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Reference radiation fields — Simulated workplace neutron fields —

Part 2: Calibration fundamentals related to the basic quantities

Champs de rayonnement de référence — Champs de neutrons simulant ceux de postes de travail —

Partie 2: Concepts d'étalonnage en relation avec les grandeurs fondamentales

Reference number
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Foreword

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ISO 12789-2 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

ISO 12789 consists of the following parts, under the general title *Reference radiation fields — Simulated workplace neutron fields*:

— *Part 1: Characteristics and methods of production*

— *Part 2: Calibration fundamentals related to the basic quantities*

Introduction

Neutron fields commonly encountered in radiation workplaces are, in most cases, quite different from routinely used calibration fields produced using standard radionuclide sources in low-scatter calibration facilities. The dose equivalent response of personal neutron dosemeters and neutron area survey meters depends upon the energy distributions of the neutron fields in which they are used, and, in the case of personal dosemeters in particular, the angle of incidence of the neutrons. Calibrations of such devices in reference neutron fields as described in ISO 8529 (all parts) do not thus provide appropriate calibration factors in most cases. For this reason, several laboratories have developed simulated workplace neutron fields that are intended to simulate the characteristics of particular types of fields in which it is necessary to make personal dosemeter and area survey instrument measurements. These provide facilities in which the performance of these devices in workplace fields can be investigate, and that, in some circumstances, can act as calibration facilities. Because workplace neutron fields depend upon the physical structure of each workplace, this part of ISO 12789 has been written to specify the methods of producing and characterizing simulated workplace neutron fields rather than standardizing reference fields as is the philosophy in the companion standard, ISO 8529 (all parts).

This part of ISO 12789 is closely related to ISO 12789-1, which describes the facilities and methods currently used to produce simulated workplace neutron radiation fields. These fields have been constructed specifically to moderate source neutrons and include neutrons scattered from the surrounding structure and equipment for the simulation of workplace environments. This part of ISO 12789 describes the methods used to determine conventional values of the operational quantities characterizing the realistic workplace neutron fields.

The operational quantities used in this part of ISO 12789 are ambient dose equivalent, $H^*(10)$, and personal dose equivalent, $H_p(10)$. For reference radiation fields, it is recommended to determine their conventional values from the neutron fluence or fluence rate as a function of neutron energy and, for the case of $H_p(10)$, the direction using the conversion coefficients listed in Annex A. In some cases, the use of conversion coefficients is not feasible for determining $H_p(10)$, necessitating its direct calculation.

At present, no simple methods exist to provide traceability of the operational quantities from a national standards institute to the simulated workplace neutron fields. The process of determining operational quantities from fluence described in this part of ISO 12789 introduces additional uncertainty.

This part of ISO 12789 incorporates accepted methods for determining the uncertainty associated with the values of the operational quantities and gives new information regarding the uncertainty associated with the inference of energy distributions of neutron fluence using accepted unfolding techniques. The uncertainties in determining $H_p(10)$ using information from the direction distribution of the neutron fluence can be large but, at present, the quantification of the uncertainty from this source is not addressed.

Reference radiation fields — Simulated workplace neutron fields —

Part 2: Calibration fundamentals related to the basic quantities

1 Scope

This part of ISO 12789 describes the characterization of simulated workplace neutron fields produced by methods described in ISO 12789-1. It specifies the procedures used for establishing the calibration conditions of radiation protection devices in neutron fields produced by these facilities, with particular emphasis on the scattered neutrons. The diversity of workplace neutron fields is such that several special facilities have been built in order to simulate them in the laboratory. In this part of ISO 12789, the neutron radiation field specifications are classified by operational quantities. General methods for characterizing simulated workplace neutron fields are recommended.

2 Terms and definitions

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

2.1
indication
reading
M
quantity value provided by a measuring instrument or a measuring system

NOTE 1 An indication may be presented in visual or acoustic form or may be transferred to another device. An indication is often given by the position of a pointer on the display for analog outputs, a displayed or printed number for digital outputs, a code pattern for code outputs, or an assigned quantity value for material measures.

NOTE 2 An indication and a corresponding value of the quantity being measured are not necessarily values of quantities of the same kind.

[ISO/IEC Guide 99:2007, 4.1]

2.2
conventional quantity value
conventional value of a quantity
quantity value attributed by agreement to a quantity for a given purpose

EXAMPLE 1 Standard acceleration of free fall (formerly called "standard acceleration due to gravity") $g_n = 9{,}806\ 65\ \mathrm{m{\cdot}s^{-2}}$.

EXAMPLE 2 Conventional quantity value of the Josephson constant, $K_{J\text{-}90} = 483\ 597{,}9\ \mathrm{GHz\ V^{-1}}$.

EXAMPLE 3 Conventional quantity value of given mass standard, $m = 100{,}003\ 47\ \mathrm{g}$.

NOTE 1 The term "conventional true quantity value" is sometimes used for this concept, but its use is discouraged.

NOTE 2 Sometimes a conventional quantity value is an estimate of a true quantity value.

NOTE 3 A conventional quantity value is generally accepted as being associated with a suitably small measurement uncertainty, which might be zero.

[ISO/IEC Guide 99:2007, 2.12]

2.3
neutron fluence
Φ
quotient of $\mathrm{d}N$ by $\mathrm{d}a$, where $\mathrm{d}N$ is the number of neutrons incident on a sphere of cross-sectional area $\mathrm{d}a$, as given in Equation (1):

$$\Phi = \frac{\mathrm{d}N}{\mathrm{d}a} \tag{1}$$

NOTE The unit of the neutron fluence is metres to the negative 2 (m^{-2}).

2.4
neutron fluence rate
φ
quotient of $\mathrm{d}\Phi$ by $\mathrm{d}t$, where $\mathrm{d}\Phi$ is the increment of neutron fluence in the time interval $\mathrm{d}t$, as given in Equation (2):

$$\varphi = \frac{\mathrm{d}\Phi}{\mathrm{d}t} = \frac{\mathrm{d}^2 N}{\mathrm{d}a\ \mathrm{d}t} \tag{2}$$

NOTE 1 The unit of neutron fluence rate is metres to the negative 2 times reciprocal seconds ($\mathrm{m}^{-2}\ \mathrm{s}^{-1}$).

NOTE 2 This quantity is also termed neutron flux density.

2.5
energy distribution of the neutron fluence
Φ_E
quotient of $\mathrm{d}\Phi$ by $\mathrm{d}E$, where $\mathrm{d}\Phi$ is the increment of neutron fluence in the energy interval between E and $E + \mathrm{d}E$, as given in Equation (3):

$$\Phi_E = \frac{\mathrm{d}\Phi}{\mathrm{d}E} \tag{3}$$

NOTE The unit of the energy distribution of the neutron fluence is metres to the negative 2 times reciprocal joules ($\mathrm{m}^{-2} \cdot \mathrm{J}^{-1}$)

2.6
energy and direction distribution of the neutron fluence
$\Phi_{E,\Omega}$
quotient of $\mathrm{d}\Phi$ by $\mathrm{d}E$ and $\mathrm{d}\Omega$, where $\mathrm{d}\Phi$ is the increment of neutron fluence in the energy interval between E and $E + \mathrm{d}E$ and the solid angle interval between Ω and $\Omega + \mathrm{d}\Omega$, as given in Equation (4):

$$\Phi_{E,\Omega} = \frac{\mathrm{d}^2\Phi}{\mathrm{d}E\,\mathrm{d}\Omega} \tag{4}$$

NOTE The unit of the energy and direction distribution of the neutron fluence is metres to the negative 2 times reciprocal joules times reciprocal steradians ($\mathrm{m}^{-2}\ \mathrm{J}^{-1}\ \mathrm{sr}^{-1}$).

2.7
ambient dose equivalent at 10 mm depth
$H^*(10)$
dose equivalent at a point in the 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 opposite the direction of the aligned field

NOTE The unit of ambient dose equivalent is joules times reciprocal kilograms (J kg^{-1}) with the special name of sievert (Sv).

2.8
personal dose equivalent at 10 mm depth
$H_p(10)$
dose equivalent in soft tissue at a depth of 10 mm below a specified point on the body

NOTE 1 The unit of personal dose equivalent is joules times reciprocal kilograms (J kg^{-1}) with the special name of sievert (Sv).

NOTE 2 In ICRU Report 47 [12], the ICRU considers 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 dosemeters is the dose equivalent at a depth of 10 mm in a phantom composed of ICRU tissue, but of the size and shape of the phantom used for calibration (30 cm × 30 cm × 15 cm parallelepiped) and the conversion coefficients, $h_{p,slab}(10)$, are calculated for this configuration.

2.9
neutron fluence-to-dose-equivalent conversion coefficient
h_Φ
quotient of the neutron dose equivalent, H, by the neutron fluence, Φ, at a point in the radiation field, as given in Equation (5):

$$h_\Phi = \frac{H}{\Phi} \tag{5}$$

NOTE Any statement of a fluence-to-dose-equivalent conversion coefficient requires a statement of the type of dose equivalent, e.g. ambient dose equivalent h^*_Φ or personal dose equivalent $h_{p,slab\ \Phi}$.

2.10
response
R
⟨of a measuring instrument⟩ indication or reading divided by the conventional value of the quantity causing it

NOTE The type of response should be specified, e.g., “fluence response”, as given in Equation (6):

$$R_\Phi = \frac{M}{\Phi} \tag{6}$$

or “dose equivalent response”, as given in Equation (7):

$$R_H = \frac{M}{H} \tag{7}$$

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.

2.11
calibration factor
N
reciprocal of the response when the response is determined under reference conditions

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

2.12
energy dependence of response with respect to fluence
$R_{\Phi}(E)$
response, R, with respect to fluence, Φ, as a function of neutron energy, E

2.13
energy dependence of response with respect to dose equivalent
$R_{H}(E)$
response, R, with respect to dose equivalent, H, as a function of neutron energy, E

2.14
point of test
point in the radiation field at which the conventional value of a quantity being measured is determined.

2.15
reference point
⟨of a device⟩ point placed at the point of test for calibrating or testing purposes

3 List of symbols

Φ	neutron fluence
φ	neutron fluence rate
Φ_E	energy distribution of the neutron fluence free-in-air at the point of test
Φ_{E_n}	energy distribution of the neutron fluence at the point in the phantom at which the operational quantity is defined
$\Phi_{E,\Omega}$	energy and direction distribution of the neutron fluence at the point of test with the phantom present
E	neutron energy
$\langle h_{\Phi} \rangle$	energy-averaged fluence-to-dose-equivalent conversion coefficient
$h^*_{\Phi}(E)$	fluence-to-ambient-dose-equivalent conversion coefficient as a function of the neutron energy, E
$h_{\text{p,slab}\ \Phi}(E,\alpha)$	fluence-to-personal-dose-equivalent conversion coefficient as a function of the neutron energy, E, and angle of incidence, α
H	dose equivalent
$H^*(10)$	ambient dose equivalent at 10 mm depth
$H_\text{p}(10)$	personal dose equivalent at 10 mm depth below a specified point on the body
$H_\text{p,slab}(10)$	personal dose equivalent at 10 mm depth in the ICRU tissue slab
k_f	kerma coefficient
M	indication (of a measuring instrument) or reading
μ_tr/ρ	mass energy transfer coefficient
N	calibration factor
Q_n	average quality factor for neutron-induced secondary charged particles
R	response of a neutron detecting instrument
R_H	dose equivalent response [alternately, $R_H(E)$ when used in relation to the energy fluence, see 2.13]
R_{Φ}	fluence response [alternately, $R_{\Phi}(E)$ when used in relation to the energy fluence, see 2.12]
Ψ_{E_γ}	energy fluence at the point in the phantom at which the operational quantity is defined

4 Properties of simulated workplace neutron field facilities

This part of ISO 12789 addresses simulated workplace neutron fields like those described in, and produced in accordance with ISO 12789-1. When establishing or selecting a simulated neutron workplace field, it is necessary to consider the characteristics (e.g. energy and direction distribution) of the neutron field simulated and the response characteristics of the devices used to determine the neutron distributions.

There are three basic methods of producing neutrons for simulating workplace neutron fields: irradiation facilities, which have been developed to use of radionuclide neutron sources, accelerators and reactors. In each case, a variety of scattering, absorbing and converting materials may be placed between the primary source and point of test in order to modify the initial source energy distribution and simulate a workplace neutron field. Whereas the recommendations of ISO 8529-1 and 8529-2 include methods for reducing the effects of scattered neutrons on the reference neutron fluence spectra, ISO 12789-1 describes radiation fields that specifically use certain materials to produce additional scattering, absorption and secondary radiation. Each of the reference radiation fields described in ISO 12789-1 uses materials such as light water (H_2O), heavy water (D_2O), polyethylene, graphite, iron, concrete and uranium.

The quantities characterizing the simulated workplace fields at the point of test (energy and direction distribution of the neutron fluence) and all correction factors necessary to allow the evaluation of the appropriate conversion coefficients shall be determined.

The method for determining the appropriate conversion coefficients includes the measurement and computation of the neutron energy and direction distributions at the point of test and using those distributions to determine the ambient or personal dose equivalent for each energy or for each energy and angle at 10 mm in the ICRU sphere or phantom, respectively.

The conversion coefficients given as a function of energy and angle in Annex A pertain to broad, parallel neutron fields. If the neutron field is sufficiently broad and uniform, i.e. is homogeneous on the whole front face of the phantom or on the device being calibrated, these conversion coefficients can be applied without any further considerations. If these assumptions are not satisfied then $H_p(10)$ shall be calculated directly by computing the neutron energy and direction distribution at the point of test and using that distribution to determine the dose equivalent at 10 mm in the ICRU slab phantom. These considerations are discussed further in 5.4.2 of this part of ISO 12789.

The geometry and dimensions of the area surrounding the point of test should be arranged so that irradiations are reproducible to the maximum extent. All possible means should be used to allow for reproducibly positioning instruments used to characterize the calibration fields as well as for reproducibly positioning devices being calibrated. The eventual differences in the neutron energy and direction distributions between the reference point and the point of test should be considered. This can be done by including an additional uncertainty taking account of the non-homogeneous field or by introducing an additional correction factor.

Where possible, additional confirmatory measurements using area monitors or personal dosemeters should be performed if the energy and angle dependence of the response of these instruments is well known for the whole energy and angle range from calibration measurements and calculations. Devices that show a small energy and angle dependence of the response are well suited for this purpose.

5 Characterization of simulated workplace neutron fields

5.1 General

The primary purpose of characterizing the simulated neutron workplace field is to determine the neutron fluence and its distribution in terms of energy and direction, from which the conventional values of the operational quantities, i.e. $H^*(10)$ or $H_p(10)$, at the point of test are derived. As described in Clause 4, determining the dose equivalent requires a detailed knowledge of the neutron energy distribution and, in the case of personal dose equivalent, the neutron direction distribution, because the conversion coefficients depend strongly on those distributions.