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## Evaluation of surface contamination —

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

*Évaluation de la contamination de surface —*

*Partie 1 : Émetteurs bêta (énergie bêta maximale supérieure à 0,15 MeV) et émetteurs alpha*

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# Foreword

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

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 7503-1 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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# Evaluation of surface contamination —

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

## 1 Scope and field of application

This part of ISO 7503 applies to the evaluation of contamination on surfaces of equipment and facilities, containers of radioactive materials and sealed sources in terms of activity per unit area.

This part of ISO 7503 does not apply to the evaluation of contamination of the skin and of clothing.

It applies to beta-emitters the maximum beta energy, $E_{\beta max}$, of which is greater than 0,15 MeV and alpha-emitters.

It is restricted to beta- and alpha-emitters, the production rate of which, with regard to beta-particles plus monoenergetic electrons and alpha-particles respectively, is near to 100 particles per 100 decays (see table 3 in the annex).

For the purposes of this part of ISO 7503 the term "beta energy" refers to maximum beta energy.

NOTE — Evaluation of tritium surface contamination is dealt with in ISO 7503-2. Other radionuclides of practical importance (for example electron capture and isomeric transition emitters) will be dealt with in a future International Standard.

## 2 References

ISO 8769, *Reference sources for the calibration of surface contamination monitors — Beta-emitters (maximum beta energy greater than 0,15 MeV) and alpha-emitters*.

IEC Publication 325 — *Alpha, beta and alpha-beta contamination meters and monitors*.

## 3 Definitions

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

**3.1 surface contamination**: Contamination of surfaces with radioactive substances.

**3.2 fixed surface contamination**: Contamination adhering to a surface in such a way that it is not transferable under normal working conditions.

**3.3 removable surface contamination**: Surface contamination which is removable or transferable under normal working conditions.

NOTES

1 The definition of the term "normal working conditions" is important for the evaluation of inhalation and incorporation risks in connection with surface contamination: it is assumed that under "normal working conditions", the maximum intensity of mechanical action which could bring about the removal of surface contamination is restricted to that of

— normal, non-accidental contacts of the human body (protected or unprotected by clothes) with surfaces, and

— non-destructive contacts of similar intensity between surfaces and parts of equipment being directly handled by men.

The intensity of action in smear testing should correspond to these types of mechanical action. A single smear will not normally remove all removable contamination.

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

**3.4 activity per unit area**: Ratio between the activity of the radionuclides present on a surface and the area of that surface. It is expressed in becquerels centimetres to the power of minus two (Bq·cm$^{-2}$).

**3.5 direct measurement of surface contamination**: Measurement of surface activity by means of a contamination meter or monitor.

Direct measurement determines the fixed plus removable surface contamination, but may be influenced by radiation from within the item under test or from the environment.

**3.6 indirect evaluation of surface contamination**: Evaluation of the removable activity on the surface by means of a smear sample.

**3.7 smear test**: Taking of a sample of removable activity by wiping the surface with dry or wet material and the subsequent evaluation of the activity transferred to the material used to wipe the surface.

**3.8 removal factor,** $F$: Ratio of the activity removed from the surface by one smear sample to the activity of the removable surface contamination prior to this sampling.

The removal factor is defined by the following relationship:

$$F = \frac{A_p}{A_T}$$

where

$A_p$   is the activity removed by smear sample;

$A_T$   is the total removable activity on the contaminated surface prior to sampling.

NOTE — For important combinations of contaminant and surface material, the removal factor $F$ can be determined experimentally using the method of "exhaustive removal by repetitive smears". The step-by-step addition of the removed activities leads to a good approximation of the total removable activity ($A_T$), to which the activity removed by the first smear ($A_p$) can then be related to yield the removal factor.

**3.9 surface emission rate of a source,** $q_{2\pi}$: Number of particles of a given type above a given energy emerging from the front face of the source per unit time.

**3.10 efficiency of a source,** $\varepsilon_s$: Ratio between the number of particles of a given type above a given energy 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 created or released within the source (for a thin source) or its saturation layer thickness (for a thick source) per unit time.

**3.11 instrument efficiency,** $\varepsilon_i$: Ratio between the instrument net reading and the surface emission rate of a source under given geometrical conditions. For a given instrument, the instrument efficiency depends on the energy of the radiations emitted by the source.

NOTE — It follows from the definitions laid down in 3.9 and 3.10 that the surface emission rate of a source is equal to the activity of the source multiplied by the efficiency of the source (see clause A.1).

# 4 Methods for evaluating surface contamination

## 4.1 General

Surface contamination can be evaluated by direct and indirect methods of measurement. Direct measurements are carried out with surface contamination meters and monitors which respond to the removable plus fixed surface contamination. Indirect evaluation is generally carried out by means of smear tests by which only removable surface contamination can be evaluated.

The aim of measuring surface contamination is twofold:

a)   firstly, to detect contamination so as to determine its existence or spread and so as to control its movement from areas of higher contamination to those of lower contamination or to inactive areas, and

b)   secondly, to evaluate activity per unit area in order to verify that the permissible limits (derived limits) are not exceeded.

The applicability and reliability of either method, direct or indirect, in meeting these aims is strongly dependent on the particular circumstances, i.e. the physical and chemical form of the contamination, the adherence of contamination on the surface (fixed or removable), the accessibility of the surface for measurement or the presence of interfering radiation fields.

Direct measurement may be especially difficult or impossible if inactive liquid or solid deposits are present on the surface or if an interfering radiation field is present. The indirect method is more generally applicable, particularly when the surfaces are not readily accessible for direct measurement because of difficult location or configuration, or where interfering radiation fields adversely affect contamination monitors. However, the indirect method cannot assess fixed contamination, and, because of the great uncertainty usually related to the removal factor, the indirect method is more generally used only for detection of removable contamination.

Due to the inherent shortcomings of both the direct and the indirect methods for evaluating surface contamination, in many cases the use of both methods in tandem ensures results which best meet the aims of the evaluation.

Because of the variation in instrument efficiency with energy, extreme care shall be taken in the evaluation of mixed beta-contamination (see also clause 5). This is especially true for instruments displaying surface activity.

## 4.2 Direct measurement of surface contamination

### 4.2.1 Requirements to be met by the measuring instruments

Characteristics and performance of the measuring instruments shall comply with IEC Publication 325.

The instruments shall be capable (see note 1) of measuring activities below the level of the surface contamination limit, to which the results of the contamination measurements are to be compared (limits set by international or national regulations or, in the absence of such regulations, defined by standards or local consensus).

NOTES

1   In a strict sense, the above-mentioned capability could better be described in terms of "lower detection limits" or "minimum detectable activities". However, there is no international agreement with regard to the definition of these terms. Furthermore, the equations for the calculation of the relevant values are too complex to be presented in the framework of this International Standard.

2   Instruments for the direct measurement of surface contamination normally have a sensitive window area of 20 to 200 cm² and are capable of measuring surface contamination levels less than 0,04 Bq·cm⁻² for alpha-emitters and 0,4 Bq·cm⁻² for beta-emitters under normal background conditions. The usefulness of a detector is not only governed by the instrument efficiency but also by the size of the sensitive window. The larger sensitive windows are especially useful for the measurement of extended areas of contamination.

### 4.2.2 Detection procedure

While avoiding contact between components of the sensitive window of the detector and the surface to be checked, move the detector slowly over the surface and listen for a change in frequency of the audio clicks. The audible indication is instantaneous — irrespective of the response time used. Once a contaminated area is detected, the detector should be positioned over this area and held stationary for a time sufficient to confirm the detection.

The distance between the detector and the surface shall be kept as small as practicable. Spacers may be used for this purpose.

### 4.2.3 Measurement procedure

**4.2.3.1** When making a measurement, the operating instructions relating to the measuring instruments used and the following requirements shall be complied with :

a) before making a measurement, the background count rate shall be determined at the place of measurement;

b) the background count rate shall be checked from time to time;

c) the correct functioning of the instrument should be verified using a suitable check source. Frequency : daily for instruments in frequent use, otherwise before each use. Deviations of more than 25 % from the agreed value shall give rise to a recalibration of the instrument;

d) the geometry conditions during a measurement should be as close as practicable to those used during instrument calibration; removable spacers may be used for this purpose;

e) for accurate measurements, the detector shall be held stationary for three times the response time (95 % indication);

f) instrument efficiency values suitable for the radionuclides to be measured shall be available (see clause 5).

**4.2.3.2** The beta- or alpha-activity per unit area, $A_s$[1], of fixed and removable contamination on the surface being checked, expressed in becquerels centimetres to the power of minus two, in relation to the measured count rate, is given by the following equation :

$$A_s = \frac{n - n_B}{\varepsilon_i \times W \times \varepsilon_s} \qquad \ldots (1)$$

where

$n$ is the measured total count rate in reciprocal seconds;

$n_B$ is the background count rate in reciprocal seconds;

$\varepsilon_i$ is the instrument efficiency for beta or alpha radiation (see clauses 5 and A.2);

$W$ is the area of the sensitive window of the measuring instrument (radiation inlet window), in centimetres squared;

$\varepsilon_s$ is the efficiency of the contamination source (see clause A.1).

As a result of plausible and conservative assumptions (see clause A.1), the following values for $\varepsilon_s$ should be used in the absence of more precisely known values :

$\varepsilon_s = 0,5$ [beta-emitters ($E_{\beta max} \geqslant 0,4$ MeV)]

$\varepsilon_s = 0,25$ [beta-emitters (0,15 MeV $< E_{\beta max} <$ 0,4 MeV) and alpha-emitters]

For possible underestimations of alpha contaminations, see clause A.1.

If necessary, dead time corrections should be applied to measured count rates.

For alpha emitters in complete or partial equilibrium with other alpha emitters in a decay chain, the evaluation method yields the total activity of the alpha emitters present. In case of complete equilibrium, the contributions of the single alpha emitters can be calculated by dividing the total alpha activtity by the number of alpha emitters participating in the equilibrium.

Similar calculations can be made for beta-emitters in a decay chain equilibrium only if their probabilities of detection are at the same level (see table 3, couples marked *eq.).

In the case of the decay couples marked § in table 3, only the underlined radionuclides will be properly detected by beta monitors used for surface contamination measurements. In the state of equilibrium, the total activity present is twice the beta activity obtained using the standard evaluation method.

NOTE — Microprocessor-based measuring instruments are able to carry out automatically the calculation of equation (1) and to produce an indication in terms of activity per unit area. For this purpose the instrument needs to have in its memory relevant numerical values for $n_B$, $W$, $\varepsilon_i$ and $\varepsilon_s$. Values of $\varepsilon_i$ and $\varepsilon_s$ have to be selected separately depending on the radionuclides to be measured and the structure of the contamination source. These factors are normally entered into the instrument's memory as one joint factor. In the case of direct calibration of such instruments (see clause 5, note 5), only the value of $\varepsilon_s$ has to be selected.

### 4.3 Indirect evaluation of surface contamination

#### 4.3.1 Requirements to be met by the measuring instruments

Measurements of smear samples are often carried out using well shielded, pulse-counting, stationary instruments. If hand-held surface contamination meters or monitors are used, the characteristics and performance of the measuring instruments shall comply with IEC Publication 325.

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1) Applicability of the equation is based on the restrictions mentioned in clause 1.

The instruments shall be capable (see 4.2.1, note 1) of measuring activities below the level of the surface contamination limit, to which the results of the contamination measurements are to be compared (limits set by international or national regulations or, in the absence of such regulations, defined by standards or local consensus).

NOTE — Currently available instruments are capable of measuring activities less than 0,4 Bq for alpha contamination and 4 Bq for beta contamination.

By complying with these activities when smearing an area of 100 cm² and applying a removal factor $F = 0,1$, removable contamination less than 0,04 Bq·cm⁻² for alpha-emitters and 0,4 Bq·cm⁻² for beta-emitters can be measured.

### 4.3.2 Guidelines on sampling

Detection and evaluation of surface contamination can be carried out using one or more dry or wet smear samples.

When taking smear samples from large areas, the following points shall be taken into consideration to determine the distribution of contamination :

a) if possible, the area to be smeared shall measure 100 cm²;

b) where regulations permit the averaging of the surface contamination over larger areas, such areas may be used for sampling and shall be included in the calculation of the result in accordance with 4.3.3;

c) the smear material should be chosen to suit the surface to be checked (for example filter paper for smooth surfaces, cotton textile for rough surfaces);

d) if a wetting agent is used for moistening the smear material, this wetting agent should not exude from the material;

**WARNING : Since the contamination may be absorbed into the structure of the smear material or may be covered by residual moisture, the use of a wetting agent may lead to a significant underestimation of the contamination in the case of alpha-emitters.**

e) the smear should be pressed moderately against the surface to be checked, using fingertips or, preferably, by means of a holder which is designed to ensure uniform and constant pressure;

f) the entire area of 100 cm² shall be smeared;

g) if possible, circular filter papers should be used as the smear material;

h) the contaminated area of the smear sample shall be smaller than or equal to the sensitive area of the probe;

i) after sampling, the smear material shall be carefully dried in such a way that loss of activity is prevented.

### 4.3.3 Measurement procedure

Smear sample measurements should be carried out as described in 4.2.3.1.

The beta- or alpha-activity per unit area, $A_{sr}$[1], of removable contamination of the surface being smeared, expressed in becquerels centimetres to the power of minus two, in relation to the measured count rate, is given by the following equation :

$$A_{sr} = \frac{n - n_B}{\varepsilon_i \times F \times S \times \varepsilon_s} \qquad \ldots (2)$$

where

$n$ is the measured total count rate, in reciprocal seconds;

$n_B$ is the background count rate, in reciprocal seconds;

$\varepsilon_i$ is the instrument efficiency for beta or alpha radiation (see clauses 5 and A.2);

$F$ is the removal factor;

$S$ is the area smeared, in centimetres squared;

$\varepsilon_s$ is the efficiency of the source represented by the smear sample (see clause A.2).

The values of $\varepsilon_s$ given in 4.2.3.2 should be used.

If $F$ is not determined experimentally, a conservative value of $F = 0,1$ shall be used.

For the evaluation of radionuclides in a decay equilibrium, see 4.2.3.2.

## 5 Determination of instrument efficiency

Instrument efficiency shall be determined by means of reference radiations provided by reference sources of known emission rate per unit area in accordance with ISO 8769.

The dimensions of the calibration source should be sufficient to cover the window of the instrument detector. Where, in extreme cases, sources of such dimensions are not available, sequential measurements with smaller distributed sources of at least 100 cm² active area shall be carried out. These measurements should cover the whole window or at least representative fractions of it and shall result in an average value for $\varepsilon_i$.

In determining instrument efficiency, a distinction shall be made between alpha and beta radiations.

In the case of alpha surface contamination, the particle sizes may reach values of 10 µm and larger. With fine-particle contamination (particle diameters from 0,1 to 2 µm), the radioactive substance becomes mixed with inactive surface dust during sampling and pressed into the material of the sample carrier. In both cases, the original line spectrum becomes

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1) Applicability of the equation is based on the restrictions mentioned in clause 1.

a continuous spectrum in which all alpha energies between zero and the line energy appear. Hence the efficiency of the detector drops below the value for a thin film source. For these reasons, saturation thickness layer sources consisting, for example, of a uranium alloy (13 % natural uranium, 0,06 mm thick) have proved suitable as working (routine calibration) sources for alpha detectors not sensitive to beta radiation.

In the case of beta-emitters, the instrument efficiency, $\varepsilon_i$, depends upon the energy of the beta particles and should be determined for a beta energy corresponding to the contamination to be measured.

In plants and laboratories where different radionuclides with different beta energies are used, it is practical to use only the instrument efficiency for a single beta energy. It shall, however, be ensured that the beta energy of this reference source is not significantly greater than that of the lowest beta energy to be measured.

The following radionuclides are appropriate for reference sources :

$^{14}$C ($E_{\beta max}$ = 0,154 MeV)

$^{147}$Pm ($E_{\beta max}$ = 0,225 MeV)

$^{36}$Cl ($E_{\beta max}$ = 0,71 MeV)

$^{204}$Tl ($E_{\beta max}$ = 0,77 MeV)

$^{90}$Sr/$^{90}$Y ($E_{\beta max}$ = 2,26 MeV)

$^{106}$Ru/$^{106}$Rh ($E_{\beta max}$ = 3,54 MeV)

Instrument efficiency shall be determined under known geometrical conditions which shall be as close as practicable to the conditions for subsequent direct or indirect measurements (see 4.2.3.1).

The instrument efficiency, $\varepsilon_i$, on the reference source (see clause A.2) is given by the following equation :

$$\varepsilon_i = \frac{n - n_B}{q_{2\pi,sc}} = \frac{n - n_B}{E_{sc} \times W} \qquad \ldots (3)$$

where

$n$ is the measured total count rate from the reference source plus background, in reciprocal seconds;

$n_B$ is the background count rate, in reciprocal seconds;

$q_{2\pi,sc}$ is the surface emission rate, in reciprocal seconds, of the reference source below the sensitive window area $W$, in centimetres squared, of the probe;

$E_{sc}$ is the surface emission rate per unit area, in reciprocal seconds centimetres to the power of minus two, of the reference source.

NOTES

1 In the case of $^{90}$Sr in equilibrium with its daughter nuclide $^{90}$Y, the surface emission rate per unit area used in the equation should be twice the surface emission rate per unit area specified for $^{90}$Sr.

2 If the surface emission rate for a source used for calibration is unknown (i.e. the source does not comply with ISO 8769), an estimated value for $E_{sc}$ can be determined in accordance with A.4.1.

3 Using reference sources with saturation thickness rather than a thin layer will result in a conservative value for the instrument efficiency.

4 In some microprocessor-based instruments, $\varepsilon_i$ is determined in the following way : the probe is positioned over a suitable large-area reference source of known emission rate per unit area ($E_{sc}$), and, by continuous shifting of the calibration factor, the rate meter indication is set to the value of $E_{sc}$. The instrument is then switched to indicate the calibration factor which, under these conditions, equals $\varepsilon_i$.

5 A direct calibration can be done with microprocessor-based measuring instruments : the probe is positioned over a suitable large-area reference source of known emission rate per unit area ($E_{sc}$) and, by continuous shifting of the calibration factor, the rate meter indication is set to a value of $E_{sc}/\varepsilon_s$ where $\varepsilon_s$ is the efficiency of the contamination source to be measured with the aid of the calibrated instrument.

# 6 Recording of contamination measurements

If a test report of surface contamination measurements is required, the following information should be included :

a) date;

b) location and sub-location;

c) type of surface for indirect measurement;

d) smear material (dry or wet);

e) wetting agent;

f) removal factor for indirect measurement (measured or assumed);

g) instrument used, serial number;

h) instrument efficiency, calibration date;

i) reference source: radionuclide, surface emission rate (per unit area);

j) instrument reading of the contamination (surface or smear);

k) background reading;

l) activity per unit area;

m) notes on the extent of the contamination;

n) other observations;

o) operator's name.

# Annex

# Explanation of basic terms and data for calibration and measurement procedures

(This annex forms part of the standard.)

## A.1 General

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

Until now, calibration of surface contamination meters has usually been carried out by determining the response of the instrument to a known activity (or activity per unit area) of the reference source.

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

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

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

In this annex the various terms related to the measurement of surface contamination and to the calibration of surface contamination meters are illustrated in order to avoid confusion and to ensure a clear understanding of the difference between the two approaches to calibration. The instrument efficiency, $\varepsilon_i$, and the recommended values for efficiency of a source, $\varepsilon_s$, are considered in more detail.

## A.2 Illustration of terms

The various terms given in table 1 are illustrated in the figure. The count rate induced by the radiation of the source is denoted by $n$, and $q_1$ to $q_6$ refer to the rates of production of the following types of particles:

Type 1 : particles reaching the detector directly;

Type 2 : particles reaching the detector as result of back-scattering from the source or holder;

Type 3 : particles leaving the source in direction of the upper solid angle of $2\pi$ sr, but not reaching the detector due to absorption in air;

Type 4 : particles emitted into the upper solid angle of $2\pi$ sr, but not leaving the source due to self-absorption;

Type 5 : particles leaving the source in direction of the upper solid angle of $2\pi$ sr, but missing the detector due to geometric reasons;

Type 6 : all particles emitted into the lower solid angle of $2\pi$ sr, including back-scattered particles with the exception of type 2 particles.
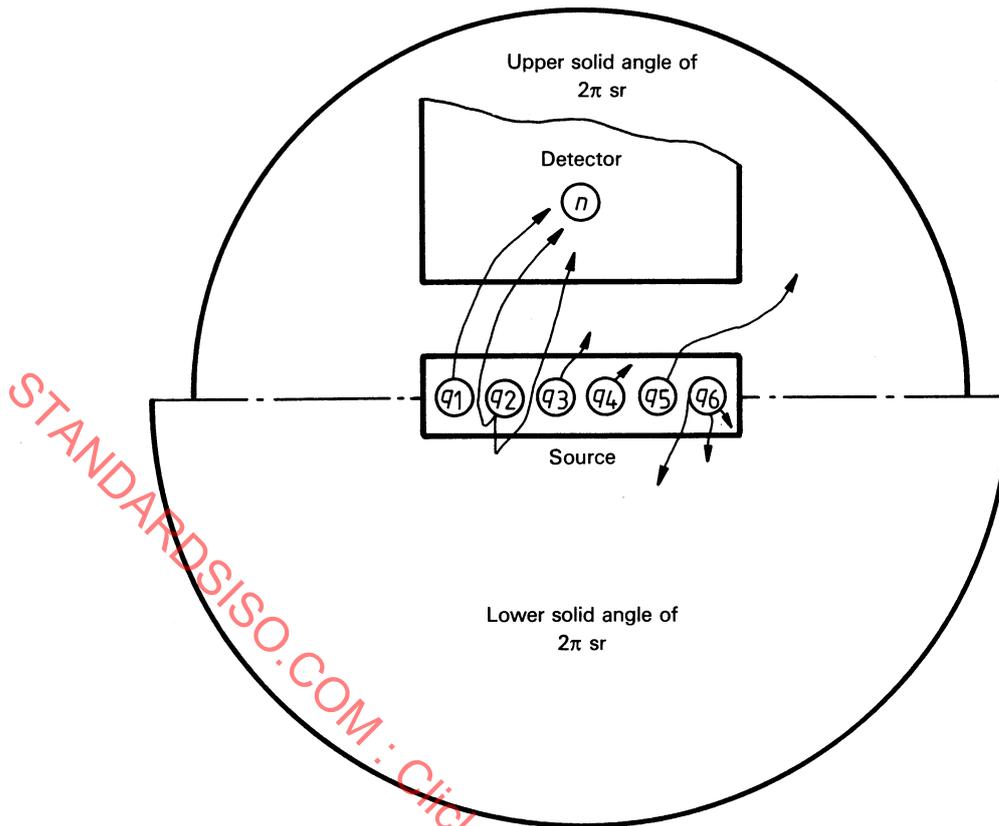
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**Figure — Cross section of a source-detector combination**

The definitions of terms given in table 1 are classified by cross-reference to the figure. The additional term "intrinsic instrument efficiency, $I_i$" is sometimes needed and is defined as "the quotient of count rate induced on the detector by the number of particles incident on the detector per unit time". For an ideal source (no self-absorption, no back-scatter), the value of $\varepsilon_s$ is 0,5. For a real source, the value of $\varepsilon_s$ is usually less than 0,5, but may also be greater than 0,5 depending on the relative importance of self-absorption and back-scatter processes.

The maximum values of $\varepsilon_i$ and $I_i$ are 1.

**Table 1 — Definition of terms**

| Term | Symbol | Unit | Definition |
|------|--------|------|------------|
| Activity of a source[1] | $A$ | Bq | $A = q_1 + q_2 + q_3 + q_4 + q_5 + q_6$ |
| Surface emission rate of a source | $q_{2\pi}$ | $s^{-1}$ | $q_{2\pi} = q_1 + q_2 + q_3 + q_5$ |
| Efficiency of a source | $\varepsilon_s$ | [2] | $\varepsilon_s = \dfrac{q_1 + q_2 + q_3 + q_5}{q_1 + q_2 + q_3 + q_4 + q_5 + q_6} = \dfrac{q_{2\pi}}{A}$ |
| Instrument efficiency | $\varepsilon_i$ | [2] | $\varepsilon_i = \dfrac{n}{q_1 + q_2 + q_3 + q_5}$ |
| Intrinsic instrument efficiency | $I_i$ | [2] | $I_i = \dfrac{n}{q_1 + q_2}$ |
| Response of the instrument to an activity $A$ | $R_i$ | [2] | $R_i = \varepsilon_i \times \varepsilon_s = \dfrac{n}{A}$ |

[1] This simplified definition of activity can only be used under the restrictions mentioned in clause 1. Strictly speaking, the activity should be defined as

$$A = \frac{1}{\varepsilon_d}(q_1 + \ldots + q_6)$$

where $\varepsilon_d$ is the number of particles of the considered type produced per decay.

However, for the nuclides considered in this part of ISO 7503 (see table 3), a value of 1 may be assigned to $\varepsilon_d$.

[2] All the efficiencies are dimensionless.

According to the definitions given in table 1, the response of the instrument, $R_i$, to an activity of the reference source can be written as

$$R_i = \varepsilon_i \times \varepsilon_s$$

i.e. the response, $R_i$ can be split up into instrument efficiency, $\varepsilon_i$ (reflecting instrument characteristics and counting geometry) and the efficiency of the source, $\varepsilon_s$ (reflecting most of the essential properties of the source). The calibration factor, $R_i$, obtained when the calibration is based on the activity of the source is, therefore, a combination of the characteristics of the detector, the source and the counting geometry.

## A.3  Comments on instrument efficiency

Theoretically, the instrument efficiency, $\varepsilon_i$, is dependent not only on the maximum beta energy or the alpha energy, but also on the actual energy distribution of the emitted particles, i.e. on the energy spectrum of the source. In other words, two sources with the same surface emission rate, but different energy spectra may induce different count rates on the same detector. This is because the intrinsic instrument efficiency, $I_i$, is generally energy-dependent and also because the number of particles incident on the detector per unit time may vary due to differing amounts of absorption in air. Strictly speaking, therefore, the instrument efficiency, $\varepsilon_i$, is also slightly dependent on the source construction and the value of $\varepsilon_i$ to be used in calculating activity per unit area should correspond to the energy distribution of the actual contamination. It shall also be noted that the number of particles incident on the detector per unit time and their energy spectrum may be quite sensitive to minor differences between the counting geometry at the calibration and that used in the actual measurements of contamination. For most practical purposes, however, the above spectral effects can be neglected and the value of $\varepsilon_i$ obtained by a suitable energy calibration source can be used (see clause 5).

## A.4  Recommended values for the efficiency of a source

### A.4.1  Reference sources

The efficiency of a reference source, $\varepsilon_{sc}$, is known whenever the source is specified in terms of both activity and surface emission rate ($\varepsilon_s = q_{2\pi}/A$, see table 1).

NOTE — In a special case of saturation layer sources, when only activity within the saturation layer thickness is quoted, it is assumed that the activity $A$ in the formula for $\varepsilon_s$ also denotes activity within the saturation layer thickness. This is necessary for a correct calculation of $\varepsilon_i$ in accordance with clause 5.

If a reference source (active area: $V$ cm²) is known only by activity ($A$) or activity per unit area ($A^*$), a value of 0,5 shall be used for $\varepsilon_{sc}$. With regard to the application of equation (3) in clause 5, this leads to $E_{sc} = (0,5 \, A)/V$ or $E_{sc} = 0,5 \, A^*$. The calculation of $\varepsilon_i$ will then result in a conservative estimate (i.e. lower than the true value) provided that back-scatter enhancement to the surface emission rate is negligible. The commercially available reference sources specified by activity are usually mounted on low back-scatter materials (e.g. aluminium). The saturation back-scatter for a thin beta source mounted on aluminium is about 30 % and less than about 20 % on plastics and other low $Z$ materials (for all beta energies considered in this part of ISO 7503). The back-scatter for alpha sources is in most cases less than 5 %.

### A.4.2  Contamination sources

The efficiency of the actual alpha or beta contamination source, $\varepsilon_s$, 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 activity per unit area.

The recommended values of $\varepsilon_s$ for beta-emitters are derived by considering the following types of contamination sources:

— thin layers of beta-emitters covered by about 2,5 mg/cm² of inactive material;

— homogeneous beta sources of the thickness of a smear test filter paper ($\approx 10$ mg/cm²).

The first type 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 ($\varepsilon_s = 0,5$) for beta-emitters with $E_{\beta max} > 0,4$ MeV. Sources of beta-emitters with $0,15$ meV $< E_{\beta max} < 0,4$ MeV will have a mean source efficiency of about 0,25 under the same conditions. Application of this value 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 $\varepsilon_s$ is more difficult because $\varepsilon_s$ for practical contamination sources can easily be very near to zero[1]. A theoretical value for a saturation layer source is $\varepsilon_{s,\alpha} = 0,25$, and for the majority of alpha-emitters the saturation layer thickness is only about 5 mg/cm². The use of value $\varepsilon_{s,\alpha} = 0,25$ will cover 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 smear sample. The value $\varepsilon_{s,\alpha} = 0,25$ will, however, underestimate 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 smear tests.

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1) RAGHQVAYA, M., GIRIDAR, J. and MARKOSE, P.M. *Correction for Self Absorption in Alpha Sources,* Health Physics, Pergamon Press, **29**, Nov. 1975: pp. 785-786.