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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

Rayonnements neutroniques de référence —

Partie 3: Étalonnage des dosimètres de zone (ou d'ambiance) et individuels et détermination de leur réponse en fonction de l'énergie et de l'angle d'incidence des neutrons

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Foreword

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

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

International Standard ISO 8529-3 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 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*

Annexes A and B of this part of ISO 8529 are for information only.

Introduction

This part of ISO 8529 is closely related to two other standards concerning the calibration of dosimeters and dose-rate meters for neutron radiation. The first standard, ISO 8529-1 (in preparation), specifies the reference neutron radiations, in the energy range from thermal up to 20 MeV, and their production methods. The second standard, ISO 8529-2 (in preparation), describes fundamentals related to the physical quantities characterizing the radiation field and calibration procedures in general terms, with emphasis on active dose-rate meters and the use of radionuclide sources. ISO 8529-2 and this part of ISO 8529 replace ISO 10647:1996, *Procedures for calibrating and determining the response of neutron-measuring devices used for radiation protection purposes*.

This part of ISO 8529 deals with dosimeters for area and individual monitoring; area dosimeters are often called area monitors or survey meters, and dosimeters for individual monitoring are often called personal dosimeters. This part of ISO 8529 describes procedures for calibrating and determining the response in terms of the International Commission on Radiation Units and Measurements (ICRU) operational quantities. These are defined in ICRU Reports 39, 43, 47 and 51 ([3], [4], [5] and [6], respectively, in the Bibliography). For radiation protection purposes, these operational quantities are considered to be a sufficiently accurate approximation to the protection quantities. For the purposes of this part of ISO 8529, neutrons of all energies are considered to be strongly penetrating and the emphasis will be on the evaluation of the operational quantities at 10 mm depth in the body or in the appropriate phantom. Cold neutrons may present special problems in dosimetry, which are outside the scope of this part of ISO 8529, as are the photon calibrations of instruments designed to measure both photons and neutrons.

The determination of the response of dosimeters is essentially a three step process. Firstly, a primary quantity such as the neutron fluence is determined at the point of test. Secondly, the reference point of the device being calibrated is then placed at the point of test to determine the fluence response. Thirdly, the response of the device with respect to the appropriate operational quantity is then determined by the application of conversion coefficients that relate the physical quantity (the fluence) to the operational quantity (the dose equivalent). This part of ISO 8529 will describe the methods and the conversion coefficients to be used for the determination of the response of personal and area dosimeters in terms of the respective ICRU operational quantities for neutrons.

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

1 Scope

This part of ISO 8529 provides guidance for those who calibrate protection-level dosimeters and dose-rate meters for area and individual monitoring with reference neutron radiations. This includes the determination of the response as a function of neutron energy and angle of incidence. The operational quantities recommended in ICRU Report 43 ([4] in the Bibliography) and in accordance with ICRU Report 47 ([5] in the Bibliography) are considered. In addition to the description of procedures, this part of ISO 8529 includes appropriate definitions and conversion coefficients and provides guidance on the statement of measurement uncertainties and the preparation of calibration records and certificates.

NOTE The characteristics of the reference radiations, their methods of production and their application are described in ISO 8529-1 and ISO 8529-2.

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.

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

ISO 8529-2:—[2], *Reference neutron radiations — Part 2: Calibration fundamentals related to the basic quantities characterizing the radiation field.*

3 Definitions

For the purposes of this International Standard, the following definitions apply:

1) To be published. (Revision of ISO 8529:1989)

2) To be published.

3.1 quantities and units

3.1.1
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:

$$H = QD$$

[ICRU 51, 1993[6]]

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

3.1.2
ambient dose equivalent

$H^*(10)$

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 of 10 mm on the radius opposing the direction of the aligned field

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

NOTE 2 In the expanded and aligned field, the fluence and its energy distribution have the same value throughout the volume of interest as at the point of test in the actual field; the field is unidirectional.

3.1.3
personal dose equivalent

$H_p(10)$

dose equivalent in soft tissue (ICRU 51, 1993[6]) at a depth of 10 mm below a specified point on the body

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

NOTE 2 In Report 47[5], the ICRU has considered the definition of the personal dose equivalent to include the dose equivalent at a depth d in a phantom having the composition of ICRU tissue. Then $H_p(10)$, for the calibration of personal dosimeters, is the dose equivalent at 10 mm depth in a phantom composed of ICRU tissue (see 6.1), but of the size and shape of the phantom used for calibration (see 6.2.2).

3.2 calibration factor and response determination

3.2.1
influence quantity

quantity that may have a bearing on the result of a measurement without being the subject of the measurement

NOTE A list of influence quantities is given in annex A.

3.2.2
reference conditions

represent the set of influence quantity values for which the calibration factor is valid without any correction

[See also the note to 3.2.3.]

NOTE The value for the quantity to be measured may be chosen freely in agreement with the properties of the instrument to be calibrated. The quantity to be measured is not an **influence quantity** (3.2.1).

3.2.3
standard test conditions
represent the range of values of a set of influence quantities under which a calibration or a determination of the response is carried out

NOTE Ideally, calibrations should be carried out under reference conditions. As this is not always achievable or convenient, a (small) interval around the reference values can be used. The deviations of the calibration factor from its value under reference conditions caused by these deviations should in principle be corrected for. In practice, the uncertainty aimed at serves as a criterion: whether the influence quantity has to be taken into account by an explicit correction or whether its effect may be incorporated into the uncertainty. During type tests, all values of influence quantities which are not the subject of the test are fixed within the interval of the standard test conditions. The standard test conditions, together with the reference conditions applicable to this part of ISO 8529, are given in annex A.

3.2.4
calibration conditions
those within the range of standard test conditions actually prevailing during the calibration

3.2.5
point of test
point in the radiation field at which the **conventional true value of a quantity** (3.2.9) to be measured is known

3.2.6
reference point
point of a dosimeter which is placed at the point of test, for calibration or test purposes

NOTE The distance of measurement refers to the distance between the axis of symmetry of the radiation source and the reference point of the dosimeter. For further explanation see 4.1.5.

3.2.7
reference direction
direction in the coordinate system of the dosimeter, with respect to which the angle of the direction of radiation incidence is measured in unidirectional fields

3.2.8
reference orientation
orientation of a dosimeter for which the direction of incident radiation coincides with the reference direction of the dosimeter

3.2.9
conventional true value of a quantity
best estimate of the value of the quantity to be measured, determined by a primary or secondary standard or by a reference instrument that has been calibrated against a primary or secondary standard

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.

3.2.10
response
R
quotient of the reading M of a measuring instrument and the conventional true value of the measured quantity

NOTE 1 The type of response should be specified, e.g. "fluence response" (response with respect to fluence Φ):

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

or "dose equivalent response" (response with respect to dose equivalent H):

$$R_\mathrm{H} = \frac{M}{H}$$

NOTE 2 The value of the response may vary with the magnitude of the quantity to be measured. In such cases an instrument is said to be non-linear.

NOTE 3 The response R (with respect to fluence or dose equivalent) usually varies with the energy and directional distribution of the incident neutrons. It is, therefore, useful to consider the response as a function $R(E, \vec{\Omega})$ of the energy E of incident monoenergetic neutrons and of the direction $\vec{\Omega}$ of incident monodirectional neutrons. $R(E)$ describes the "energy dependence" and $R(\vec{\Omega})$ the "angle dependence" of the response; for the latter, $\vec{\Omega}$ may be expressed by the angle α between the reference orientation of the device and the direction of an external monodirectional field.

NOTE 4 Some evaluation algorithms of multi-element detectors may not be additive, if the dosimeter is irradiated by a combination of radiations of various energies and angles of incidence. For example, if there are two such contributions to the dose equivalent, H_1 and H_2, the sum of the two corresponding readings may differ from the reading caused by a single irradiation with $H_1 + H_2$, i. e. $M_{\mathrm{H},1} + M_{\mathrm{H},2} \neq M_{\mathrm{H1+H2}}$. In such cases, the function $R(E, \vec{\Omega})$, dealt with in the previous note is not sufficient to characterize the dosimeter in all radiation fields.

3.2.11
calibration
quantitative determination, under a controlled set of standard test conditions, of the reading given by a dosimeter as a function of the value of the quantity to be measured

NOTE Normally, the calibration conditions are the full set of standard test conditions (see annex A). A routine calibration can be performed, under simplified conditions, either to check the calibration carried out by the manufacturer or to check whether the calibration factor is sufficiently stable during a continued long-term use of a dosimeter. In general, the methods of a routine calibration will be worked out on the basis of the results of a type test or it may be one of the objectives of a type test, to establish the procedures for a routine calibration in a way that the result of a routine calibration approximates that of a calibration under standard test conditions as closely as possible.

3.2.12
calibration factor
N
conventional true value of the quantity the instrument is intended to measure, divided by the instrument's reading, M (corrected if necessary)

EXAMPLE

The calibration factor of a dosimeter with respect to personal dose equivalent is given by:

$$N = \frac{H_\mathrm{p}(10)}{M}$$

NOTE 1 The calibration factor N is dimensionless when the instrument indicates the quantity to be measured. A dosimeter indicating the conventional true value correctly has a calibration factor of unity.

NOTE 2 The reciprocal of the calibration factor of a dosimeter is equal to the response under reference conditions. In contrast to the calibration factor which refers to the reference conditions only, the response refers to any conditions prevailing.

NOTE 3 The value of the calibration factor may vary with the magnitude of the quantity to be measured. In such cases, the dosimeter is said to have a non-linear response.

3.2.13
normalization
procedure in which the calibration factor is multiplied with a factor in order to achieve, over a certain range of influence quantities, a better estimate of the quantity to be measured

NOTE A normalization may be practical when a dosimeter will be used mostly under conditions differing from the reference conditions. In this case, the normalization takes account of differences in response under reference conditions and under conditions of normal operation.

3.3
neutron fluence-to-dose equivalent conversion coefficient
h_Φ
quotient of the dose equivalent, H, and the fluence, Φ, at a point in the radiation field:

$$h_\Phi = \frac{H}{\Phi}$$

NOTE Any statement of a fluence-to-dose equivalent conversion coefficient requires a statement of the type of dose equivalent, e.g. ambient or personal dose equivalent. The conversion coefficients $h^*_\Phi(10)$ for the ambient dose equivalent and $h_{p\Phi}(10)$ for the personal dose equivalent both vary strongly with neutron energy. For $h_{p\Phi}(10)$, there is an additional variation with the direction of the incident radiation. It is, therefore, useful to consider the conversion coefficient as a function $h_\Phi(E)$ of the energy E of monoenergetic neutrons at several angles of incidence. This set of basic data is frequently called a conversion function.

4 Procedures

4.1 General principles

4.1.1 Neutron fields

This part of ISO 8529 deals with neutron fields (reference neutron radiations) chosen from and produced in accordance with ISO 8529-1 and characterized using the techniques of ISO 8529-2. In general, when selecting an appropriate neutron field, it will be useful to take into account the specified energy and dose or dose-rate ranges of the dosimeter to be tested. The basic quantities characterizing the radiation fields (energy and angle distribution of the neutron fluence) should be determined and all corrections necessary to allow the use of the conversion coefficients should be considered in accordance with ISO 8529-2. The conversion coefficients given in this part of ISO 8529 refer to the nominal energies or reference spectra given in ISO 8529-1; experimental deviations with respect to the spectral distribution should be taken into account (see 4.2.3).

4.1.2 Conversion coefficients

All of the conversion coefficients given in tables 1 to 4 pertain to broad parallel neutron beams or fields composed of such beams. It is understood that, for calibration and test purposes, the neutron fields used should be regarded as sufficiently broad, i.e. extending over the whole device to be calibrated (area dosimeter or phantom with personal dosimeter) and are parallel or composed of parallel beams. For calibrations of bulky devices in divergent beams as described in detail in ISO 8529-2, geometry corrections are introduced to correct for inhomogeneous irradiation of the device at close distances from point sources.

The fluence to which the conversion coefficients refer should be measured at the point of test; it is then assumed that this fluence is homogeneous on the whole front face of the dosimeter or phantom and the fluence-to-dose equivalent conversion coefficient can be applied without any further considerations.

4.1.3 Standard test conditions

Calibrations and the determination of response should be performed under standard test conditions. The range of values of influence quantities within the standard test conditions are given in annex A.

4.1.4 Variation of influence quantities

For those measurements intended to determine the effects of variation in one influence quantity on the response, the other influence quantities should be maintained at fixed values within the standard test conditions, unless otherwise specified.

4.1.5 Test point and reference point

Measurements should be carried out by positioning the reference point of the dosimeter at the point of test. The reference point and the reference direction of the dosimeter to be tested should be stated by the manufacturer. The reference point should be marked on the outside of the dosimeter. If this proves impossible, the reference point should be indicated in the accompanying documents supplied with the instrument. All distances between the radiation source and the dosimeter should be taken as the perpendicular distance between the axis of symmetry of the radiation source and the dosimeter's reference point.

In the absence of information on the reference point or the reference direction of the dosimeter to be tested, these parameters should be fixed by the testing laboratory. They should be stated in the test certificate.

For most applications, the reference point of the dosimeter will be closely related to the dosimeter's sensitive volume. Personal dosimeters should be fixed on the phantom front face in such a way that their reference direction coincides with the normal to the front face.

NOTE 1 For personal dosimeters that are substantially sensitive to radiation backscattered from the phantom (particularly the albedo dosimeter), it may be advisable to locate the reference point on the back surface of the dosimeter so that it coincides with that point on the front surface of the phantom where the dosimeter is fixed. When several such personal dosimeters are irradiated simultaneously on a phantom surface, corrections may need to be applied for variations over the phantom surface in the magnitude and energy and angle distributions of the backscattered field, the effects of which are dosimeter dependent. In addition, consideration may need to be given to the perturbation of the radiation field incident on the phantom by the array of dosimeters (see also 6.2.3).

NOTE 2 In the case of point sources (and in the absence of scattered radiation) where the dose rate changes with the inverse square of the distance l, a misplacement of the dosimeter's reference point in the beam by the amount of Δl in the direction of the main beam will lead to a relative error in the calibration factor of $(\Delta d/l)^2$ at the distance l. Misalignment perpendicular to the beam axis by Δd causes a relative error of $(\Delta d/l)^2$. If several personal dosimeters are irradiated simultaneously on a phantom surface, they should be fixed at equal distances from the radiation source to the point of test or corrections should be made to take account of the differences in distance.

4.1.6 Axes of rotation

To examine the effect of the direction of radiation incidence, a rotation of the area dosimeter or of the combination of personal dosimeter and phantom is required. The variation of response with direction of radiation incidence should be examined by rotation around at least two axes perpendicular to the direction of beam incidence. The directions of the axes should be mutually perpendicular to each other, if two axes are used. The axes of rotation should pass through the reference point of the dosimeter.

NOTE For an irradiation on a phantom, it may be practical to rotate the phantom only around one axis and to place the dosimeter alternatively in two mutually perpendicular orientations on the surface of the phantom.

4.1.7 Condition of the dosimeter to be calibrated

Before any calibration is made, the dosimeter should be checked to ensure that it is in good serviceable condition and is free of radioactive contamination. Where appropriate, the operation of the instrument should be checked electronically. The set-up procedure and the mode of operation of the measuring instrument should be in accordance with its instruction manual.

4.2 Monoenergetic and polyenergetic reference neutron fields

4.2.1 General considerations

The response or calibration factor of a dosimeter is a unique property of the type of dosimeter, and will in general depend on the neutron fluence spectrum and the angle of incidence of the neutrons, but should not be a function of other characteristics of the calibration facility or of the experimental techniques employed. Hence, the procedures for calibration or determining the response should ensure that the results are independent of the technique, and of such factors as the source-to-device distance and room size (for exceptions see clause 7). For determining their response or calibration factor, instruments are placed in a reference radiation field of known free-field fluence rate and known spectral distribution. In accordance with the above, the reading shall be corrected for all extraneous effects, if they are not required by the calibration conditions, including effects from neutrons having other than the desired energies or from neutron scattering by the air and by the walls, floor and ceiling of the calibration room (see ISO 8529-2).

4.2.2 Measurements with monoenergetic neutrons

Measurements of the dose-equivalent response may be necessary over a wide neutron-energy range. Methods of production of neutron fields in the range from thermal to 20 MeV are described in ISO 8529-1. In order to obtain the response of an instrument as a function of incident energy, the reading of the instrument exposed in the reference radiation and the conventional true value of the measurand at the point of test shall be corrected for any contributions due to radiation other than the desired monoenergetic neutrons (see ISO 8529-2).

The fluence response is then obtained as:

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

where

M is the reading corrected as mentioned;

Φ is the fluence of monoenergetic neutrons. The dose equivalent response is derived as:

$$R_H = \frac{M}{H} = \frac{R_\Phi}{h_\Phi}$$

where h_Φ is the appropriate fluence-to-dose equivalent conversion coefficient.

Numerical values of fluence-to-dose-equivalent conversion coefficients for various irradiation conditions are given in clauses 5 and 6.

NOTE The above formulation of deriving R_H from R_Φ is equivalent to the following: first the conventional true value of the dose equivalent quantity H at the point of test is determined as $H = h_\Phi \Phi$ Then the dosimeter is placed at the point of test and its dose equivalent response is derived as $R_H = M/H$.

4.2.3 Measurements with polyenergetic neutrons

Reference neutron radiations from radionuclide sources (see ISO 8529-1) with well-known spectral distributions of the fluence rate are used for dosimeter calibrations, i.e. the determination of a calibration factor for a set of specified conditions. Procedures for the calibration of radiation protection instruments using radionuclide neutron sources and for the correction of unwanted effects are described in ISO 8529-2.

Numerical values of fluence-to-dose equivalent conversion coefficients for various irradiation conditions are given in clauses 5 and 6.

NOTE For a spectral fluence distribution $\Phi_E(E)$, the dose equivalent response is:

$$R_H = \frac{\int R_\Phi(E)\Phi_E(E)\mathrm{d}E}{\int h_\Phi(E)\Phi_E(E)\mathrm{d}E}$$

4.3 Measurement procedures

4.3.1 Procedure characteristics

The procedure for calibration or determining the response of a dosimeter involves the determination of the corrected dosimeter reading and of the conventional true value of the measurand (see 4.2). The procedure may depend on the knowledge of the reference radiation: in the simplest case, the primary quantities characterizing the reference field (fluence rate, spectrum) are known from previous investigations or from the radiation source characteristics and are stable with time. In other cases, the reference radiation may have to be characterized by a standard instrument. If necessary, a monitor can be used for correcting variations in fluence or dose equivalent rate during the calibration procedure.

4.3.2 Measurement in a known neutron radiation field

Neutron dosimeters are usually calibrated in neutron fields of known energy (and angle) distribution of the fluence rate. For example, when using radionuclide sources, the fluence rate φ is determined using the neutron source strength B and the angular source strength B_Ω ($\varphi = B_\Omega / l^2$, l being the distance from the source axis of symmetry, see ISO 8529-2). The conventional true value of the measurand H is then determined from the fluence and the appropriate fluence-to-dose equivalent conversion coefficient. Then, the calibration factor, N_B is obtained by:

$$N_B = \frac{h_\Phi \Phi}{M_B}$$

where

- N_B is the calibration factor of the dosimeter under calibration;
- M_B is the measured value (at reference conditions) of the dosimeter under calibration, corrected, if necessary, for all extraneous neutron-scattering effects;
- Φ is the neutron fluence at the point of test;
- h_Φ is the fluence-to-dose equivalent conversion coefficient pertaining to the energy and angle distribution of the neutron fluence at the point of test.

For the reference conditions, the dose equivalent response is determined as

$$R_H = \frac{M_B}{h_\Phi \Phi}$$

4.3.3 Measurement using a standard instrument

In certain cases, for example in reactor or accelerator-produced neutron fields, the calibration factor or dose equivalent response of a dosimeter can be determined using a standard instrument. Standard instruments for neutron radiation usually do not measure dose equivalent, but a more basic physical quantity like fluence or absorbed dose. The equations in this subclause are given for the case of standard instruments calibrated in terms of fluence.

If the fluence rate in the radiation field is stable over a time span that is long enough for calibration results of the required accuracy to be obtained, the standard instrument and the dosimeter under test can be irradiated sequentially at the point of test for the same time; the calibration factor is then determined by:

$$N_B = \frac{h_\Phi N_A M_A}{M_B}$$

where:

N_A is the calibration factor of the standard instrument;

M_A is the measured value of the standard instrument at reference conditions.

Calibrations may also be performed by simultaneous irradiation of the detectors of the standard instrument and the instrument under test in a field, by locating them symmetrically to the axis of the radiation field at the same distance from the source. This procedure is sometimes used with accelerator-based radiations and the calibration of area dosimeters. The distance between the two detectors shall be sufficiently large that the reading of either instrument is not influenced by the presence of the other to an extent exceeding 2 %.

To eliminate the influence of asymmetry of the radiation field, the measurements may be repeated after exchanging the positions of the two instruments and the calibration factor determined using the geometrical mean of the readings :

$$N_B = h_\Phi N_A \sqrt{\left(\frac{M_A}{M_B}\right)_1 \left(\frac{M_A}{M_B}\right)_2}$$

4.3.4 Measurement using a monitor

Variations of the fluence or dose equivalent rate during the calibration procedure (short-term variations occurring at reactors or accelerators) can be corrected for by using a monitor instrument and by irradiating a standard instrument and the dosimeter under test sequentially. The monitor reading shall have a fixed relationship to the reference radiation: the detector of the monitor instrument may be positioned symmetrically to the dosimeter under test in the field (with the aforementioned precautions, see 4.3.3) or at a place not disturbing the dosimeter calibration but measuring a representative part of the field, or it may measure another quantity with a fixed relationship to the field. This technique relates the measured values M_A and M_B to the respective readings of the monitor instrument:

$$N_B = \frac{h_\Phi N_A (M_A / m_A)}{M_B / m_B}$$

where:

m_A is the measured value of the monitor instrument at reference conditions for the irradiation of the standard instrument;

m_B is the measured value of the monitor instrument at reference conditions for the irradiation of the instrument to be calibrated.

NOTE 1 In practice, if the irradiations of the secondary standard instrument and the instrument to be calibrated are performed shortly one after another, the ambient conditions of the monitor instrument remain the same and corrections of the indicated value of the monitor instrument to reference conditions are unnecessary.

NOTE 2 In cases where the monitor instrument has a good long-term stability, it may serve as the reference instrument itself after having been calibrated using the standard instrument.

5 Procedures for calibrating and determining the dose equivalent response of portable and installed area dosimeters

5.1 Quantity to be measured and conversion coefficients

The quantity to be measured in area monitoring is the ambient dose equivalent, $H^*(10)$ (see 3.1.2). Tables 1 and 2 contain conversion coefficients, h^*_Φ, converting neutron fluence to ambient dose equivalent for the reference radiations recommended in ISO 8529-1.

5.2 Irradiation conditions

5.2.1 Required response characteristics

Ideally, ambient dose equivalent meters or ambient dose equivalent rate meters should have a fluence response independent of the direction of neutron incidence and with an energy dependence similar to that of the fluence-to-ambient dose equivalent conversion coefficient.

5.2.2 Instrument conditions

The measurement should be performed free in air under a controlled set of conditions required by the manufacturer in the accompanying documents or by a product standard. Annex A lists standard test conditions and reference conditions for an electronic direct-reading dose-rate meter.

5.2.3 Irradiation geometry

Calibrations or determinations of the response are ideally performed in broad, parallel beams of neutrons providing a uniform irradiation of the total volume of the instrument. With the use of point sources (accelerator targets, radionuclide neutron sources), this can in general only be achieved by a sufficient distance between source and instrument, the minimum distance being dependent on the size of the instrument. For spherical devices, a geometry correction has been developed allowing smaller distances between source and instrument (ISO 8529-2). If a narrow, collimated beam of neutrons is used, such as is usually found at reactors, a broad-beam irradiation shall be simulated by moving the instrument appropriately across the beam.

5.3 Evaluation of measurement

The response (or calibration factor) of the instrument under the conditions specified in 5.2 is obtained by determining

— the reading of the instrument, corrected for extraneous effects;

— the fluence of incident neutrons, corrected for unwanted contributions;

and applying the appropriate fluence-to-dose-equivalent conversion coefficient according to 5.1 (see also clause 4).

Table 1 — Conversion coefficient $h^*_\Phi(10; E)$ from neutron fluence Φ to ambient dose equivalent $H^*(10)$ for monoenergetic neutron radiation (ICRP 74[11])

Neutron energy keV	$h^*_\Phi(10; E)$ pSv·cm^2
Thermal	10,6
2	7,7
25	19,3
144	127
250	203
565	343
1 200	425
2 500	416
2 800	413
3 200	411
5 000	405
14 800	536
19 000	584

Table 2 — Conversion coefficient $h^*_\Phi(10)$ from neutron fluence Φ to ambient dose equivalent $H^*(10)$ for ISO-recommended radionuclide sources — Average value, $\overline{h^*_\Phi(10)}$ (ICRP 74[11])

Neutron source	$h^*_\Phi(10)$ pSv·cm^2
^{252}Cf(D_2O-moderated)	105
^{252}Cf	385
^{241}Am-B (α,n)	408
^{241}Am-Be (α,n)	391

6 Procedures for calibrating and determining the dose equivalent response of personal dosimeters

6.1 Quantity to be measured and conversion coefficients

The quantity to be measured for individual monitoring is the personal dose equivalent, $H_p(10)$ (see 3.1.3). Tables 3 and 4 contain conversion coefficients, $h_{p\Phi}$, for converting neutron fluence to $H_p(10)$ at 10 mm depth below the front-face centre of a 30 cm × 30 cm × 15 cm slab phantom of the four-component ICRU tissue-equivalent material with a density of 1 g cm^{-3} (ICRU tissue) (ICRU 47[5]) for the reference radiations recommended in ISO 8529-1.

6.2 Irradiation conditions

6.2.1 Required response characteristics

Ideally, personal dosimeters should have a fluence response with an energy and angle dependence similar to that of the fluence-to-personal dose equivalent conversion coefficient, if it is fixed on the appropriate phantom (see 6.2.2). It is then assumed that it measures the personal dose equivalent when fixed on the body. The range of angles within which the tests are performed is given by national regulations or other standards.

6.2.2 Calibration phantom

Measurements of the response as a function of neutron energy and direction of radiation incidence and calibrations of personal dosimeters should be carried out on a phantom of outer dimensions 30 cm × 30 cm × 15 cm made of PMMA walls (front wall 2,5 mm thick, other walls 10 mm thick) and filled with water, termed the ISO water slab phantom. First, the personal dosimeter is fixed on the front face of the phantom in such a way that the reference direction of the dosimeter coincides with the normal to the phantom front face. Then, the reference point of the dosimeter is placed at the point of test and the dosimeter together with the phantom turned around an axis through the reference point so that the reference direction of the dosimeter forms the desired angle with the direction of radiation incidence.

When the ISO water slab phantom is used as described above, no corrections shall be applied to the reading of the personal dosimeter under test due to differences in backscatter between this and the ICRU tissue slab phantom (see also McDonald et al., 1995[12]).

Table 3 — Conversion coefficient $h_{p\Phi}(10; E, \alpha)$ from neutron fluence Φ to the dose equivalent $H_p(10)$ in the ICRU tissue slab phantom (see 3.1.3) for monoenergetic and parallel neutron radiation (expanded field) (ICRP 74[11])

Neutron energy in keV	$h_{p\Phi}(10; E, \alpha)$, in pSv cm^2, for angles of incidence, α, of 0°	15°	30°	45°	60°	75°
Thermal	11,4	10,6	9,11	6,61	4,04	1,73
2	8,72	8,22	7,27	5,43	3,46	1,67
24	20,2	19,9	17,2	13,6	7,85	2,38
144	134	131	121	102	69,9	22,9
250	215	214	201	173	125	47,0
565	355	349	347	313	245	115
1 200	433	427	440	412	355	210
2 500	437	434	454	441	410	294
2 800	433	431	451	441	412	302
3 200	429	427	447	439	412	309
5 000	420	418	437	435	409	331
14 800	561	563	581	572	576	517
19 000	600	596	621	614	620	568

Table 4 — Conversion coefficient $h_{p\Phi}(10; \alpha)$ from neutron fluence Φ to the dose equivalent $H_p(10)$ in the ICRU tissue slab phantom (see 3.1.3) for parallel neutron radiation (expanded field) — Average value $\overline{h_{p\Phi}(10; \alpha)}$ (ICRP 74[11])

Neutron source	$h_{p\Phi}(10; \alpha)$ in pSv cm^2, for angles of incidence, α, of 0°	15°	30°	45°	60°	75°
^{252}Cf(D_2O-moderated)	110	109	109	102	87,4	56,1
^{252}Cf	400	397	409	389	346	230
^{241}Am-B (α,n)	426	424	443	431	399	289
^{241}Am-Be(α,n)	411	409	424	415	389	293

Routine calibrations (see note 2 to 3.2.11) need not always be performed on the ISO water slab phantom but may sometimes be done more simply, e.g. free in air, or even with a type of radiation different from that which the instrument is intended to measure. Such simplifications, if they are to be applied, shall be justified prior to their adoption by demonstrating that they lead to results identical to those from procedures described in this part of ISO 8529, or that any differences can be reliably corrected for. This may be done on the basis of type test. A calibration on a phantom is preferable if the dosimeter is very sensitive to backscattered radiation.

6.2.3 Irradiation geometry

Calibrations or determinations of the response are ideally performed in broad, parallel beams of neutrons providing a uniform irradiation of the total volume of the dosimeter and the phantom. With the use of point sources (accelerator targets, radionuclide neutron sources), this can in general only be achieved by a sufficient distance between source and the point of test. If a narrow, collimated beam of neutrons is used, such as is usual at reactors, a broad-beam irradiation shall be simulated by moving the phantom appropriately across the beam.

The variation of the angle of incidence is effected by rotating the phantom around a vertical axis which passes through the point of test.

If several personal dosimeters are irradiated simultaneously on the front face of the slab phantom, they shall be fixed on a circle around the centre of the front face in such a way that no sensitive element of the dosimeter is positioned outside a circle of 15 cm diameter. The effect of changes in backscatter from the phantom caused by partial shielding of the phantom by the array of dosimeters may need to be considered.

For a simultaneous determination of the response of several dosimeters as a function of the direction of radiation incidence, several points of test shall be positioned on the axis of rotation.

6.3 Evaluation of measurement

The response (or calibration factor) of the instrument under the conditions specified above is obtained by determining:

- the reading of the dosimeter, corrected for extraneous effects, but not for differences in backscatter between the ISO water slab phantom and the ICRU tissue slab phantom;
- the fluence of incident neutrons, corrected for unwanted contributions and applying the appropriate fluence-to-dose-equivalent conversion coefficients according to 6.1 (see also clause 4).

7 Determination of the dose equivalent response in stray neutron fields

Since the dose equivalent response of most neutron-monitoring instruments is more or less energy dependent, it will often be useful to obtain a calibration factor that is not in one of the reference fields specified in ISO 8529-1, but in special fields produced to closely simulate the existing fields in the workplace. For example, this is especially the case for the albedo neutron dosimeter. In this case, the calibration may only be valid for this one field and may depend on parameters such as the source detector distance or the room size (contrary to the general principles described in 4.1).

In the case of a personal dosimeter, the appropriate quantity is the personal dose equivalent, $H_p(10)$. An investigation of this kind serves to test the suitability of the instrument in this special field rather than to determine a unique calibration factor or response.

8 Presentation of results

8.1 Records and certificates

National regulations often specify details and format and the details to be included in both calibration records and certificates as well as the frequency of calibration and the length of time for which calibration records or certificates should be kept.

The records or certificates should include:

a) date and place of calibration;

b) description of dosimeter, its type and serial number;

c) owner of the dosimeter;

d) details of the radiation sources and field characteristics and, if applicable, information on the standard instrument used;

e) reference conditions, calibration conditions and/or standard test conditions;

f) results;

g) name of person carrying out the calibration;

h) any special observations.

8.2 Statement of uncertainties

The statement of uncertainties shall be consistent with the approaches recommended by the *Guide to the Expression of Uncertainty in Measurement* (1993)[1]. The following component uncertainties shall be taken into account:

a) uncertainty of the conventional true value;

b) uncertainty in the exact positioning of standard and test instruments (see 4.1.5 and ISO 8529-2), to be assessed by the test laboratory;

c) uncertainty of the conversion coefficient; by convention taken to be zero for monoenergetic neutrons, for broad spectra see also ISO 8529-2;

d) uncertainty due to field inhomogeneities over the cross-sectional area of the beam in the plane of measurement owing to beam divergence;

e) uncertainty due to simultaneous irradiation of several dosimeters; an estimate on the effect of absorption of the primary radiation by the dosimeters shall be made and added to the component uncertainties, where applicable, with upper limit 2 %;

f) uncertainties due to simplified procedures; where applicable, to be assessed by the test laboratory, with upper limit 2 % (see 6.2.2).

The numerical values given are to serve as a guideline and are quoted as standard uncertainties. For further information, see ISO 8529-2.

Annex A
(informative)

Statement of reference conditions and required standard test conditions

Table A.1 — Radiological parameters

Influence quantities	Reference conditions	Standard test conditions (unless otherwise indicated)
Neutron energy	^{241}Am-Be(α, n)[a]	^{241}Am-Be(α, n)[a]
Angle of radiation incidence	Reference orientation	Reference orientation ± 5°
Contamination by radioactive elements	Negligible	Negligible
Radiation background	$\dot{H}^*(10) \leqslant 0{,}1$ µSv/h	$\dot{H}^*(10) \leqslant 0{,}25$ µSv/h

a Another radiation quality may be used if more appropriate.

Table A.2 — Other parameters

Influence quantities	Reference conditions	Standard test conditions (unless otherwise indicated)
Ambient temperature	20 °C	18 °C to 22 °C [b]
Relative humidity	65 %	50 % to 75 % [b]
Atmospheric pressure	101,3 kPa	86 kPa to 106 kPa [b]
Stabilization time	15 min	> 15 min
Power supply voltage	Nominal power supply voltage	Nominal power supply voltage ± 3 %
Frequency [a]	Nominal frequency	Nominal frequency ± 1 %
A.C. power supply waveform [a]	Sinusoidal	Sinusoidal with total wave-form harmonic distortion less than 5 %[a]
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to the earth's magnetic field
Assembly controls	Set up for normal operation	Set up for normal operation

a Only for assemblies which are operated from the main voltage supply.

b The actual values of these quantities at the time of test shall be stated. The values in this table are intended for tests performed in temperate climates. In other climates, it may be permitted to exceed the ranges of standard test conditions beyond those stated in this table, where instruments are to be used in these climates.

Annex B
(informative)

List of symbols used in this part of ISO 8529

B	Source strength
B_{Ω}	Angular source strength
d	Distance (misalignment)
D	Absorbed dose
E	Radiation (neutron) energy
H	Dose equivalent
$\dot{H}^*(10)$	Ambient dose equivalent
$H_p(10)$	Personal dose equivalent
h_{Φ}	Fluence-to-dose equivalent conversion coefficient
h_{Φ}^*	Fluence-to-ambient dose equivalent conversion coefficient
$h_{p\Phi}$	Fluence-to-personal dose equivalent conversion coefficient
l	Source-detector distance
M	Reading of a measuring instrument (measured value)
M_A	Measured value of a standard instrument at reference conditions
M_B	Measured value (at reference conditions) of instrument under calibration
m	Measured value of a monitor
N	Calibration factor
N_A	Calibration factor of a standard instrument
N_B	Calibration factor of instrument under calibration
Q	Quality factor
R	Response
R_{Φ}	Fluence response
R_H	Dose equivalent response
α	Angle between a specified direction and the direction of a parallel neutron field
φ	Neutron fluence rate
Φ	Neutron fluence
Φ_E	Spectral neutron fluence
$\vec{\Omega}$	Direction of radiation incidence

Bibliography

[1] BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML:1993, *Guide to the Expression of Uncertainty in Measurement.*

[2] ICRU Report 33:1990, *Radiation Quantities and Units.* ICRU, Washington, D.C.

[3] ICRU Report 39:1985, *Determination of Dose Equivalents Resulting from External Radiation Sources* — ICRU, Bethesda, MD.

[4] ICRU Report 43:1988, *Determination of Dose Equivalents from External Radiation Sources — Part 2.* ICRU, Bethesda, MD.

[5] ICRU Report 47:1992, *Measurement of Dose Equivalents from External Photon and Electron Radiations.* ICRU, Bethesda, MD.

[6] ICRU Report 51:1993, *Quantities and Units in Radiation Protection Dosimetry.* ICRU, Bethesda, MD.

[7] IEC 1005:1990, *Portable neutron ambient dose equivalent rate-meters for use in radiation protection.* Geneva.

[8] IEC 1525:1996, *Radiation protection instrumentation — X, gamma, high energy beta and neutron radiations — Direct reading personal dose equivalent and/or dose equivalent rate monitors.*

[9] ICRP Publication 21:1971, *Data for Protection against Ionizing Radiation from External Sources.*

[10] ICRP Publication 60:1990, Recommendations of the International Commission on Radiological Protection. *Annals of the ICRP*, **21**, 1-3 (1991).

[11] ICRP Publication 74:1995, Conversion Coefficients for Use in Radiological Protection against External Radiation. *Annals of the ICRP*, **27**, 4 (1996).

[12] McDonald, J.C., Tanner, J.E., Stewart, R.D., Michel, R., Murphy, M.K. and Traub, R.J.: Effect of Phantom Size and Composition on Neutron Dosemeter Reading. Radiation Protection Dosimetry **59** (1995), pp. 263-268.

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