INTERNATIONAL
STANDARD

ISO
8529-3

Second edition
2023-06

Neutron reference radiation fields —

Part 3:
Calibration of area and personal dosemeters and determination of their response as a function of neutron energy and angle of incidence

Champs de rayonnement neutronique de référence —

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

Reference number
ISO 8529-3:2023(E)

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Published in Switzerland

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection,* Subcommittee SC 2, *Radiation protection*.

This second edition cancels and replaces the first edition (ISO 8529-3:1998), which has been technically revised.

The main changes are as follows:

- The second and last edition of ISO 8529-1:2021 revised the neutron reference radiation fields produced with radionuclide sources as well as those produced with monoenergetic neutrons, thus requiring calculation of new conversion coefficients from neutron fluence to ambient dose equivalent or personal dose equivalent.

A list of all parts in the ISO 8529 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is closely related to ISO 8529-1 and ISO 8529-2 concerning the calibration of dosemeters and doserate meters for neutron radiation. ISO 8529-1 specifies the reference neutron radiation fields, in the energy range from thermal up to 20 MeV, and their production methods. ISO 8529-2 describes the calibration fundamentals of radiation protection devices related to basic quantities characterising the radiation field and specifies the procedures to be used for realising the calibration conditions of radiation protection devices produced by calibration sources with emphasis on correction for extraneous effects.

This document deals with dosemeters for area and individual monitoring. Unless differently specified, the word "dosemeter" always refers to both. Area dosemeters are often called area monitors or area survey meters, and dosemeters for individual monitoring are often called personal dosemeters or personal dosimeters. This document 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 Report 39[1] and ICRU Report51[2]. For radiation protection purposes, these operational quantities are considered to be a sufficiently accurate approximation to the protection quantities. For the purposes of this document, the emphasis will be on the evaluation of the operational quantities at 10 mm depth defined in the body using conversion coefficients in the appropriate phantom. Cold neutrons may present special problems in dosimetry and are outside the scope of this document, as are the photon calibrations of instruments designed to measure both photons and neutrons.

The determination of the response of dosemeters is essentially a three-step process. First, a primary quantity such as the neutron fluence is determined at the point of test. Second, the reference point of the device being calibrated is then placed at the point of test to determine the fluence response. Third, 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 document describes the methods and the conversion coefficients to be used for the determination of the response of area and personal dosemeters in terms of the respective ICRU operational quantities for neutrons.

Neutron reference radiation fields —

Part 3:
Calibration of area and personal dosemeters and determination of their response as a function of neutron energy and angle of incidence

1 Scope

This document provides guidance for those who calibrate protection-level dosemeters and doserate meters for area and individual monitoring with reference neutron radiation fields. This includes the determination of the response as a function of neutron energy and angle of incidence. The operational quantities recommended in ICRU Report 51[2] are considered. In addition to the description of procedures, this document includes appropriate definitions and conversion coefficients and provides guidance on the statement of measurement uncertainties.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8529-1, *Neutron reference radiations fields — Part 1: Characteristics and methods of production*

ISO 8529-2, *Reference neutron radiations — Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field*

ISO 12789-1, *Reference radiation fields — Simulated workplace neutron fields — Part 1: Characteristics and methods of production*

ISO 12789-2, *Reference radiation fields — Simulated workplace neutron fields — Part 2: Calibration fundamentals related to the basic quantities*

ISO 29661, *Reference radiation fields for radiation protection — Definitions and fundamental concepts*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions of ISO 29661 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
free-field neutron fluence
Φ
fluence that would be present at a point in absence of any dosemeter, calibration phantom if present, and scattering from the room and the air

3.2
uniform irradiation

irradiation of an area (extending over an area dosemeter or phantom with personal dosemeter) in which the uncertainty component introduced by differences in fluence or its energy distribution does not significantly impact the overall uncertainty of the calibration procedure

Note 1 to entry: The calibration laboratory determines the impact that can be regarded as significant.

4 Procedures applicable to area and personal dosemeters

4.1 Neutron fields

This document deals with neutron reference radiation fields that shall be 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 dosemeter to be tested. The basic quantities characterizing the radiation fields (energy and direction distribution of the neutron fluence) shall be determined and all necessary corrections shall be considered in accordance with ISO 8529-2 to allow the use of the recommended conversion coefficients.

4.2 Conversion coefficients

The conversion coefficients given in this document refer to the monoenergetic energies or the continuous energy distributions given in ISO 8529-1 and were derived from those recommended by ICRU[3].

All of the conversion coefficients given in Tables 1 to 4 have been determined assuming broad parallel neutron beams or fields composed of such beams. If these coefficients are used for calibration and test purposes, the neutron fields used should be uniform over a broad area, i.e. extending over the whole item to be calibrated (area dosemeter or phantom with personal dosemeter) and also should be almost parallel or composed of almost-parallel beams. For calibrations of large devices in divergent beams as described in detail in ISO 8529-2, geometric corrections shall be used to correct for non-uniform irradiation of the item at close distances from point sources.

The fluence to which the conversion coefficients refer should be measured at the point of test.

If the fluence is uniform on the whole front face of the dosemeter or phantom the fluence-to-dose equivalent conversion coefficient can be applied without any further considerations.

If not, corrections should be applied for all influencing factors, especially for calibrations of multiple personal dosemeters:

- the calibration of multiple personal dosemeters in broad spectrum reference neutron fields, where the fluence and direction vary across the face of the phantom[4];
- the calibration of multiple personal dosemeters in monoenergetic reference neutron fields, where the fluence, energy, and direction distributions vary across the face of the phantom[5].

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

If the calibration field differs in energy distribution from the reference fields given in ISO 8529-1, the average fluence to dose equivalent conversion coefficient, h_{Φ}, should be derived from the energy distribution of the neutron fluence, Φ_E, and the energy-dependent fluence to dose equivalent conversion coefficients $h_{\Phi}(E)$[3] using Formula (1):

$$h_{\Phi} = \frac{1}{\Phi} \int h_{\Phi}(E) \Phi_E \, \mathrm{d}E \qquad (1)$$

where

Φ is the neutron fluence;

$h_{\Phi}(E)$ is the energy-dependent fluence to dose equivalent conversion coefficients.

4.3 Determination of the response

The response or calibration factor of a dosemeter is a unique property of the dosemeter, and will, in general, depend on the energy and direction distributions of the radiation field, 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 other factors such as the source-to-device distance and room size. For determining their response or calibration factor, dosemeters are placed with their reference point at the point of test of a reference radiation field with known energy distribution and free-field fluence value. Personal dosemeters should be positioned on the appropriate phantom.

In accordance with the above, the dosemeter indication shall be corrected for all extraneous effects, including neutrons scattered by the air and by the calibration room (see ISO 8529-2) and neutrons having other than the desired energies, such as the target-scattered neutrons in accelerator-based reference monoenergetic neutron fields. These are type-S influence quantities for which corrections need to be applied when deriving the "corrected indication" defined in ISO 29661.

Once the free-field fluence and the corrected indication are obtained, the response or calibration factor can be calculated. If the calibration is performed in terms of the ICRU-recommended operational quantities, the operational quantities are obtained by multiplying the free-field fluence and the corresponding fluence-to-dose-equivalent conversion coefficients.

Since the dose equivalent response of neutron dosemeters is generally energy dependent, it is often useful to obtain a calibration factor that is not in one of the reference fields specified in ISO 8529-1, but is in a field that closely simulates the fields that exist in the workplace. These are called simulated workplace neutron fields. To derive such calibration factors, ISO 12789-1 and ISO 12789-2 shall be used. This is especially the case for the albedo neutron personal dosemeter, for which a calibration factor can only be valid for a field identical to the calibration field and can depend on parameters such as the source-detector distance or the room size. An investigation of this kind serves to test the suitability of the dosemeter in these workplace neutron fields rather than to determine a unique calibration factor or response.

4.4 Calibration procedures

Different calibration procedures are applied in radionuclide or reactor- and accelerator-based reference neutron fields.

For radionuclide reference neutron fields the quantities characterizing the field (fluence and its energy and direction distribution) should be known from previous investigations of the radiation source characteristics and be predictable with time. In other cases, additional measurements are needed such as monitoring variations in fluence or dose equivalent rate during the calibration procedure.

As explained in ISO 29661, the calibration procedure can rely on the usage of a standard instrument, either sequentially or simultaneously exposed with respect to the dosemeter to be calibrated.

Calibrations at reactor- or accelerator-based reference neutron fields require the use of a monitor to transfer the quantity value and to monitor variations of the fluence or dose equivalent rate during the calibration procedure. The monitor and the dosemeter are simultaneously exposed. The monitor and dosemeter should be placed such that each does not influence the response of the other.

5 Procedures for calibrating and determining the ambient dose equivalent response of area dosemeters

5.1 Quantity to be measured and conversion coefficients

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

5.2 Required response characteristics

Ideally, the response of area dosemeters should be isotropic. Under this assumption the fluence response, R_Φ, only depends on the energy distribution of the incident field, Φ_E , and can be derived using Formula (2):

$$R_\Phi = \frac{1}{\Phi} \int R_\Phi \, (E) \Phi_E \, \mathrm{d}E \tag{2}$$

where

Φ is the incident neutron fluence;

$R_\Phi(E)$ is the response to monoenergetic neutrons of energy E, usually derived via a combination of measurements and simulation.

To properly measure the ambient dose equivalent, the energy dependence of $R_\Phi(E)$ should be similar to that of the fluence-to-ambient dose equivalent conversion coefficient[3].

5.3 Dosemeter conditions

The measurement should be performed 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 area dosemeter.

5.4 Irradiation geometry

Calibrations or determinations of the response are ideally performed in broad, parallel beams providing a uniform irradiation of the total area of the dosemeter or, more precisely, of the parts to be irradiated, i.e. ideally, the dose rate is constant across the beam diameter.

With the use of point sources (accelerator targets, radionuclide neutron sources), this can, in general, only be achieved by having a sufficient distance between source and dosemeter, the minimum distance being dependent on the size of the dosemeter. For spherical devices, a geometry correction has been developed allowing smaller distances between source and dosemeter (see 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 dosemeter appropriately across the beam[6].

5.5 Evaluation of measurement

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

- the dosemeter corrected indication. The influence of the scattering from the room and the air on the dosemeter indication shall be considered as indicated in ISO 8529-2;
- the free-field neutron fluence, Φ;