^2\right\} + 0,456 \cdot \left\{1 - \left(1 - \dfrac{\varepsilon_{30}}{E_{30,\gamma}}\right)^2\right\} + 0,195 \cdot \left\{1 - \left(1 - \dfrac{\varepsilon_{30}}{E_{30,\gamma}}\right)\right\} \\ \qquad + 0,021 \cdot \left\{1 - \left(1 - \dfrac{\varepsilon_{30}}{E_{30,\gamma}}\right)\right\} + 0,195 \cdot \left\{1 - \left(1 - \dfrac{\varepsilon_{30}}{E_{30,\gamma}}\right)\right\} \end{array} \tag{B.1}$$

$$S_{\text{p}} \cdot 0,505 \cdot \left\{1 - \left(1 - \frac{\varepsilon_{30}}{E_{30,\gamma}}\right)^2\right\} + 0,411 \cdot \left\{1 - \left(1 - \frac{\varepsilon_{30}}{E_{30,\gamma}}\right)\right\}$$

Consider a NaI detector 2 mm thick, Al window 14 mg cm^{-2}, where $\varepsilon_{30} = 1$.

For an ideal source i.e. no absorption or attenuation, $E_{30,\gamma} = 2$, giving

$I(A)_{\text{I-125}} = 0{,}58 \cdot S_{\text{p}}$

For a greasy, porous surface, it might be estimated that only 70 % of the 30 keV photons are transmitted through the surface layer so that $E_{30,\gamma} = 3$, giving

$I(A)_{\text{I-125}} = 0{,}42 \cdot S_{\text{p}}$

B.3 Example 2: Calibration for the radionuclide ^{32}P

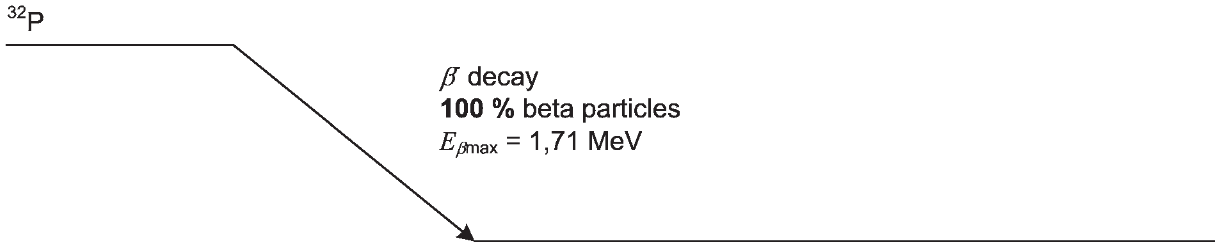


Figure B.2 — Decay scheme of ^{32}P

In this case, there is just a single decay branch and no cascade emissions. The activity instrument response figure is therefore:

$$I(A)_{\text{P-32}} = S_{\text{p}} \cdot \frac{\varepsilon_{1710}}{E_{1710,\beta}}$$

Using the data in Figure 3 given in 5.5.1, the instrument efficiency at 1,71 MeV is estimated to be 0,545.

For most surfaces, there is almost no absorption and the E-factor may be taken as 2, giving:

$$I(A)_{\text{P-32}} = \frac{0{,}545 \cdot S_{\text{p}}}{2} = 0{,}27 \cdot S_{\text{p}}$$

B.4 Example 3: Calibration for the radionuclide $^{99\text{m}}$Tc

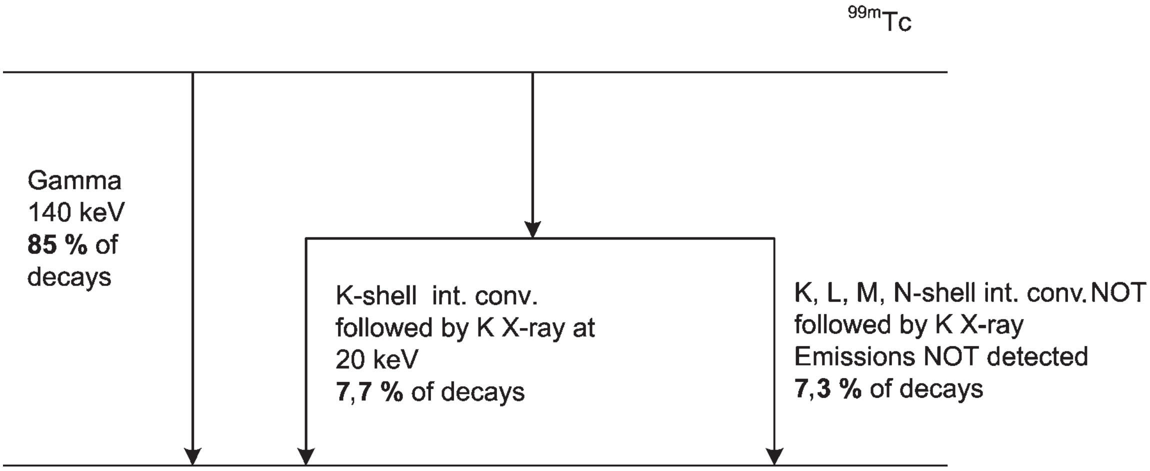


Figure B.3 — Decay scheme of $^{99\text{m}}$Tc

$^{99\text{m}}$Tc decays by isomeric transition with the emission of a 140 keV photon or the emission of conversion electrons, X-rays and Auger electrons following the internal conversion process. It is assumed that the conversion electrons, Auger electrons and the L, M, N, etc. X-rays are of sufficiently low energy that they are not detected.

There are no cascade emissions to be taken into account. Therefore the activity instrument response factor is given by:

$$I(A)_{\text{Tc-99m}} = S_{\text{p}} \cdot \left[0{,}85 \cdot \left\{ 1 - \left(1 - \frac{\varepsilon_{140}}{E_{140,\gamma}} \right) \right\} + 0{,}077 \cdot \left\{ 1 - \left(1 - \frac{\varepsilon_{20}}{E_{20,\gamma}} \right) \right\} \right] \tag{B.2}$$

Consider a NaI detector 2 mm thick, Al window 14 mg cm^{-2}, where $\varepsilon_{20} = 1$ and $\varepsilon_{140} = 0{,}5$.

For an ideal source i.e. no absorption or attenuation, $E_{20,\gamma} = E_{140,\gamma} = 2$, giving

$$I(A)_{\text{Tc-99m}} = 0{,}25 \cdot S_{\text{p}}$$

For a greasy, porous surface, it might be estimated that only 70 % of the 20 keV photons are transmitted through the surface layer while the 140 keV photons have a transmission efficiency of 90 % so that $E_{20,\gamma}$ approximately 3 and $E_{140,\gamma}$ approximately 2,2, giving

$$I(A)_{\text{Tc-99m}} = 0{,}22 \cdot S_{\text{p}}$$

B.5 Example 4: Calibration for the radionuclide ^{111}In

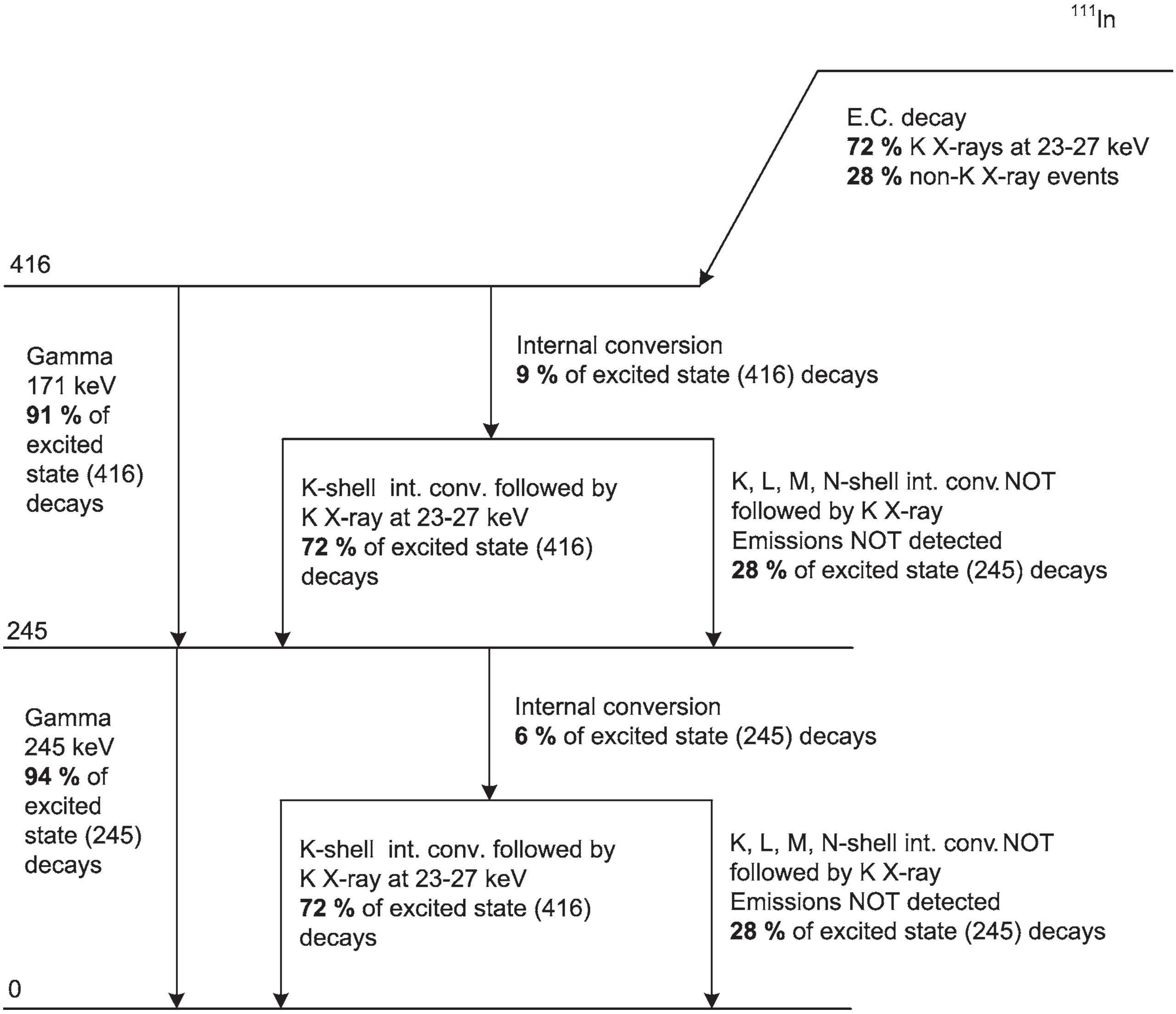


Figure B.4 — Decay scheme of ^{111}In

The following assumptions are made:

All X-rays other than K-shell X-rays are absorbed by the source and/or the detector window and are not detected.

Conversion electrons are absorbed by the source and detector window.

The following abbreviations are used for the individual paths:

ecK	electron capture event resulting in a K X-ray
ecL	electron capture event NOT resulting in a K X-ray
g171	171 keV photon
g245	245 keV photon
ic171K	internal conversion from the 416 keV excited state resulting in a K X-ray

ic171L	internal conversion from the 416 keV excited state NOT resulting in a K X-ray
ic245K	internal conversion from the 245 keV excited state resulting in a K X-ray
ic245L	internal conversion from the 245 keV excited state NOT resulting in a K X-ray

There are then 18 separate pathways to consider (see Table B.2):

Table B.2 — Decay path abundances and products for ^{111}In

Components of paths	Decay path abundance	Product, k_i
ecK, g171, g245	0,72 × 0,91 × 0,94	0,62
ecK, g171, ic245K	0,72 × 0,91 × 0,06 × 0,72	0,03
ecK, g171, ic245L	0,72 × 0,91 × 0,06 × 0,28	0,01
ecK, ic171K, g245	0,72 × 0,09 × 0,72 × 0,94	0,04
ecK, ic171K, ic245K	0,72 × 0,09 × 0,72 × 0,06 × 0,72	0,002
ecK, ic171K, ic245L	0,72 × 0,09 × 0,72 × 0,06 × 0,28	0,001
ecK, ic171L, g245	0,72 × 0,09 × 0,28 × 0,94	0,02
ecK, ic171L, ic245K	0,72 × 0,09 × 0,28 × 0,06 × 0,72	0,001
ecK, ic171L, ic245L	0,72 × 0,09 × 0,28 × 0,06 × 0,28	0,001
ecL, g171, g245	0,28 × 0,91 × 0,94	0,24
ecL, g171, ic245K	0,28 × 0,91 × 0,06 × 0,72	0,01
ecL, g171, ic245L	0,28 × 0,91 × 0,06 × 0,28	0,004
ecL, ic171K, g245	0,28 × 0,09 × 0,72 × 0,94	0,02
ecL, ic171K, ic245K	0,28 × 0,09 × 0,72 × 0,06 × 0,72	0,001
ecL, ic171K, ic245L	0,28 × 0,09 × 0,72 × 0,06 × 0,28	0,0003
ecL, ic171L, g245	0,28 × 0,09 × 0,28 × 0,94	0,007
ecL, ic171L, ic245K	0,28 × 0,09 × 0,28 × 0,06 × 0,72	0,0003
ecL, ic171L, ic245L	0,28 × 0,09 × 0,28 × 0,06 × 0,28	0,0001 (no detections)

It should be noted that for the last path (electron capture and internal conversions, all with no K X-rays) the detection efficiency is zero i.e. none of the emissions is detected.

The total expression for the activity instrument response factor is propagated in the same way as for the ^{125}I example. For reasons of space, the total propagation is not given here but two pathway examples are shown below for illustration.

For the (ecK, g171, g245) pathway, the relevant term is:

$$S_\mathrm{p} \cdot 0{,}62 \cdot \left\{1 - \left(1 - \frac{\varepsilon_{25}}{E_{25,\gamma}}\right) \cdot \left(1 - \frac{\varepsilon_{171}}{E_{171,\gamma}}\right) \cdot \left(1 - \frac{\varepsilon_{245}}{E_{245,\gamma}}\right)\right\}$$

and for the (ecL, ic171K, g245) pathway, the relevant term is:

$$S_\mathrm{p} \cdot 0{,}02 \cdot \left\{1 - \left(1 - \frac{\varepsilon_{25}}{E_{25,\gamma}}\right) \cdot \left(1 - \frac{\varepsilon_{245}}{E_{245,\gamma}}\right)\right\}$$

There is no efficiency term for ecL as it is not detected.

If $a=\left(1-\dfrac{\varepsilon_{25}}{E_{25,\gamma}}\right)$, $b=\left(1-\dfrac{\varepsilon_{171}}{E_{171,\gamma}}\right)$ and $c=\left(1-\dfrac{\varepsilon_{245}}{E_{245,\gamma}}\right)$, the total expression for the radionuclide activity instrument response factor reduces to:

$$I(A)_{\text{In-111}}=S_{\text{p}}\cdot\left[\begin{array}{c}0,62\cdot\left(1-a\cdot b\cdot c\right)+0,03\cdot\left(1-a^{2}\cdot b\right)+0,04\cdot\left(1-a^{2}\cdot c\right)+0,003\cdot\left(1-a^{2}\right)\\ +0,002\cdot\left(1-a^{3}\right)+0,02\cdot\left(1-a\cdot b\right)+0,04\cdot\left(1-a\cdot c\right)+0,24\cdot\left(1-b\cdot c\right)\\ +0,001\cdot\left(1-a\right)+0,004\cdot\left(1-b\right)+0,007\cdot\left(1-c\right)\end{array}\right] \tag{B.3}$$

Consider a NaI detector 2 mm thick, Al window 14 mg cm^{-2}, where ε_{25} = 0,9, ε_{171} = 0,4 and ε_{245} = 0,15.

For an ideal source i.e. no absorption or attenuation, $E_{25,\gamma}$ = $E_{171,\gamma}$ = $E_{245,\gamma}$ = 2, giving

$I(A)_{\text{In-111}}$ = 0,52 · S_{p}

For a greasy, porous surface, it might be estimated that $E_{25,\gamma}$ approximately 4, $E_{171,\gamma}$ approximately 2, $E_{245,\gamma}$ approximately 2, giving

$I(A)_{\text{In-111}}$ = 0,39 · S_{p}

B.6 Example 5: Calibration for the radionuclide ^{131}I

B.6.1 Radionuclide data treatment

B.6.1.1 Preparation of beta and photon emission probabilities $\eta_{i,\beta}$ and $\eta_{i,\gamma}$

Data source for this example are NuDat data files (by National Nuclear Data Center, Brookhaven National Laboratory) derived from ENSDF (Evaluated Nuclear Structure Data File). Decay data are first edited by deleting emission probabilities or intensities less than 0,1 % (Table B.3).

Table B.3 — Nuclear data for the radionuclide example ^{131}I

Radionuclide	Half-life	Unit	Radiation type	Energy keV	u_E	Intensity %	u_I
I-131	8,0207	d	beta particles	69,36	0,19	2,1	0,03
I-131	8,0207	d	beta particles	86,94	0,2	0,651	0,023
I-131	8,0207	d	beta particles	96,62	0,2	7,27	0,1
I-131	8,0207	d	beta particles	191,58	0,23	89,9	0,8
I-131	8,0207	d	beta particles	283,24	0,23	0,48	0,01
I-131	8,0207	d	E AU K	24,6	0	0,6	0,04
I-131	8,0207	d	E AU L	3,43	0	5,1	0,4
I-131	8,0207	d	E CE K	45,6236	0	3,5	0,3
I-131	8,0207	d	E CE K	249,744	0,005	0,252	0,017
I-131	8,0207	d	E CE K	329,928	0,005	1,55	0,2
I-131	8,0207	d	E CE L	74,7322	0	0,46	0,04
I-131	8,0207	d	E CE L	359,036	0,005	0,246	0,022
I-131	8,0207	d	gamma	80,185	0	2,62	0,04
I-131	8,0207	d	gamma	177,214	0	0,27	0,004
I-131	8,0207	d	gamma	284,305	0,005	6,14	0,07

Table B.3 *(continued)*

Radionuclide	Half-life	Unit	Radiation type	Energy keV	u_E	Intensity %	u_I
I-131	8,0207	d	gamma	325,789	0,004	0,274	0,022
I-131	8,0207	d	gamma	364,489	0,005	81,7	0,8
I-131	8,0207	d	gamma	503,004	0,004	0,36	0,004
I-131	8,0207	d	gamma	636,989	0,004	7,17	0,1
I-131	8,0207	d	gamma	642,719	0,005	0,217	0,005
I-131	8,0207	d	gamma	722,911	0,005	1,77	0,03
I-131	8,0207	d	X KA1	29,779	0	2,56	0,16
I-131	8,0207	d	X KA2	29,458	0	1,38	0,09
I-131	8,0207	d	X KB	33,6	0	0,91	0,06
I-131	8,0207	d	X L	4,11	0	0,57	0,18

B.6.1.2 Sorting and addition of beta and of photon emission probabilities

In the next step, intensity data are sorted according to radiation type and emission energy into energy regions (A.3) and the intensity data per energy region are added (Table B.4). The summarized data converted from percent to absolute figures form the radionuclide and radiation type specific $\eta_{i,j}$ values (marked bold in Table B.4).

Table B.4 — Added intensities for beta and photon emission energy regions for ^{131}I

Radio-nuclide	Half-life	Unit	Radiation type	Energy keV	Intensity %	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV
I-131	8,0207	d	beta part.	69,36	2,1	2,1	0	0	0				
I-131	8,0207	d	beta part.	86,94	0,651	0	0,651	0	0				
I-131	8,0207	d	beta part.	96,62	7,27	0	7,27	0	0				
I-131	8,0207	d	beta part.	191,58	89,9	0	0	89,9	0				
I-131	8,0207	d	beta part.	283,24	0,48	0	0	0,48	0				
I-131	8,0207	d	E AU K	24,6	0,6	0	0	0	0				
I-131	8,0207	d	E AU L	3,43	5,1	0	0	0	0				
I-131	8,0207	d	E CE K	45,6236	3,5	3,5	0	0	0				
I-131	8,0207	d	E CE K	249,744	0,252	0	0	0,252	0				
I-131	8,0207	d	E CE K	329,928	1,55	0	0	1,55	0				
I-131	8,0207	d	E CE L	74,7322	0,46	0	0,46	0	0				
I-131	8,0207	d	E CE L	359,036	0,246	0	0	0,246	0				
I-131	8,0207	d	gamma	80,185	2,62					0	2,62	0	0
I-131	8,0207	d	gamma	177,214	0,27					0	0	0,27	0
I-131	8,0207	d	gamma	284,305	6,14					0	0	6,14	0
I-131	8,0207	d	gamma	325,789	0,274					0	0	0	0,274
I-131	8,0207	d	gamma	364,489	81,7					0	0	0	81,7
I-131	8,0207	d	gamma	503,004	0,36					0	0	0	0,36
I-131	8,0207	d	gamma	636,989	7,17					0	0	0	7,17
I-131	8,0207	d	gamma	642,719	0,217					0	0	0	0,217
I-131	8,0207	d	gamma	722,911	1,77					0	0	0	1,77
I-131	8,0207	d	X KA1	29,779	2,56					0	2,56	0	0
I-131	8,0207	d	X KA2	29,458	1,38					0	1,38	0	0
I-131	8,0207	d	X KB	33,6	0,91					0	0,91	0	0
I-131	8,0207	d	X L	4,11	0,57					0	0	0	0
I-131						**0,0560**	**0,0838**	**0,9243**	**0,0000**	**0,0000**	**0,0747**	**0,0641**	**0,9149**

B.6.2 Calculation of the summation term of Formula (A.3)

For illustration, the data necessary for calculation are represented in a 8 x 4 "matrix" (Table B.5).

Table B.5 — Calculation scheme for the summation term of Formula (A.3)

	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV
Instrument efficiency $\varepsilon_{i,j}$	0,275	0,416	0,485	0,553	0,019	0,003	0,003	0,009
Emission probability $\eta_{i,j}$	0,056 0	0,083 8	0,924 3	0,000 0	0,000 0	0,074 7	0,064 1	0,914 9
Contamination source eff. $E_{i,j}^{-1}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5
Product of indiv. columns	0,003 9	0,008 7	0,224 1	0,000 0	0,000 0	0,000 1	0,000 1	0,004 1

The number products formed for the individual columns are added to give the summation term of Formula (A.3):

$$\sum_{i,j}\left(\varepsilon_{i,j}\cdot\eta_{i,j}\cdot E_{i,j}^{-1}\right)=0,241$$

B.6.3 Calculation of calibration factor, instrument response and instrument net count rate for the guideline value

With the averaging area S_G of 100 cm^2 for the surface contamination guideline value the activity calibration factor for ^{131}I becomes:

$$C(A)_{\mathrm{I-131}}=\frac{1}{S_G\cdot\sum\limits_{i,j}\left(\varepsilon_{i,j}\cdot\eta_{i,j}\cdot E_{i,j}^{-1}\right)}=0,041\ (\mathrm{Bq\cdot cm^{-2}})/\mathrm{s^{-1}}$$

and the instrument response is given by:

$$I(A)_{\mathrm{I-131}}=S_G\cdot\sum_{i,j}\left(\varepsilon_{i,j}\cdot\eta_{i,j}\cdot E_{i,j}^{-1}\right)=24,1\ \mathrm{s^{-1}}/(\mathrm{Bq\cdot cm^{-2}})$$

For a surface contamination guideline value $G_{\text{I-131}}$ of 3 Bq cm^{-2} the instrument net count rate $r_{G,\text{I-131}}$ becomes:

$$r_{G,\text{I-131}}=\frac{G_{\text{I-131}}}{C(A)_{\text{I-131}}}=73\ \mathrm{s^{-1}}$$

The relative effect of summation according to A.8 amounts to 1,1 % for ^{131}I.

B.7 Case comparisons

B.7.1 General

In the following, calibration results obtained according to Clause 5 are compared to calibration results obtained by using the calibration method given in Annex A.

B.7.2 Case 1: ^{125}I

In the upper part of Table B.6 a) and b), $\varepsilon_{i,j} \cdot \eta_{i,j} \cdot E_{i,j}^{-1}$ products are formed for the respective energy regions using Formula (A.3) and summarized in the column "Sum". Multiplication with S_p = 100 cm^2 gives the activity instrument response $I(A)$ in s^{-1}/(Bq cm^{-2}) and as reciprocal of $I(A)$ the activity calibration factor $C(A)$ in (Bq cm^{-2})/s^{-1}. In the last row of the tables, the calculation is performed according to Formula (B.1). The two respective results for $C(A)$ and $I(A)$ in Table B.6 a) agree.

Table B.6 — Comparison of $I(A)$ calculation for ^{125}I according to Annex A and Annex B

a)	**Electrons**				**Photons**				**"Sum"**	**$C(A)$**	**$I(A)$**
I-125	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV			
$\varepsilon_{i,j}$	0,339	0,602	0,662	0,659	0,071	0,095	0,009	0,016			
$\eta_{i,j}$	0,000	0,000	0,000	0,000	0,000	1,400	0,000	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			
Annex A	0,000	0,000	0,000	0,000	0,000	0,067	0,000	0,000	0,067	0,150	6,65
Annex B				$a = \varepsilon_{30}$		0,953			0,066	0,151	6,64
b)	**Electrons**				**Photons**				**"Sum"**	**$C(A)$**	**$I(A)$**
I-125	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV			
$\varepsilon_{i,j}$	0,339	0,602	0,662	0,659	0,071	1,000	0,009	0,016			
$\eta_{i,j}$	0,000	0,000	0,000	0,000	0,000	1,400	0,000	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			
Annex A	0,000	0,000	0,000	0,000	0,000	0,700	0,000	0,000	0,700	0,014	70,0
Annex B				$a = \varepsilon_{30}$		0,500			0,584	0,017	58,4

If $\varepsilon_{i,j}$ for the photon energy region (15 to 90) keV is set to 1 as given in B.2, a higher activity instrument response results for the calculation using Formula (A.3) compared to the calculation using Formula (B.1) [Table B.6 b)]. A 100 % instrument efficiency for the photon energy region (15 to 90) keV however is unrealistic for a SCM (A.5).

B.7.3 Case 3: $^{99\text{m}}$Tc

In the upper part of Table B.7 a), b) and c), $\varepsilon_{i,j} \cdot \eta_{i,j} \cdot E_{i,j}^{-1}$ products are formed for the respective energy regions using Formula (A.3) and summarized in the column "Sum". Multiplication with S_p = 100 cm^2 gives the activity instrument response $I(A)$ in s^{-1}/(Bq cm^{-2}) and as reciprocal of $I(A)$ the activity calibration factor $C(A)$ in (Bq cm^{-2})/s^{-1}. In the last two rows of the Table B.7, the calculation is performed according to Formula (B.2).

Table B.7 — Comparison of $I(A)$ calculation for $^{99\text{m}}$Tc according to Annex A and Annex B

a)	**Electrons**				**Photons**				**"Sum"**	**$C(A)$**	**$I(A)$**
Tc-99m	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV			
$\varepsilon_{i,j}$	0,339	0,602	0,662	0,659	0,071	0,095	0,009	0,016			
$\eta_{i,j}$	0,000	0,114	0,000	0,000	0,000	0,076	0,885	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			

Table B.7 *(continued)*

Annex A	0,000	0,017	0,000	0,000	0,000	0,004	0,004	0,000	0,025	0,400	2,50
Annex B				$a = \varepsilon_{20}$		0,952					
				$b = \varepsilon_{140}$			0,995		0,008	1,299	0,77
b)	**Electrons**				**Photons**				**“Sum”**	***C*(*A*)**	**I(*A*)**
Tc-99m	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV			
$\varepsilon_{i,j}$	0,339	0,000	0,662	0,659	0,071	0,095	0,009	0,016			
$\eta_{i,j}$	0,000	0,114	0,000	0,000	0,000	0,076	0,885	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			
Annex A	0,000	0,000	0,000	0,000	0,000	0,004	0,004	0,000	0,008	1,283	0,78
Annex B				$a = \varepsilon_{20}$		0,952					
				$b = \varepsilon_{140}$			0,995		0,008	1,299	0,77
c)	**Electrons**				**Photons**				**“Sum”**	***C*(*A*)**	***I*(*A*)**
Tc-99m	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV			
$\varepsilon_{i,j}$	0,339	0,000	0,662	0,659	0,071	1,000	0,500	0,016			
$\eta_{i,j}$	0,000	0,114	0,000	0,000	0,000	0,076	0,885	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			
Annex A	0,000	0,000	0,000	0,000	0,000	0,038	0,221	0,000	0,259	0,039	25,9
Annex B				$a = \varepsilon_{20}$		0,500					
				$b = \varepsilon_{140}$			0,750		0,251	0,040	25,1

If $\varepsilon_{i,j}$ for the beta energy region (70 to 140) keV is left unchanged, a higher activity instrument response results for the calculation using Formula (A.3) compared to the calculation using Formula (B.2) [Table B.7 a)].

If $\varepsilon_{i,j}$ for the beta energy region (70 to 140) keV is changed to 0 as given in B.4, the two respective results for *C*(*A*) and *I*(*A*) in Table B.7 b) agree. The same holds true, if in addition the instrument efficiencies for the photon energy regions (15 to 90) keV and (90 to 300) keV are changed to 1 and 0,5, respectively, as given in B.4 [Table B.7 c)]. A 100 % instrument efficiency for the photon energy region (15 to 90) keV however is unrealistic for a SCM (A.5).

B.7.4 Case 4: ^{111}In

In the upper part of Table B.8 a), b) and c), $\varepsilon_{i,j} \cdot \eta_{i,j} \cdot E_{i,j}^{-1}$ products are formed for the respective energy regions using Formula (A.3) and summarized in the column “Sum”. Multiplication with S_p = 100 cm^2 gives the activity instrument response *I*(*A*) in s^{-1}/(Bq cm^{-2}) and as reciprocal of *I*(*A*) the activity calibration factor *C*(*A*) in (Bq cm^{-2})/s^{-1}. In the last three rows of the Table B.8, the calculation is performed according to Formula (B.3).

Table B.8 — Comparison of $I(A)$ calculation for ^{111}In according to Annex A and Annex B

a)	**Electrons**				**Photons**				**“Sum”**	**$C(A)$**	**$I(A)$**
In-111	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV			
$\varepsilon_{i,j}$	0,339	0,602	0,662	0,659	0,071	0,095	0,009	0,016			
$\eta_{i,j}$	0,000	0,000	0,149	0,000	0,000	0,823	1,842	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			
Annex A	0,000	0,000	0,049	0,000	0,000	0,039	0,009	0,000	0,097	0,103	9,74
Annex B				$a = \varepsilon_{25}$		0,952					
				$b = \varepsilon_{171}$			0,995				
				$c = \varepsilon_{245}$			0,995		0,048	0,208	4,80
b)	**Electrons**				**Photons**				**“Sum”**	**$C(A)$**	**$I(A)$**
In-111	(40 to 70) keV	(70 to 140) keV	(140 to 400) keV	>400 keV	(5 to 15) keV	(15 to 90) keV	(90 to 300) keV	>300 keV			
$\varepsilon_{i,j}$	0,339	0,602	0,000	0,659	0,071	0,095	0,009	0,016			
$\eta_{i,j}$	0,000	0,000	0,149	0,000	0,000	0,823	1,842	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			
Annex A	0,000	0,000	0,000	0,000	0,000	0,039	0,009	0,000	0,048	0,208	4,80
Annex B				$a = \varepsilon_{25}$		0,952					
				$b = \varepsilon_{171}$			0,995				
				$c = \varepsilon_{245}$			0,995		0,048	0,208	4,80
c)	**Electrons**				**Photons**				**“Sum”**	**$C(A)$**	**$I(A)$**
In-111	40–70 keV	70–140 keV	140–400 keV	> 400 keV	5–15 keV	15–90 keV	90–300 keV	> 300 keV			
$\varepsilon_{i,j}$	0,339	0,602	0,000	0,659	0,071	0,900	0,400	0,016			
$\eta_{i,j}$	0,000	0,000	0,149	0,000	0,000	0,823	1,842	0,000			
$1/E_{i,j}$	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5			
Annex A	0,000	0,000	0,000	0,000	0,000	0,370	0,368	0,000	0,739	0,014	73,9
Annex B				$a = \varepsilon_{25}$		0,550					
				$b = \varepsilon_{171}$			0,800				
				$c = \varepsilon_{245}$			0,800		0,581	0,017	58,1

If $\varepsilon_{i,j}$ for the beta energy region (140 to 400) keV is left unchanged, a higher activity instrument response results for the calculation using Formula (A.3) compared to the calculation using Formula (B.3) [Table B.8 a)].

If $\varepsilon_{i,j}$ for the beta energy region (140 to 400) keV is changed to 0 as given in B.5, the two respective results for $C(A)$ and $I(A)$ in Table B.8 b) agree. If in addition the instrument efficiencies for the photon energy regions (15 to 90) keV and (90 to 300) keV are changed to 0,9 and 0,4, respectively, as given in B.5, a higher activity instrument response results for the calculation using Formula (A.3) compared to the calculation using Formula (B.3) [Table B.8 c)]. A 90 % instrument efficiency for the photon energy region (15 to 90) keV however is unrealistic for a SCM (A.5).

Annex C
(informative)

Surface contamination evaluation for radionuclide mixtures

C.1 Principal considerations

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. First, the radionuclides involved shall be identified; - often the facility history is sufficient to determine this value. In other circumstances, it may be necessary to use gamma spectrometry or radiochemical separation analysis to identify the radionuclides present. Alternatively, there may be some situations where simple processes may be applied using a portable contamination monitor to provide estimates with acceptable uncertainties. Each situation should be assessed separately.

C.2 Evaluation methods for radionuclide mixtures

C.2.1 General

In the following, two methods of surface contamination evaluation are considered.

If the radionuclides of a mixture are identified without knowledge about the fraction of each radionuclide constituting the mixture, an absorber technique may be applied to estimate the activity per unit area of the individual radionuclides.

If the relative fraction of each radionuclide in the mixture and the activity calibration factor of each radionuclide in the mixture is known, a calculation can be applied which results in the activity calibration factor for the radionuclide mixture. An example for such a scenario may be given by a used nuclear fuel rod transport container where the fuel material had to be transported surrounded by water. The radionuclide mixture of a potential surface contamination can then be derived from a radioanalytical analysis of the water inside the container.

C.2.2 Absorber technique

A realistic example whereby relatively simple steps can be made which allow the determination of the activity of the individual radionuclides is given in ISO 7503-1:2016, Annex B.

C.2.3 Calibration factor for the evaluation of surface contaminations of a radionuclide mixture

The calculation of a calibration factor for a radionuclide mixture given below is only applicable if the radionuclides and their ratios are known.

If a surface contamination monitor is used for the evaluation of surface contaminations of a radionuclide mixture for which the activity calibration factors $C(A)_n$ of the n radionuclides are known, Formula (C.1) can be used.

The activity calibration factor $C(A)_m$ (= $1/I(A)_m$) for a given radionuclide mixture m with known radionuclide contribution to the mixture is calculated according to:

$$C(A)_m = \frac{1}{\sum_{n=1}^{N} \frac{f_n}{C(A)_n}} \tag{C.1}$$

where

$C(A)_n$ is the activity calibration factor for a given radionuclide n in Bq·cm^{-2}/s^{-1};

f_n is the fraction of radionuclide n in the mixture $\left(\sum_{n=1}^{N} f_n = 1\right)$.

The instrument net count rate $r_{G,m}$ equivalent to the surface contamination guideline value G_m for a given radionuclide mixture m with known radionuclide contribution to the mixture can be expressed by:

$$r_{G,m} = G_m \cdot \sum_{n=1}^{N} \left(\frac{f_n}{G_n} \cdot r_{G,n} \right) \tag{C.2}$$

where

$$G_m = \frac{1}{\sum_{n=1}^{N} \frac{f_n}{G_n}}$$

f_n is the fraction of radionuclide n in the mixture $\left(\sum_{n=1}^{N} f_n = 1\right)$;

$$r_{G,n} = \frac{G_n}{C(A)_n} = G_n \cdot I(A)_n$$

The activity of fixed and removable contamination of a radionuclide mixture m on the surface being checked can be calculated using the multiple, $M_{G,m}$, of the surface contamination guideline value. The multiple $M_{G,m}$ of the surface contamination guideline value G_m[5] is calculated according to:

$$M_{G,m} = \frac{\left(\rho_{\mathrm{g}} - \rho_0\right)}{r_{G,m}} \tag{C.3}$$

where

ρ_{g} is the measured total count rate from the surface contamination in s^{-1};

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

C.3 Calculation of the activity per unit area for surface contaminations of a radionuclide mixture

The activity per unit area, $A_{s,m}$, of fixed and removable contamination of a radionuclide mixture m in relation to the measured count rate is expressed in Bq cm^{-2} and is given by Formula (C.4):

$$A_{s,m} = C(A)_m \cdot \left(\rho_\text{g} - \rho_0\right) \tag{C.4}$$

where

$C(A)_m$ is the calibration factor for a given radionuclide mixture m with known radionuclide contribution to the mixture in Bq·cm^{-2}/s^{-1};

ρ_g is the measured total count rate from the surface contamination in s^{-1};

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

Annex D
(informative)

Calibration for the indirect evaluation of surface contaminations

D.1 General

Assessment of the activity on wipe samples can be carried out using any laboratory counting equipment which has been appropriately calibrated. Generally, the counting system should have a calibration that is traceable to national standards for the radionuclide or radionuclides in question. If laboratory equipment is not available, calibrated portable instruments may be used to measure the samples in a reproducible geometry. The calculation of calibration factors for portable instruments is derived in D.2 to D.4.

D.2 Calibration sources for portable instruments

Portable instrument calibration shall be performed by reference sources of the planchet type. Their active area should correspond in diameter to the wipe material.

D.3 Calibration geometry for portable instruments

The calibration source should be placed in the centre position below the detector window area in known geometrical conditions. These conditions shall be as close as practicable to the conditions for subsequent direct measurements of the wipe material.

D.4 Calculation of the instrument efficiency for the indirect method

The instrument efficiency $\varepsilon_{i,j}$ for a given radionuclide with radiation type j (alpha, beta or photon radiation) or for a given energy range represented by radiation type j is calculated according to:

$$\varepsilon_{i,j} = \frac{\rho_c - \rho_0}{R_c} \tag{D.1}$$

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 surface emission rate for radiation type j (alpha, beta or photon radiation) of the calibration source in s^{-1}.

D.5 Indirect method calibration factor for the evaluation of surface contaminations

The calibration factor $C(A)_n^{\mathrm{ind}}$ for a given radionuclide n is calculated according to:

$$C(A)_n^{\mathrm{ind}} = \frac{1}{S_{\mathrm{w}} \cdot \varepsilon_{\mathrm{w}} \cdot \sum_{i,j} \left(\varepsilon_{i,j} \cdot \eta_{i,j} \cdot E_{i,j}^{-1} \right)} \tag{D.2}$$

where

S_{w} is the wiped area in cm^2;

ε_{w} is the wiping efficiency.

If the wiping efficiency ε_{w} is not determined experimentally, a conservative value of $\varepsilon_{\mathrm{w}} = 0{,}1$ may be used.

$\varepsilon_{i,j}$ is the instrument efficiency for a given energy or energy region i and for the radiation type j (alpha or beta or photon radiation);

$\eta_{i,j}$ is the summarized emission intensity data for a given energy region i and for the radiation type j (alpha or beta or photon radiation);

$E_{i,j}^{-1}$ is the reciprocal of the 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).

The summation index refers to the radiation type and its specific energy regions.

The instrument net count rate $r_{G,n}$ equivalent to the radionuclide specific surface contamination guideline value G_n for a single radionuclide n can be expressed by:

$$r_{G,n} = \frac{G_n}{C(A)_n^{\mathrm{ind}}} \tag{D.3}$$

where S_{w} in Formula (D.2) is set to 100 cm^2.

The instrument net count rate $r_{L,n}$ equivalent to the radionuclide specific surface contamination limit L_{n} can be expressed by:

$$r_{L,n} = \frac{L_n}{C(A)_n^{\mathrm{ind}}} \tag{D.4}$$

where in compliance with requirements of Reference [2] the calibration factor $C(A)_n^{\mathrm{ind}}$ has to be calculated using an area S_{w} of 300 cm^2.

D.6 Indirect method calibration factor for the evaluation of surface contaminations of a radionuclide mixture

The wipe test calibration factor $C(A)_m^{\text{ind}}$ for a given radionuclide mixture m with known radionuclide contribution to the mixture and for a calibration source area equal to the wipe material area is calculated according to:

$$C(A)_m^{\text{ind}} = \frac{1}{\sum_{n=1}^{N} \frac{f_n}{C(A)_n^{\text{ind}}}} \tag{D.5}$$

where

$C(A)_n^{\text{ind}}$ is the wipe test calibration factor for a given radionuclide n and for a calibration source area equal to the wipe material area in Bq·cm^{-2}/s^{-1};

f_n is the fraction of radionuclide n in the mixture $\left(\sum_{n=1}^{N} f_n = 1\right)$.

The instrument net count rate $r_{G,m}$ equivalent to the surface contamination guideline value G_m for a given radionuclide mixture m with known radionuclide contribution to the mixture can be expressed by:

$$r_{G,m} = G_m \cdot \sum_{n=1}^{N} \left(\frac{f_n}{G_n} \cdot r_{G,n} \right) \tag{D.6}$$

with

$$G_m = \frac{1}{\sum_{n=1}^{N} \frac{f_n}{G_n}}$$

f_n is the fraction of radionuclide n in the mixture $\left(\sum_{n=1}^{N} f_n = 1\right)$.

The instrument net count rate $r_{L,m}$ equivalent to the surface contamination limit L_m for a given radionuclide mixture m with known radionuclide contribution to the mixture can be expressed by:

$$r_{L,m} = L_m \cdot \sum_{n=1}^{N} \left(\frac{f_n}{L_n} \cdot r_{L,n} \right) \tag{D.7}$$

with

$$L_m = \frac{1}{\sum_{n=1}^{N} \frac{f_n}{L_n}}$$

f_n is the fraction of radionuclide n in the mixture $\left(\sum_{n=1}^{N} f_n = 1\right)$.

NOTE If Formula (D.7) is applied to radionuclide unspecific surface contamination limits for beta and gamma radiation or to radionuclide unspecific surface contamination limits for alpha radiation (e.g. $L_{\beta,\gamma}$ and L_α surface contamination limits required by Reference [2]), then

$$r_{L,m} = \sum_{n=1}^{N} \left(f_n \cdot r_{L,n} \right).$$

D.7 Calculation of the activity per unit area for indirect measurement results

The activity per unit area a_r of the removable contamination of the wiped surface, expressed in Bq·cm^{-2}, can be calculated according to Formula (D.8):

$$a_\mathrm{r} = C(A)_n^\mathrm{ind} \cdot \left(\rho_\mathrm{g} - \rho_0 \right) \tag{D.8}$$

where

$C(A)_n^\mathrm{ind}$	is the wipe test calibration factor for a given radionuclide n and for a calibration source area equal to the wipe material area in Bq·cm^{-2}/s^{-1};
ρ_g	is the measured total count rate in s^{-1};
ρ_0	is the background count rate in s^{-1}.

D.8 Determination of characteristic limits according to ISO 11929

The calculation of the characteristic limits (decision threshold, detection limit and limits of the confidence interval) according to ISO 11929 is given in Annex F.

Annex E

(informative)

Application of ISO 11929 for the direct evaluation of surface contaminations

E.1 General

Radiation protection authorities may demand a statistical comparison of the result of a surface contamination activity determination with a surface contamination guideline value (e.g. Reference [1] with radionuclide specific "Derived Concentration Guideline Levels (DCGL)") or with a surface contamination limit (e.g. Reference [2] with radionuclide unspecific limits for the removable surface contamination). Therefore, examples of uncertainty budgets and characteristic limits derived according to ISO 11929 for the direct determination of the surface activity concentration are given below.

E.2 Expression of the measurand

For the examination of the fixed and removable surface contamination of a radionuclide *n* by means of direct measurement, the measurand $A_{s,n}$ is the activity per unit area. The model of the evaluation can be expressed as the following:

$$A_{s,n} \sim y = \frac{\rho_g - \frac{(\rho_0 \cdot t_0 + 1)}{t_0}}{S \cdot F} = \frac{\rho_g - \rho_0 - \frac{1}{t_0}}{S \cdot F} \tag{E.1}$$

with

$$F = \sum_{i,j} \frac{\varepsilon_{i,j} \cdot \eta_{i,j}}{E_{i,j}} \tag{E.2}$$

where

$A_{s,n}$ is the activity per unit area of fixed and removable contamination of a radionuclide *n* in $\text{Bq}\cdot\text{cm}^{-2}$;

y is the primary measurement result of fixed and removable surface activity $A_{s,n}$ in $\text{Bq}\cdot\text{cm}^{-2}$;

ρ_g is the gross count rate in s^{-1};

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

t_0 is the measurement duration of the background count rate in s;

$S = S_p$ is the effective detector window area in cm^2, in case of no requirement for averaging the instrument reading;

$S = S_G$ is the active calibration source area equal to the averaging area for the surface contamination guideline value in cm^2, in case of a requirement for averaging the instrument reading;

$\varepsilon_{i,j}$ is the instrument efficiency for a given energy or energy region *i* and for the radiation type *j* (alpha or beta or photon radiation);

$\eta_{i,j}$ is the summarized emission intensity data for a given energy region *i* and for the radiation type *j* (alpha or beta or photon radiation);

$E_{i,j}$ is the 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).

NOTE 1 The term $\frac{1}{t_0}$ in Formula (E.1) is used to treat very low background count rates.

NOTE 2 Using Formula (E.2), $S_\mathrm{p} \cdot F = I(A)$ where $I(A)$ is the instrument response in activity per unit area defined in Table 1 (see 5.2).

E.3 Expression of the standard uncertainty

The standard uncertainty is calculated according to:

$$u(y) = \sqrt{\frac{1}{S^2 \cdot F^2} \cdot \left[\frac{\rho_\mathrm{g}}{t_\mathrm{g}} + \frac{\rho_0}{t_0}\right] + y^2 \cdot \left[\frac{u(S)^2}{S^2} + \frac{u(F)^2}{F^2}\right]} \tag{E.3}$$

$$u(F) = \sqrt{\sum_{i,j} \left[\frac{\eta_{i,j}{}^2}{E_{i,j}{}^2} \cdot u\left(\varepsilon_{i,j}\right)^2 + \frac{\varepsilon_{i,j}{}^2}{E_{i,j}{}^2} \cdot u\left(\eta_{i,j}\right)^2 + \varepsilon_{i,j}{}^2 \cdot \eta_{i,j}{}^2 \cdot u\left(\frac{1}{E_{i,j}}\right)^2\right]} \tag{E.4}$$

and

$$\frac{u\left[I(A)\right]}{I(A)} = \sqrt{\frac{u(F)^2}{F^2} + \frac{u(S)^2}{S^2}} \tag{E.5}$$

where

t_g is the measurement duration of the gross count rate in s.

E.4 Expression of the decision threshold

The decision threshold is calculated according to

$$y^* = k_{1-\alpha} \cdot u(y = 0) \tag{E.6}$$

where

$k_{1\text{-}\alpha}$ is the quantile of a standard normal distribution for a probability $1 - \alpha$, α being the probability of error of the first kind, that is to say, the probability of rejecting a hypothesis if it is true.

For $y = 0$ according to Formula (E.1): $\rho_\mathrm{g} = \rho_0 + \frac{1}{t_0}$.

Then according to Formulae (E.3) and (E.6)

$$y^* = \frac{k_{1-\alpha}}{S \cdot F} \cdot \sqrt{\rho_0 \cdot \left(\frac{1}{t_\mathrm{g}} + \frac{1}{t_0}\right) + \frac{1}{t_0 \cdot t_\mathrm{g}}} \tag{E.7}$$

A determined primary measurement result, y, for a non-negative measurand is only significant if it is larger than the decision threshold ($y > y^*$).

E.5 Expression of the detection limit

The detection limit is calculated according to

$$y^{\#} = y^{*} + k_{1-\beta} \cdot u\left(y = y^{\#}\right) \tag{E.8}$$

where

$k_{1-\beta}$ is the quantile of a standard normal distribution for a probability $1 - \beta$;

β is the probability of error of the second kind, i.e. the probability of accepting a hypothesis when it is false.

For $y = y^{\#}$ according to Formula (E.1): $\rho_{\mathrm{g}} = S \cdot F \cdot y^{\#} + \rho_0 + \frac{1}{t_0}$.

According to Formula (E.3):

$$u\left(y = y^{\#}\right)^2 = \left[\frac{u\left(S\right)^2}{S^2} + \frac{u\left(F\right)^2}{F^2}\right] \cdot y^{\#2} + \frac{1}{S \cdot F \cdot t_{\mathrm{g}}} \cdot y^{\#} + \frac{1}{S^2 \cdot F^2} \cdot \left[\rho_0 \cdot \left(\frac{1}{t_{\mathrm{g}}} + \frac{1}{t_0}\right) + \frac{1}{t_0 \cdot t_{\mathrm{g}}}\right] \tag{E.9}$$

According to Formula (E.7):

$$\rho_0 \cdot \left(\frac{1}{t_{\mathrm{g}}} + \frac{1}{t_0}\right) + \frac{1}{t_0 \cdot t_{\mathrm{g}}} = \frac{S^2 \cdot F^2 \cdot y^{*2}}{{k_{1-\alpha}}^2} \tag{E.10}$$

Formula (E.9) can be expressed as

$$u\left(y = y^{\#}\right)^2 = \left[\frac{u\left(S\right)^2}{S^2} + \frac{u\left(F\right)^2}{F^2}\right] \cdot y^{\#2} + \frac{1}{S \cdot F \cdot t_{\mathrm{g}}} \cdot y^{\#} + \frac{y^{*2}}{{k_{1-\alpha}}^2} \tag{E.11}$$

Knowing that according to Formula (E.8):

$$u\left(y = y^{\#}\right)^2 = \frac{y^{\#2}}{{k_{1-\beta}}^2} + \frac{2 \cdot y^{*}}{{k_{1-\beta}}^2} \cdot y^{\#} + \frac{y^{*2}}{{k_{1-\beta}}^2} \tag{E.12}$$

By subtracting Formula (E.12) from Formula (E.11) and considering that $k_{1-\alpha} = k_{1-\beta}$

$$y^{\#} = \frac{2 \cdot y^{\#} + \dfrac{{k_{1-\beta}}^2}{S \cdot F \cdot t_{\mathrm{g}}}}{1 - {k_{1-\beta}}^2 \cdot \left[\dfrac{u\left(S\right)^2}{S^2} + \dfrac{u\left(F\right)^2}{F^2}\right]} \tag{E.13}$$

and $\sqrt{\frac{u\left(S\right)^2}{S^2} + \frac{u\left(F\right)^2}{F^2}} < \frac{1}{k_{1-\beta}}$

$$\text{Let } U_R = \sqrt{\frac{u\left(S\right)^2}{S^2} + \frac{u\left(F\right)^2}{F^2}} \tag{E.14}$$

If $U_R = 0$ then Formula (E.13) becomes

$$y^{\#}\left(U_R = 0\right) = 2 \cdot y^{*} + \frac{{k_{1-\beta}}^{2}}{S \cdot F \cdot t_{\mathrm{g}}} \tag{E.15}$$

Figure E.1 displays $\dfrac{y^{\#} - y^{\#}\left(U_R = 0\right)}{y^{\#}\left(U_R = 0\right)}$ in % v.s. U_R in %. It appears that:

- with $\alpha = \beta = 2{,}5$ % if $U_R \leq 15$ % then Formula (E.15) is a good approximation within 10 % of the detection limit,
- with $\alpha = \beta = 5$ % if $U_R \leq 20$ % then Formula (E.15) is a good approximation within 10 % of the detection limit.

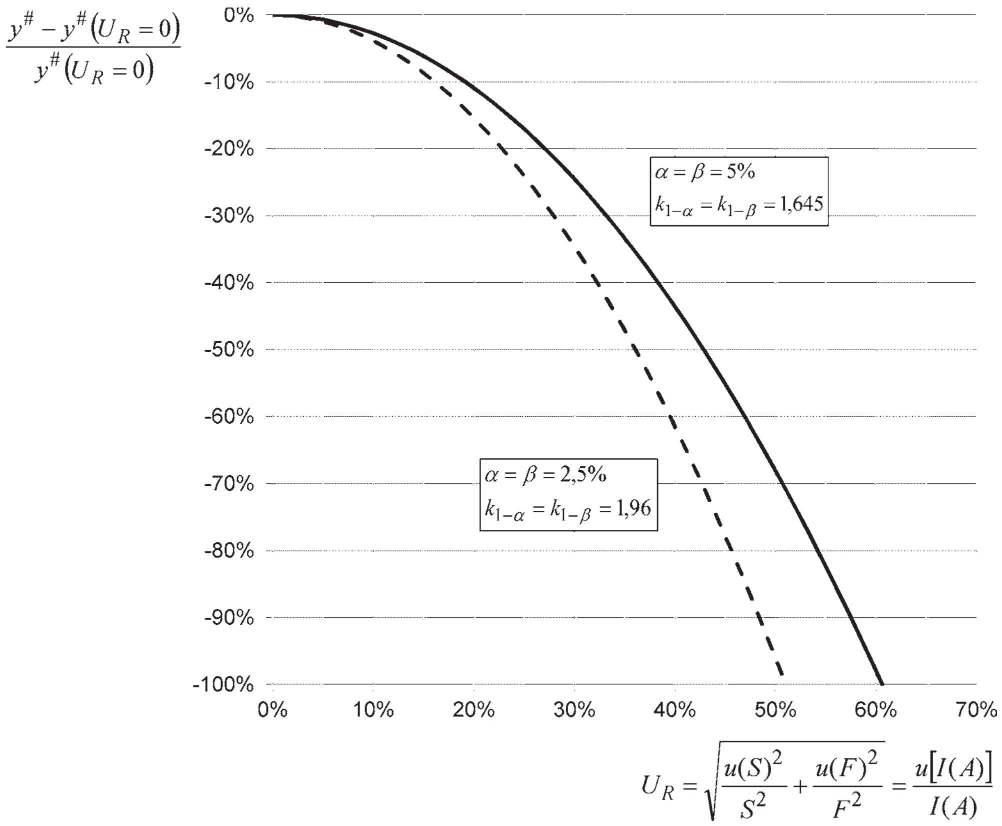


Figure E.1 — Detection limit vs relative uncertainty

E.6 Limits of the confidence interval

The limits of the confidence interval are provided for a physical effect, recognized as present according to E.4, in such a way that the confidence interval contains the true value of the measurand with the specified probability $1 - \gamma$. Usually the value of 0,05 is chosen for γ, then $k_{1-\frac{\gamma}{2}} = 1{,}96$.

E.7 Assessment of a measurement result

The determined primary measurement result, y, of the measurand shall be compared with the decision threshold y^*. If $y > y^*$, the physical effect quantified by the measurand is recognized as present. Otherwise, it is decided that the effect is absent. Then if $y \geq y^*$, the measurement result is given as $Y = y \pm k_{1-\frac{\gamma}{2}} \cdot u\left(y\right)$, and if $y < y^*$, the measurement result is given as $Y < y^*$.

If the lower value of the confidence interval is negative, then the calculation of the best estimate of the measurand and the non-symmetrical limits of the confidence interval according to ISO 11929 can be applied.

E.8 Assessment of a measurement procedure

The decision on whether or not a measurement procedure to be applied sufficiently satisfies the requirements regarding the detection of the physical effect quantified by the measurand is made by comparing the detection limit $y^{\#}$ with the specified guideline value y_r. If $y^{\#} > y_r$ or if in Formula (E.13) $U_R \geq 1/k_{1-\beta}$, the measurement procedure is not suitable for the intended measurement purpose with respect to the requirements.

To improve the situation in the case of $y^{\#} > y_r$ it can be necessary to extend the duration of a measurement or to undertake specific studies in order to reduce component parameters of U_R. If despite the provisions U_R still cannot be reduced reasonably and in the absence of any better knowledge of the values and the uncertainties of the most penalizing component parameters of U_R, reasonable conservative values without associated uncertainties can be used (see Table E.1).

Table E.1 — Reasonable conservative values used for the direct measurement method

Radiation type *j*	Alpha	Electrons				Photons			
Energy region *i* in keV	all	40 to 70	70 to 140	140 to 400	>400	5 to 15	15 to 90	90 to 300	>300
Source efficiency $1/E_{i,j}$[a]	0,05	0,25	0,25	0,5	0,5	0,25	0,5	0,5	0,5
[a] See 5.3 and A.7.									

E.9 Example

E.9.1 Purpose

Determination of fixed and removable surface contamination by means of direct measurement in contact with the surface during 2 s and verification that the measuring instrument used is appropriate to measure a guideline value of 4 Bq cm^{-2} averaged on the effective detector window area.

The radionuclides involved are: ^{14}C, ^{60}Co, ^{137}Cs/^{137m}Ba, ^{169}Er, ^{18}F, ^{125}I, ^{131}I, ^{153}Sm, ^{90}Sr/^{90}Y and ^{99m}Tc.

E.9.2 Instrument used

A surface contamination monitor with the following characteristics is used:

— ZnS(Ag) scintillator with a 170 cm^2 effective detector window area,

— instrument efficiencies $\varepsilon_{i,j}$ as given in Table E.2.

Table E.2 — Instrument efficiencies

Radiation type *j*	Electrons				Photons			
Energy region *i* in keV	40 to 70	70 to 140	140 to 400	>400	5 to 15	15 to 90	90 to 300	>300
Instrument efficiency $\varepsilon_{i,j}$	0,26[a]	0,6[b]	0,7[c]	0,67[d]	0[e]	0,1[f]	0,06[g]	0,02[h]

[a] Data given by the manufacturer. ^{14}C beta-ray calibrated surface emission source.

[b] Data given by the manufacturer. ^{99}Tc beta-ray calibrated surface emission source.

[c] Data given by the manufacturer. ^{36}Cl beta-ray calibrated surface emission source.

[d] Data given by the manufacturer. ^{90}Sr/^{90}Y beta-ray calibrated surface emission source.

[e] No existing data and no ^{55}Fe X-ray calibrated surface emission source available so in a conservative way a zero value is chosen.

[f] Experimental value from ^{129}I gamma-ray calibrated surface emission source (Suppression of electron emission by means of filters according to ISO 8769).

[g] No existing data and no ^{57}Co gamma-ray calibrated surface emission source available so an average value between f and h is chosen.

[h] Experimental value from ^{137}Cs gamma-ray calibrated surface emission source (Suppression of electron emission by means of filters according to ISO 8769).

E.9.3 Nuclear data $\eta_{i,j}$

Nuclear data sources for this example are from JEFF 3.1 (Joint Evaluated Fission and Fusion File) which is an evaluated library produced via an international collaboration of Data Bank member countries coordinated under the auspices of the NEA (Nuclear Energy Agency) Data Bank. Energy regions are given as mean emission energies.

Table E.3 — Nuclear data $\eta_{i,j}$ for the radionuclide examples

Radionuclide ^{14}C								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$	1,00E+00							
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$								
Radionuclide ^{60}Co								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$		9,99E-01	2,00E-05	1,20E-03			4,15E-07	2,92E-04
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$				2,00E+00	1,10E-04			
Radionuclide ^{137}Cs/^{137m}Ba								

Table E.3 *(continued)*

Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$			1,00E+00					9,05E-02
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$			5,80E-06	8,52E-01		6,88E-02		
Radionuclide ^{169}Er								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$		1,00E+00			3,02E-05	5,28E-06		
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90–300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$	2,00E-03		1,40E-05		6,98E-06	2,72E-05		
Radionuclide ^{18}F								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$			9,69E-01					
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$								1,94E+00
Radionuclide ^{125}I								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$								
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$		6,67E-02				1,40E+00		
Radionuclide ^{131}I								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$	2,11E-02	8,00E-02	8,98E-01		3,53E-02	1,13E-02	2,48E-02	4,55E-04
Radiation type *j*	gamma				X			

Table E.3 *(continued)*

Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$		2,61E-02	6,41E-02	9,13E-01		5,42E-02		
Radionuclide ^{153}Sm								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$	1,27E-03		9,97E-01		4,75E-01	8,82E-02	6,31E-05	
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$		5,28E-02	3,02E-01	2,06E-03	1,18E-01	6,04E-01		
Radionuclide ^{90}Sr/^{90}Y								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$			1,00E+00	1,00E+00				1,15E-04
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$				1,40E-08		7,47E-05		
Radionuclide ^{99m}Tc								
Radiation type *j*	beta				electron			
Energy interval *i* in keV	40 to 70	70 to 140	140 to 400	>400	40 to 70	70 to 140	140 to 400	>400
$\eta_{i,j}$					1,22E-05	1,08E-01	7,75E-04	
Radiation type *j*	gamma				X			
Energy interval *i* in keV	5 to 15	15 to 90	90 to 300	>300	5 to 15	15 to 90	90 to 300	>300
$\eta_{i,j}$		1,04E-05	8,91E-01	9,69E-07		7,32E-02		

E.9.4 Uncertainties

The efficiencies of the instrument, $\varepsilon_{i,j}$, are usually determined using a calibration source with a certified relative standard uncertainty of 5 %. Having no specific information about the uncertainties from the manufacturers, $u(\varepsilon_{i,j})/\varepsilon_{i,j}$ = 10 % is chosen.

The relative standard uncertainty of the effective detector window area of the instrument is evaluated to be equal to $u(S_p)/S_p$ = 10 %.

Having no specific information about the source efficiency $1/E_{i,j}$, the values given in Table E.1 are considered, and $u(1/E_{i,j}) = 0$.

It is also considered that uncertainties related to the nuclear data are negligible, so $u(\eta_{i,j}) = 0$.

E.9.5 Results and conclusion

The results in Table E.5 show that in all cases the measuring instrument used is suitable to measure 4 Bq cm^{-2} of each radionuclide.

Table E.4 — Calculation of the instrument activity response and associated uncertainty

Radionuclide example	$I(A) = S \cdot F = S \cdot \sum_{i,j} \frac{\varepsilon_{i,j} \cdot \eta_{i,j}}{E_{i,j}}$ in s^{-1}/Bq cm^{-2}	$\frac{u[I(A)]}{I(A)} = \sqrt{\frac{u(F)^2}{F^2} + \frac{u(S)^2}{S^2}} = U_R$ [see Formulae (E.4) and (E.5)]
	$S = S_p$ (see E.9.2)	$u(S_p)/S_p = 10\ \%$ (see E.9.4)
	$\varepsilon_{i,j}$ (see E.9.2)	$u(\varepsilon_{i,j})/\varepsilon_{i,j} = 10\ \%$ (see E.9.4)
	$\eta_{i,j}$ (see E.9.3)	$u(\eta_{i,j}) = 0$ (see E.9.4)
	$1/E_{i,j}$ (see Table E.1)	$u(1/E_{i,j}) = 0$ (see E.9.4)
^{14}C	11,1	14 %
^{60}Co	29,0	13 %
^{137}Cs/^{137m}Ba	66,7	13 %
^{169}Er	25,5	14 %
^{18}F	61,0	14 %
^{125}I	12,5	14 %
^{131}I	60,4	13 %
^{153}Sm	74,0	13 %
^{90}Sr/^{90}Y	116,5	12 %
^{99m}Tc	8,0	12 %

Table E.5 — Input data, intermediate values and results

Input data and specifications			
Quantity	**Symbol**	**Value**	**Standard uncertainty**
rate meter measurement, gross effect: gross count rate $\left(\sqrt{\frac{\rho_g}{t_g}}\right)$	ρ_g	15 s^{-1}	2,74 s^{-1}
measurement duration	t_g	2 s	neglected
rate meter measurement, background effect: background count rate $\left(\sqrt{\frac{\rho_0}{t_0}}\right)$	ρ_0	12 s^{-1}	2,45 s^{-1}
measurement duration	t_0	2 s	neglected
effective detector window area	$S = S_p$	170 cm^2	17 cm^2
efficiency of the instrument	$\varepsilon_{i,j}$	see E.9.2	$u(\varepsilon_{i,j})/\varepsilon_{i,j} = 10\ \%$
instrument response in activity per unit area	$I(A)$	see Table E.4	see Table E.4
Inverse of emergence factor of a source	$1/E_{i,j}$	see Table E.1	0
summarized emission intensity	$\eta_{i,j}$	see E.9.3	0
probabilities:	α, β	2,5 %	-

Table E.5 *(continued)*

Input data and specifications			
	γ	5 %	-
quantile of a standard normal distribution for a probability 1 - α and 1 - β	$k_{1-\alpha} = k_{1-\beta}$	1,96	-
probability 1-γ/2	$k_{1-\frac{\gamma}{2}}$	1,96	-
guideline value	y_r	0,4 Bq cm^{-2}	-
Intermediate values			
quantity and calculation		**value**	
U_R [Formula (E.13)]	-	see Table E.4	-
$1/k_{1-\beta}$	-	0,51	-
$U_R < 1/k_{1-\beta}$	-	yes	-
Results	**measurand:**		
quantity	**symbol**	**radionuclide**	**values in Bq cm^{-2}**
primary measurement result: Formula (E.1)	y	**^{14}C**	0,23
		^{60}Co	0,09
		^{137}Cs/$^{137\mathrm{m}}$Ba	0,04
		^{169}Er	0,10
		^{18}F	0,04
		^{125}I	0,20
		^{131}I	0,04
		^{153}Sm	0,03
		^{90}Sr/^{90}Y	0,02
		$^{99\mathrm{m}}$Tc	0,31
decision threshold: Formula (E.7)	y^*	**^{14}C**	0,62
		^{60}Co	0,24
		^{137}Cs/$^{137\mathrm{m}}$Ba	0,10
		^{169}Er	0,27
		^{18}F	0,11
		^{125}I	0,55
		^{131}I	0,11
		^{153}Sm	0,09
		^{90}Sr/^{90}Y	0,06
		$^{99\mathrm{m}}$Tc	0,86
measurement effect present?	$y > y^*$?		no
measurement result: see E.7	$A_{s,n}$	**^{14}C**	< 0,62
		^{60}Co	< 0,24
		^{137}Cs/$^{137\mathrm{m}}$Ba	< 0,10
		^{169}Er	< 0,27
		^{18}F	< 0,11

Table E.5 *(continued)*

Input data and specifications				
		^{125}I	< 0,55	
		^{131}I	< 0,11	
		^{153}Sm	< 0,09	
		^{90}Sr/^{90}Y	< 0,06	
		^{99m}Tc	< 0,86	
Results	**measurand:**		**values in** Bq cm^{-2}	
quantity	**symbol**	**radionuclide**	value[a]	value[b]
detection limit: Formulae (E.13) and (E.15)	$y^\#$	**^{14}C**	1,5	1,4
		^{60}Co	0,6	0,5
		^{137}Cs/^{137m}Ba	0,3	0,2
		^{169}Er	0,7	0,6
		^{18}F	0,3	0,3
		^{125}I	1,4	1,3
		^{131}I	0,3	0,3
		^{153}Sm	0,2	0,2
		^{90}Sr/^{90}Y	0,1	0,1
		^{99m}Tc	2,1	2,0
measurement procedure suitable?	$y^\# \leq y_r$?		yes	yes

[a] $U_R \neq 0$ (see E.5).

[b] $U_R = 0$ (see E.5).

Annex F
(informative)

Application of ISO 11929 for the indirect evaluation of surface contaminations

F.1 General

The main uncertainty component of any removable surface contamination evaluation originates from the wiping efficiency (ISO 7503-2:2016, Clause 14). Despite this fact, radiation protection authorities may demand a statistical comparison of the result of a removable surface activity determination with a surface contamination guideline value or with a surface contamination limit. Therefore, an example of uncertainty budget and characteristic limits derived according to ISO 11929 for the determination of the removable surface activity concentration by means of a wipe test is given below. Gas proportional counting measurement is assumed.

F.2 Expression of the measurand

For the examination of a surface contamination by means of the wipe test, the measurand Y is the removable surface activity concentration a_r (activity divided by the wiped area). The model of the evaluation in this case can be expressed as following:

$$a_\mathrm{r} \sim y = \frac{\rho_\mathrm{g} - \frac{\left(\rho_0 \cdot t_0 + 1\right)}{t_0}}{S_\mathrm{w} \cdot \varepsilon_\mathrm{w} \cdot F} = \frac{\rho_\mathrm{g} - \rho_0 - \frac{1}{t_0}}{S_\mathrm{w} \cdot \varepsilon_\mathrm{w} \cdot F} \tag{F.1}$$

with

$$F = \sum_{i,j} \frac{\varepsilon_{i,j} \cdot \eta_{i,j}}{E_{i,j}} \tag{F.2}$$

where

a_r is the removable surface activity in Bq·cm^{-2};

y is the primary measurement result of removable surface activity a_r in Bq·cm^{-2};

ρ_g is the gross count rate in s^{-1};

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

t_0 is the measurement duration of the background count rate in s;

S_w is the wiping area in cm^2;

ε_w is the wiping efficiency;

$\varepsilon_{i,j}$ is the instrument efficiency for a given energy or energy region *i* and for the radiation type *j* (alpha or beta or photon radiation);

$\eta_{i,j}$ is the summarized emission intensity data for a given energy region *i* and for the radiation type *j* (alpha or beta or photon radiation);

$E_{i,j}$ is the 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).

NOTE The term $1/t_0$ in Formula (F.1) is used to treat very low background count rates.

F.3 Expression of the standard uncertainty

The standard uncertainty is calculated according to

$$u\left(y\right)=\sqrt{\frac{1}{{S_{\mathrm{w}}}^{2}\cdot{\varepsilon_{\mathrm{w}}}^{2}\cdot F^{2}}\cdot\left[\frac{\rho_{\mathrm{g}}}{t_{\mathrm{g}}}+\frac{\rho_{0}}{t_{0}}\right]+y^{2}\cdot\left[\frac{u(S_{\mathrm{w}})^{2}}{{S_{\mathrm{w}}}^{2}}+\frac{u(\varepsilon_{\mathrm{w}})^{2}}{{\varepsilon_{\mathrm{w}}}^{2}}+\frac{u(F)}{F^{2}}^{2}\right]} \tag{F.3}$$

and

$$u(F)=\sqrt{\sum_{i,j}\left[\frac{{\eta_{i,j}}^{2}}{{E_{i,j}}^{2}}\cdot u(\varepsilon_{i,j})^{2}+\frac{{\varepsilon_{i,j}}^{2}}{{E_{i,j}}^{2}}\cdot u(\eta_{i,j})^{2}+{\varepsilon_{i,j}}^{2}\cdot{\eta_{i,j}}^{2}\cdot u(\frac{1}{E_{i,j}})^{2}\right]} \tag{F.4}$$

where

t_{g} is the measurement duration of the gross count rate in s.

F.4 Expression of the decision threshold

The decision threshold is calculated according to

$$y^{*}=k_{1-\alpha}\cdot u(y=0) \tag{F.5}$$

where

$k_{1\text{-}\alpha}$ is the quantile of a standard normal distribution for a probability 1 - α, α being the probability of error of the first kind, that is to say, the probability of rejecting a hypothesis if it is true.

For $y = 0$ according to Formula (F.1): $\rho_{\mathrm{g}}=\rho_{0}+\frac{1}{t_{0}}$.

Then according to Formulae (F.3) and (F.5)

$$y^{*}=\frac{k_{1-\alpha}}{S_{\mathrm{w}}\cdot\varepsilon_{\mathrm{w}}\cdot F}\cdot\sqrt{\rho_{0}\cdot\left(\frac{1}{t_{\mathrm{g}}}+\frac{1}{t_{0}}\right)+\frac{1}{t_{0}\cdot t_{\mathrm{g}}}} \tag{F.6}$$

A determined primary measurement result, y, for a non-negative measurand is only significant if it is larger than the decision threshold ($y > y^*$).

F.5 Expression of the detection limit

The detection limit is calculated according to

$$y^{\#}=y^{*}+k_{1-\beta}\cdot u(y=y^{\#}) \tag{F.7}$$

where

$k_{1\text{-}\beta}$ is the quantile of a standard normal distribution for a probability 1 - β;

β is the probability of error of the second kind, i.e. the probability of accepting a hypothesis when it is false.

For $y = y^{\#}$ according to Formula (F.1): $\rho_\mathrm{g} = S_\mathrm{w} \cdot \varepsilon_\mathrm{w} \cdot F \cdot y^{\#} + \rho_0 + \frac{1}{t_0}$.

According to Formula (F.3):

$$u(y=y^{\#})^2=\left[\frac{u(S_{\mathrm{w}})^2}{{S_{\mathrm{w}}}^2}+\frac{u(\varepsilon_{\mathrm{w}})^2}{{\varepsilon_{\mathrm{w}}}^2}+\frac{u(F)^2}{F^2}\right]\cdot y^{\#2}+\frac{1}{S_{\mathrm{w}}\cdot\varepsilon_{\mathrm{w}}\cdot F\cdot t_{\mathrm{g}}}\cdot y^{\#}+\frac{1}{{S_{\mathrm{w}}}^2\cdot{\varepsilon_{\mathrm{w}}}^2\cdot F^2}\cdot\left[\rho_0\cdot\left(\frac{1}{t_{\mathrm{g}}}+\frac{1}{t_0}\right)+\frac{1}{t_0\cdot t_{\mathrm{g}}}\right]$$

(F.8)

According to Formula (F.6):

$$\rho_0\cdot\left(\frac{1}{t_{\mathrm{g}}}+\frac{1}{t_0}\right)+\frac{1}{t_0\cdot t_{\mathrm{g}}}=\frac{{S_{\mathrm{w}}}^2\cdot{\varepsilon_{\mathrm{w}}}^2\cdot F^2\cdot y^{*2}}{{k_{1-\alpha}}^2} \tag{F.9}$$

Formula (F.8) can be expressed as

$$u(y=y^{\#})^2=\left[\frac{u(S_{\mathrm{w}})^2}{{S_{\mathrm{w}}}^2}+\frac{u(\varepsilon_{\mathrm{w}})^2}{{\varepsilon_{\mathrm{w}}}^2}+\frac{u(F)^2}{F^2}\right]\cdot y^{\#2}+\frac{1}{S_{\mathrm{w}}\cdot\varepsilon_{\mathrm{w}}\cdot F\cdot t_{\mathrm{g}}}\cdot y^{\#}+\frac{y^{*2}}{{k_{1-\alpha}}^2} \tag{F.10}$$

Knowing that according to Formula (F.7):

$$u(y=y^{\#})^2=\frac{y^{\#2}}{{k_{1-\beta}}^2}-\frac{2\cdot \mathrm{y}^{*}}{{k_{1-\beta}}^2}\cdot y^{\#}+\frac{\mathrm{y}^{*2}}{{k_{1-\beta}}^2} \tag{F.11}$$

By subtracting Formula (F.11) from Formula (F.10) and considering that $k_{1\text{-}\alpha}=k_{1\text{-}\beta}$:

$$y^{\#}=\frac{2\cdot y^{*}+\dfrac{{k_{1-\beta}}^2}{S_{\mathrm{w}}\cdot\varepsilon_{\mathrm{w}}\cdot F\cdot t_{\mathrm{g}}}}{1-{k_{1-\beta}}^2\cdot\left[\dfrac{u(S_{\mathrm{w}})^2}{{S_{\mathrm{w}}}^2}+\dfrac{u(\varepsilon_{\mathrm{w}})^2}{{\varepsilon_{\mathrm{w}}}^2}+\dfrac{u(F)^2}{F^2}\right]} \tag{F.12}$$

and

$$\sqrt{\frac{u(S_{\mathrm{w}})^2}{{S_{\mathrm{w}}}^2}+\frac{u(\varepsilon_{\mathrm{w}})^2}{{\varepsilon_{\mathrm{w}}}^2}+\frac{u(F)^2}{F^2}}<\frac{1}{k_{1-\beta}}$$

Let

$$U_R=\sqrt{\frac{u(S_{\mathrm{w}})^2}{{S_{\mathrm{w}}}^2}+\frac{u(\varepsilon_{\mathrm{w}})^2}{{\varepsilon_{\mathrm{w}}}^2}+\frac{u(F)^2}{F^2}} \tag{F.13}$$

If $U_R=0$ then Formula (F.12) becomes

$$y^{\#}\left(U_R=0\right)=2\cdot y^{*}+\frac{{k_{1-\beta}}^2}{S_{\mathrm{w}}\cdot\varepsilon_{\mathrm{w}}\cdot F\cdot t_{\mathrm{g}}} \tag{F.14}$$

Figure F.1 displays $\dfrac{y^{\#}-y^{\#}\left(U_R=0\right)}{y^{\#}\left(U_R=0\right)}\left[\%\right]$ v.s. U_R in %. It appears that

- with $\alpha=\beta=2{,}5\ \%$ if $U_R\leq 15\ \%$ then Formula (F.14) is a good approximation within 10 % of the detection limit, and
- with $\alpha=\beta=5\ \%$ if $U_R\leq 20\ \%$ then Formula (F.14) is a good approximation within 10 % of the detection limit.

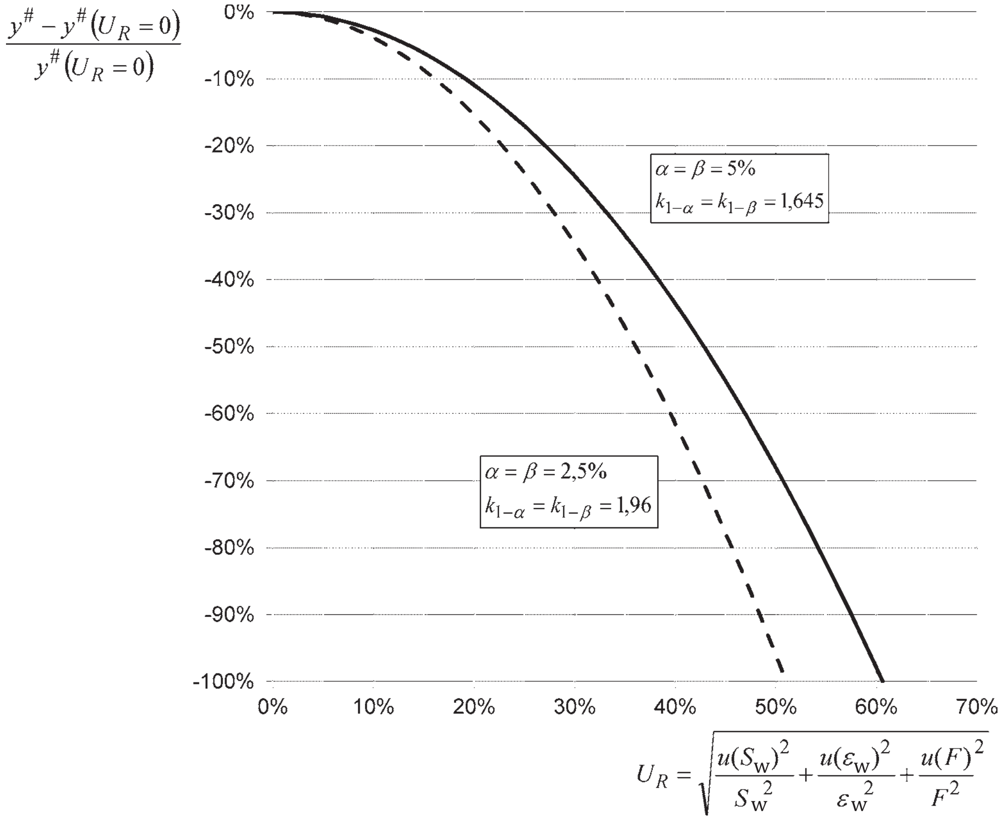


Figure F.1 — Detection limit vs relative uncertainty

F.6 Limits of the confidence interval

The limits of the confidence interval are provided for a physical effect, recognized as present according to F.4, in such a way that the confidence interval contains the true value of the measurand with the specified probability $1 - \gamma$. Usually, the value of 0,05 is chosen for γ, then $k_{1-\frac{\gamma}{2}} = 1{,}96$.

F.7 Assessment of a measurement result

The determined primary measurement result, y, of the measurand shall be compared with the decision threshold y^*. If $y > y^*$, the physical effect quantified by the measurand is recognized as present. Otherwise it is decided that the effect is absent. Then if $y \geq y^*$, the measurement result is given as $Y = y \pm k_{1-\frac{\gamma}{2}} \cdot u(y)$, and if $y < y^*$ the measurement result is given as $Y < y^*$.

If the lower value of the confidence interval is negative, the calculation of the best estimate of the measurand and the non-symmetrical limits of the confidence interval according to ISO 11929 can be applied.

F.8 Assessment of a measurement procedure

The decision on whether or not a measurement procedure to be applied sufficiently satisfies the requirements regarding the detection of the physical effect quantified by the measurand is made by comparing the detection limit $y^{\#}$ with the specified guideline value y_r. If $y^{\#} > y_r$ or if in Formula (F.12) $U_R \geq 1/k_{1-\beta}$, the measurement procedure is not suitable for the intended measurement purpose with respect to the requirements.

To improve the situation in the case of $y^{\#} > y_r$, it can be necessary to extend the duration of a measurement, to increase in a reasonable manner the wiped surface or to undertake specific studies in order to reduce component parameters of U_R. If despite the provisions U_R still cannot be reduced reasonably and in the absence of any better knowledge of the values and the uncertainties of the most penalizing component parameters of U_R, reasonable conservative values without associated uncertainties can be used (see Table F.1).

Table F.1 — Reasonable conservative values used for a wipe-test method

Radiation type j	Alpha	Electrons				Photons			
Energy region i in keV	all	40 to 70	70 to 140	140 to 400	>400	5 to 15	15 to 90	90 to 300	>300
Source efficiency $1/E_{i,j}$[a]	0,25	0,25	0,25	0,5	0,5	0,25	0,5	0,5	0,5
Wiping efficiency ε_w	0,1								

[a] See 5.3 and A.7.

F.9 Example

F.9.1 Purpose

Determination of a removable surface activity and verification that the measuring instrument used is suitable to measure 0,4 Bq cm^{-2} of an alpha emitter with a wipe-test method.

F.9.2 Instrument used

The detector probe is made of a ZnS(Ag) scintillator associated with a rate meter whose characteristics are given in Table F.2.

Table F.2 — Dynamic characteristics of the rate meter

Measurement range s^{-1}	**Relaxation time constant, τ** s	**Measurement duration $t = 2\tau$** s
0 to 10	5	10
0 to 100	2	4
0 to 1 000	0,9	1,8
0 to 10 000	0,5	1

The efficiency $\varepsilon_{i,j}$ of the instrument for alpha radiation (based on a ^{239}Pu alpha surface emission rate calibration source) is given by the manufacturer technical document as 0,44 s^{-1}/α s^{-1} (2π steradian emission) and the probe is insensitive to other types of radiation.

F.9.3 Uncertainties

The efficiency of the instrument $\varepsilon_{i,j}$ = 0,44 s^{-1}/α s^{-1} (2π steradian emission) is determined using a calibration source with a certified relative standard uncertainty of 5 %. On the assumption that the statistical contribution to the measurement uncertainty of the instrument efficiency is negligible, then $u(\varepsilon_{i,j}) = 0{,}022$.

Having no specific information about the source efficiency $1/E_{i,j}$, the values given in Table E.1, $1/E_{i,j} = 0{,}25$ and $u(1/E_{i,j}) = 0$, are used.

It is also considered that uncertainties related to the nuclear data are negligible, so $\eta_{i,j} = 1$ and $u(\eta_{i,j}) = 0$.

The wiping efficiency ε_w of the wipe test is known from previous measurements to be randomly distributed between 0,12 and 0,6. This yields the mean estimate $\varepsilon_w = 0{,}36$ and the associated standard uncertainty $u(\varepsilon_w) = \Delta\varepsilon_w/\sqrt{12} = 0{,}14$ by specifying a rectangular distribution over the region of the possible values of ε_w with the width $\Delta\varepsilon_w = 0{,}48$ (see ISO 11929, 5.2.2 last but one paragraph). The wiping efficiency ε_w has a rather large relative standard uncertainty $u(\varepsilon_w)/\varepsilon_w = 0{,}39$ and therefore can have a great influence on the detection limit [see Formula (F.12)].

The relative standard uncertainty of the wiped area $S_w = 300\ \text{cm}^2$ is given as 10 % from experience, leading to $u(S_w) = 30\ \text{cm}^2$.

F.9.4 Results and conclusion

The results in Table F.3 show that in all cases the measuring instrument used is suitable to measure 0,4 Bq cm^{-2} of alpha emitters.

Table F.3 — Input data, intermediate values and results

Input data and specifications			
Quantity	**Symbol**	**Value**	**Standard uncertainty**
rate meter measurement, gross effect: gross count rate $\left(\sqrt{\frac{\rho_g}{t_g}}\right)$	ρ_g	$2\ \text{s}^{-1}$	$0{,}45\ \text{s}^{-1}$
relaxation time constant (Table F.2)	τ	5 s	neglected
measurement duration	t_g	10 s	neglected
rate meter measurement, background effect: background count rate $\left(\sqrt{\frac{\rho_0}{t_0}}\right)$	ρ_0	$0\ \text{s}^{-1}$	$0\ \text{s}^{-1}$
relaxation time constant (Table F.2)	τ	5 s	neglected
measurement duration	t_0	10 s	neglected
wiped area	S_w	$300\ \text{cm}^2$	$30\ \text{cm}^2$
wiping efficiency	ε_w	0,36	0,14
detection efficiency of the instrument	$\varepsilon_{i,j}$	$0{,}44\ \text{s}^{-1}$	$0{,}022\ \text{s}^{-1}$
source efficiency (Table F.1)	$1/E_{i,j}$	0,25	0
emission probability of ^{239}Pu	$\eta_{i,j}$	1	0
factor [Formula (F.2)]	F	0,11	0,0055
probabilities:	α, β	2,5 %	-
	γ	5 %	-
quantile of a standard normal distribution for a probability 1 - α and 1 - β	$k_{1-\alpha} = k_{1-\beta}$	1,96	-
probability 1-γ/2	$k_{1-\frac{\gamma}{2}}$	1,96	-
guideline value	y_r	0,4 Bq cm^{-2}	-
Intermediate values			
quantity and calculation		**value**	

Table F.3 *(continued)*

Input data and specifications			
U_R [Formula (F.13)]		0,405	
$1/k_{1\text{-}\beta}$		0,51	
$U_R < 1/k_{1\text{-}\beta}$		yes	
Results **measurand:**		**Values in Bq cm⁻²**	
Quantity	**symbol**	$\boldsymbol{a_\mathrm{r}}$[a]	$\boldsymbol{a_\mathrm{r}}$[b]
primary measurement result: Formula (F.1)	y	0,160 (0,576)	0,576
standard uncertainty associated with y: Formula (F.3)	$u(y)$	0,075 (0,150)	0,135
decision threshold: Formula (F.6)	y^*	0,0165 (0,06)	0,06
measurement effect present?	$y > y^*$?	yes (yes)	yes
detection limit: Formula (F.12) or Formula (F.14)	$y^\#$	0,176 (0,247)	0,235
measurement procedure suitable?	$y^\# \leq y_r$?	yes (yes)	yes
measurement result: see F.7	Y	0,160 ± 0,147 (0,576 ± 0,294)	0,576 ± 0,266

[a] $U_R \neq 0$ and in brackets $\varepsilon_\mathrm{w} = 0{,}1$ (see Table F.1)

[b] $U_R = 0$ and $\varepsilon_\mathrm{w} = 0{,}1$ (see Table F.1)

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