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Reference neutron radiations —

Part 2:
Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field

Rayonnements neutroniques de référence —

Partie 2: Concepts d'étalonnage des dispositifs de radioprotection en relation avec les grandeurs fondamentales caractérisant le champ de rayonnement

Reference number
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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

Attention is drawn to the possibility that some of the elements of this part of ISO 8529 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 8529-2 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

ISO 8529 consists of the following parts, under the general title *Reference neutron radiations*:

- *Part 1: Characteristics and methods of production*
- *Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field*
- *Part 3: Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence*

Annex C forms a normative part of this part of ISO 8529.

Annexes A, B, D, E and F are for information only.

Introduction

This part of ISO 8529, and its companion standards ISO 8529-1 and ISO 8529-3, apply to the calibration of personal dosimeters and to area-survey instruments.

Reviews of the physical characteristics of personal dosimeters are given by Griffith *et al*. [1]. Reviews of calibration procedures are given by Eisenhauer *et al*. [2] and by Burger and Schwartz [3].

More details concerning the characteristics of area-survey instruments, and of their calibration requirements and procedures are given in publications [3,4,5] in the bibliography. Complete definitions of radiation quantities and units can be found in ICRP 51, ICRP 74, ICRU 33, ICRU 39, ICRU 43, ICRU 47, ICRU 51, ICRU 57 (see [24] and [28] to [32] in the bibliography) and ISO 8529-1. The actual procedures for calibrating these devices are given in ISO 8529-3.

Reference neutron radiations —

Part 2:
Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field

1 Scope

This part of ISO 8529 takes as its starting point the neutron sources described in ISO 8529-1. It specifies the procedures to be used for realizing the calibration conditions of radiation protection devices in neutron fields produced by these calibration sources, with particular emphasis on the corrections for extraneous effects (e.g., the neutrons scattered from the walls of the calibration room).

In this part of ISO 8529, particular emphasis is placed on calibrations using radionuclide sources (clauses 4 to 6) due to their widespread application, with less details given on the use of accelerator and reactor sources (8.2 and 8.3).

This part of ISO 8529 then leads to ISO 8529-3 which gives conversion coefficients and the general rules and procedures for calibration.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 8529. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 8529 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ICRU Report 33:1980, *Radiation Quantities and Units*.

ICRU Report 60:1998, *Fundamental Quantities and Units for Ionizing Radiation*.

ISO 8529-1:—[1], *Reference neutron radiations — Part 1: Characteristics and methods of production*.

ISO 8529-3:1998, *Reference neutron radiations — Part 3: Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence*.

ISO 12789:—[1], *Reference neutron radiations — Characteristics and methods of production of simulated workplace neutron fields.*

BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML:1993, *International vocabulary of basic and general terms in metrology*.

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[1] To be published.

3 Terms, definitions and symbols

For the purposes of this part of ISO 8529, the terms and definitions given in ICRU Reports 33 and 60 and the *International vocabulary of basic and general terms in metrology,* and the following apply.

The symbols used in this part of ISO 8529 are listed in annex A.

3.1
reading
M
value of the quantity indicated by an instrument

3.2
conventional true value of a quantity
best estimate of the value of the quantity to be measured

NOTE A conventional true value is, in general, regarded as being sufficiently close to the true value for the difference to be insignificant for the given purpose

3.3
dose equivalent
H
product of Q and D at a point in tissue, where D is the absorbed dose at that point and Q the quality factor: $H = QD$

3.3.1
[**ambient dose equivalent**
$H^*(d)$
dose equivalent at a point in a radiation field that would be produced by the corresponding expanded and aligned field in the ICRU sphere at a depth, d, on the radius opposing the direction of the aligned field

3.3.2
personal dose equivalent
$H_p(d)$
dose equivalent in soft tissue below a point on the body at an appropriate depth, d

NOTE The unit of the dose equivalent is joule per kilogram ($\text{J}\cdot\text{kg}^{-1}$) with the special name sievert (Sv).

3.4
fluence
Φ
quotient of dN by da, where dN is the number of neutrons incident on a sphere of cross-sectional area da

$$\Phi = \mathrm{d}N/\mathrm{d}a$$

3.5
response
R
reading divided by the conventional true value of the quantity causing it

NOTE The type of response should be specified, e.g., “fluence response”:

$$R_\Phi = \frac{M}{\Phi} \tag{1}$$

or “dose equivalent response”:

$$R_H = \frac{M}{H} \tag{2}$$

or “photon dose equivalent response,”:

$$R\gamma = \frac{M}{H\gamma} \tag{3}$$

If M is a measurement of a rate, then the quantities fluence (Φ) and dose equivalent (H) are replaced by fluence rate (φ) and dose equivalent rate ($\dot{H}$), respectively.

3.6
calibration factor

N

reciprocal of the response, when the response is determined under reference conditions

NOTE The calibration factor is the factor by which the reading M is multiplied to obtain the value of the quantity to be measured.

3.7
energy dependence of response

$R_\Phi(E)$ or $R_H(E)$

response R, with respect to fluence Φ or dose equivalent H, to monoenergetic neutrons as a function of neutron energy E

3.8
photon sensitivity

change in the neutron reading of a device when photons are added to a neutron field

cf. photon dose equivalent response (3.5)

3.9
free-field quantity

quantity which would exist if irradiations were performed in free space with no scatter or background effects

3.10
point of test

point in the radiation field at which the conventional true value of the quantity to be measured is known

3.11
reference point

point of the instrument which is placed at the point of test for calibration or testing purposes

NOTE The measurement distance is the distance between the centre of the radiation source and the reference point of the instrument.

3.12
effective centre

point within the instrument for which its reading behaves as if it were a point detector; that is, its reading varies with the inverse square of the distance from a point source

EXAMPLE For a spherically symmetric instrument, this will generally be its geometric centre.

4 Calibration and traceability of the reference radiation field

4.1 General considerations

The neutron fluence rate of a radiation field established for a calibration in accordance with this part of ISO 8529 shall be traceable to a recognized national standard. The method used to provide this calibration link is dependent upon the type of reference radiation field, but measurement traceability is usually achieved through the utilization of a transfer standard. This may be, for example, a radionuclide source (4.2) or an agreed-upon transfer instrument (4.2). The calibration of the field is valid in exact terms only at the time of the calibration, and thereafter can be inferred, for example, from a knowledge of the half-life and isotopic composition of the radionuclide source or knowledge of the properties of the transfer instrument.

The measurement technique used by a calibration laboratory for calibrating a neutron-measuring device shall also be approved as required by national regulations. An instrument of the same, or similar, type to that routinely calibrated by the calibration laboratory shall be calibrated by both a reference laboratory recognized by a country's approval body or institution, and the calibration laboratory. These measurements shall be performed within each laboratory using its own approved calibration methods. In order to demonstrate that adequate traceability has been achieved, the calibration laboratory should obtain the same calibration factor, within agreed-upon limits, as that obtained by the reference laboratory.

The frequency of field calibrations should be such that there is reasonable confidence that its value will not move outside the limits of its specification between successive calibrations. The frequency of calibration of the radionuclide neutron sources is given in ISO 8529-1. The calibration of the laboratory-approved transfer instrument, and the check on the measurement techniques used by the calibration laboratory should be carried out at least every five years, or whenever there are significant changes in the laboratory environment.

4.2 Traceability for radionuclide neutron sources

For calibrations using neutron fields produced by radionuclide neutron sources, traceability shall be provided either by using a radionuclide source whose angular source strength has been determined by a reference laboratory (see 5.2.1 for angular source strength), or by determining the fluence rate at the position of the tested instrument using an agreed-upon transfer instrument, calibrated at a reference laboratory. If the source is encapsulated according to the recommendations in ISO 8529-1:—[1], 4.1.2, it may then be assumed that the spectral neutron fluence from the source is sufficiently similar to the appropriate spectral fluence given in ISO 8529-1 that the recommended fluence-to-dose equivalent conversion coefficients may be used. The uncertainties in the conversion coefficients recommended in 10.2.9 reflect both uncertainties in the spectra given in ISO 8529-1, as well as variations in the spectra caused by differences in source construction and encapsulation.

4.3 Traceability for accelerator-produced neutrons

Traceability shall be provided by using a transfer instrument which has been agreed upon by the calibration and the reference laboratories. The transfer instrument should be used in the same manner, for similar neutron fields, as when it was calibrated, and the proper corrections should be applied.

The laboratories' transfer and monitoring instruments shall be checked at intervals as required by national regulations (for example, by using an appropriate radionuclide neutron source), and the results recorded.

4.4 Traceability for neutron beams produced by reactors

The same general principle of traceability to a recognized standard shall be applied to the calibration of these specialized reference radiation fields (thermal or filtered neutron beams). For example, the thermal-neutron fluence rate may be measured by the activation of gold foils, for which the measurement is traceable to a primary standard.

5 Calibration principles for calibrations with radionuclide neutron sources

5.1 General principles

The response or calibration factor of a device is a unique property of the type of device, and may depend on the dose-equivalent rate, the neutron source spectrum or the angle of incidence of the neutrons, but should not be a function of the characteristics of the calibration facility or experimental techniques employed. Hence, in this part of ISO 8259, detailed procedures are given for the calibration of neutron-measuring devices which should ensure that their calibration is independent of the technique, and of such factors as the source-to-device distance and calibration-room size.

For simplicity, general principles are given for the calibration of devices such as area-survey instruments, but most of the principles apply to other devices as well. The instrument is placed in a radiation field of known free-field fluence rate and the instrument reading is noted. In accordance with the above paragraph, the reading should be corrected for all extraneous neutron-scattering effects, including neutron scattering by the air and by the walls, floor and ceiling of the calibration room (see 5.3). It may also have to be corrected for effects due to the source or detector size (see the discussion of the geometry correction factor $F_1(l)$ in 6.2).

The free-field fluence response, R_Φ, of the instrument is then given by

$$R_\Phi = \frac{M_c}{\Phi} \tag{4}$$

where M_c is the measured reading corrected for all extraneous effects. If M_c is a count-rate measurement, then

$$R_\Phi = \frac{M_c}{\varphi} \tag{4a}$$

The free-field fluence rate, φ, (see 3.9) to which the instrument has been exposed is calculated from

$$\varphi = \frac{B_\Omega}{l^2} \tag{5}$$

where

l is the distance from the centre of the source to the point of test (3.10);

B_Ω is the neutron angular source strength defined in ISO 8529-1. It is calculated from

$$B_\Omega = \frac{BF_1(\theta)}{4\pi} \tag{6}$$

where

B is the neutron source strength (i.e., the total neutron-emission rate into 4π sr);

$F_1(\theta)$ is the source anisotropy correction factor (see reference [6]).

Anisotropy functions for two types of sources are shown in ISO 8529-1.

It is sometimes convenient to introduce the source-detector characteristic constant, k, fully corrected for all scattering effects (see 5.3).

In general,

$$k = M_c \times l^2 \tag{7}$$

Then, from equations (4a) and (5), we obtain,

$$k = R_{\Phi} \times \varphi \times l^{2} \tag{8}$$

$$k = R_{\Phi} \times B_{\Omega} \tag{8a}$$

The constant k is specific to each source-detector combination, since it depends on the quantities B_{Ω} and R_{Φ}.

Finally, the dose-equivalent response is obtained from

$$R_{H} = \frac{R_{\Phi}}{h_{\Phi}} \tag{9}$$

where h_{Φ} is the fluence to dose equivalent conversion coefficient. Recommended values of h_{Φ} are given in ISO 8529-3 for ISO standard sources. (The value of h_{Φ}, and an appropriate reference, should be stated in any calibration report.)

5.2 Important features of a neutron calibration facility

5.2.1 Source

The calibration field of the radionuclide source shall be traceable to a reference laboratory (see clause 4). To minimize anisotropic neutron emission, the source should be spherical, or cylindrical with the diameter and length approximately the same. For cylindrical sources, the detector should be calibrated at $\theta = 90^{\circ}$ to the cylindrical axis (see ISO 8529-1). The anisotropy should be measured for each source used. The encapsulation should be as light as possible, consistent with relevant national and international standards for the integrity of sealed radioactive sources. For heavily encapsulated sources, there may be spectral changes associated with the anisotropic emission. If it is not practical to measure the anisotropy, it may be possible to calculate it, bearing in mind that the anisotropy will depend on the location of the radionuclide material within the source capsule (reference [6]). See 10.2.3. See ISO 8529-1:—1), 4.3 and Eisenhauer *et al*. [2] for a more complete discussion.

The source should be located at the centre of the room or, in the case of an open facility, as high as practical above the ground. The source should be supported by a non-hydrogenous structure with as small a mass as possible.

In order to perform a complete linearity check, a variation in dose-equivalent rate of more than three orders of magnitude may be required (e.g. from approximately 1 μSv·h^{-1} to approximately 10 mSv·h^{-1}). It will usually be impractical to cover this range by varying only the distance, l. Rather, two (or more) sources, varying in source strength by factors of 10 to 100, will generally be required. The anisotropy factor, $F_{l}(\theta)$, will not necessarily be the same for the different sources, even if they are nominally similar in construction.

5.2.2 Irradiation set-up

A support system should be used to position the instrument under test at a known distance and angle relative to the calibration source. The support shall be rigid, but designed to minimize scattered radiation. It should be possible to move the detector such that the detector-to-source separation distance can be varied. When a calibrated device is used to determine the fluence rate, its support system should satisfy the same requirements.

5.2.3 Irradiation room

The response of the device to room-scattered neutrons will vary with the size, shape and construction of the room. The room should be such that scatter contributions are as low as possible, but in any case they should not cause an increase in instrument reading of more than 40 % at the calibration point (see annex B).