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Passive neutron dosimetry systems —

Part 2: Methodology and criteria for the qualification of personal dosimetry systems in workplaces

Systèmes dosimétriques passifs pour les neutrons —

Partie 2: Méthodologie et critères de qualification des systèmes dosimétriques individuels aux postes de travail

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Foreword

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

A list of all the parts in the ISO 21909 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

ISO 21909-1 provides laboratory-based type tests, and performance requirements for passive neutron dosimetry systems to be used for measurement of personal dose equivalent, $H_p(10)$, for neutrons ranging from thermal energy to approximately 20 MeV[1]. No distinction between the different techniques available in the marketplace is made in the description of the tests. ISO 21909 (series) aims at covering all passive neutron detectors that can be used as a personal dosemeter in parts of, or in the complete above-mentioned neutron energy range.

The main objective of ISO 21909 series is to achieve correspondence between performance tests and conditions of use at the workplaces. Dosimetry systems complying totally with ISO 21909-1 should give consistent dosimetry results in workplace environments without the requirement of precise information on the characteristics of the radiation fields (neutron energy and direction distributions).

For the case that a dosimetry system does not comply with the full range of requirements in ISO 21909-1 with regard to the dependence of the response on the energy and direction distributions of the neutron fluence, it remains necessary to evaluate the performance of the dosimetry system for the conditions of the workplace. That means that this document is systematically used to qualify at workplaces a dosimetry system that does not fulfil the criteria of ISO 21909-1 on the dependence of the response on neutron energy and direction of incidence.

This document aims to address dosimetry systems with responses that show energy and directional dependencies that do not comply with the test requirements in ISO 21909-1, but that are able to give consistent and reliable dosimetry results at selected workplaces. In this case, a specific study of the workplace where the dosimetry systems are used is necessary to demonstrate that the dosimetry systems are suited for the workplace of application and, if needed, to determine the appropriate corrections to be applied. This document gives requirements for the qualification of the dosimetry system as well as methods for evaluating its performance and qualifying it for use in the workplace.

In cases where the dosimetry system meets the requirements of ISO 21909-1, it may still be desirable to perform a similar study at the workplace to improve the performance of the neutron dosemeters. It is also recommended that this document may be implemented, not only for passive dosimetry systems, but for active dosimetry systems as well.

No qualification or correction of the dosimetry system at a workplace is required if the dosimetry system fulfils the criteria of ISO 21909-1.

All the estimations of the uncertainties in this document have to be considered in accordance with the GUM[2]. Uncertainties quoted in this document are provided using a coverage factor k=2.

Passive neutron dosimetry systems —

Part 2: Methodology and criteria for the qualification of personal dosimetry systems in workplaces

1 Scope

This document provides methodology and criteria to qualify the dosimetry system at workplaces where it is used. The criteria in this document apply to dosimetry systems which do not meet the criteria with regard to energy and direction dependent responses described in ISO 21909-1.

The qualification of the dosimetry system at workplace aims to demonstrate that:

— either, the non-conformity of the dosimetry system to some of the requirements on the energy or direction dependent responses defined in ISO 21909-1 does not lead to significant discrepancies in the dose determination for a certain workplace field;

— or, that the correction factor or function used for this specific studied workplace enables the dosimetry system to accurately determine the conventional dose value with uncertainties similar to the ones given in ISO 21909-1.

NOTE This document is directed at all stakeholders who are involved: IMSs, accreditation or regulatory bodies, and users of the particular dosimetry (the user is meant as the entity which assigns the dosimetry system to the radiation worker and records the assigned dose.)

The methodologies to characterize the work place field in order to perform the qualification of the dosimetry system are given in Annex A. Annex B is complementary as it gives the practical methods to follow, once one methodology is chosen.

The provider of the dosimetry system shall provide the type test results corresponding to ISO 21909-1. However, when the dosimetry system to be qualified does not comply with all the criteria of ISO 21909-1 dealing with the energy and angle dependence of the response, some tests of the ISO 21909-1 can be not performed.

The links between ISO 21909-1 and ISO 21909-2 are described in Annex E.

This document only addresses neutron personal monitoring and not criticality accident conditions.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitute 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 21909-1:2021, *Passive neutron dosimetry systems — Part 1: Performance and test requirements for personal dosimetry*

ISO 8529-2:2000, *Reference neutron radiations — Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field*

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

3 Terms, definitions and symbols

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

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

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

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

3.1 General terms and definitions

3.1.1
detector
radiation detector
apparatus or substance used to convert incident ionizing radiation energy into a signal suitable for indication and/or measurement

[SOURCE: IEC 60050-394:2007, 394-24-01, modified — the term “detector” has been added as the first preferred term]

3.1.2
dosemeter
dosimeter
device having a reproducible, measurable response to radiation that can be used to measure the absorbed dose or dose equivalent quantities in a given system

[SOURCE: ISO 12749-2:2013, 5.5]

3.1.3
personal dosemeter
meter designed to measure the personal dose equivalent (rate)

Note 1 to entry: A personal dosemeter can be worn on the trunk (whole-body personal dosemeter), at the extremities (extremity personal dosemeter) or close to the eye lens (eye lens dosemeter).

[SOURCE: ISO 29661:2012, 3.1.21]

3.1.4
individual monitoring service
IMS
organization that operates a personal-dosimetry system which includes the evaluation of the reading of dosemeters after their use and may include:

— providing the user with dosemeters;

— recording the results;

— reporting the results to the user

3.1.5
dosimetry system
system used for measuring absorbed dose or dose equivalent, consisting of dosemeters, measurement instruments and their associated reference standards, and procedures for the system’s use

[SOURCE: ISO 12749-4:2015, 3.1.3, modified — the wording of the definition was slightly modified.]

3.2 Quantities

3.2.1
dose equivalent
H
product of the absorbed dose *D* to tissue at the point of interest and the quality factor *Q* at that point:

$$H = DQ$$

Note 1 to entry: The unit of dose equivalent is joule per kilogram ($J \cdot kg^{-1}$), and its special name is sievert (Sv).

[SOURCE: ISO 80000-10:2019, 10-83, modified — Note 1 to entry added.]

3.2.2
neutron fluence
$\boldsymbol{\Phi}$
differential quotient of *N* with respect to *a*, where *N* is the number of neutrons incident on a sphere of cross-sectional area *a*:

$$\Phi = \frac{dN}{da}$$

Note 1 to entry: The unit of neutron fluence is m^{-2}, a frequently unit used is cm^{-2}.

[SOURCE: ISO 80000-10:2019, 10-43, modified — the wording of the definition was slightly modified.]

3.2.3
energy distribution of the neutron fluence
Φ_E
quotient of $d\Phi$ by dE, where $d\Phi$ is the fluence of neutrons with energy between E and $E + dE$

$$\Phi_E = \frac{d\Phi}{dE}$$

Note 1 to entry: The SI unit of the energy distribution of the neutron fluence is ($m^{-2} \cdot J^{-1}$); a widely-used unit is ($cm^{-2} \cdot MeV^{-1}$).

Note 2 to entry: The energy distribution of the neutron fluence rate ϕ_E is the quotient of $d\Phi_E$ by dt, where $d\Phi_E$ is the increment of the energy distribution of the fluence in time interval dt. The unit is ($m^{-2} \cdot J^{-1} \cdot s^{-1}$); a widely-used unit is ($cm^{-2} \cdot MeV^{-1} \cdot s^{-1}$).

3.2.4
energy and direction distribution of the neutron fluence
$\Phi_{E,\Omega}$
quotient of $d\Phi$ by dE and $d\Omega$, where $d\Phi$ is the *fluence* of neutrons with energy between E and $E + dE$ and propagating within a solid angle $d\Omega$ around a specified direction, Ω, expressed as

$$\Phi_{E,\Omega} = \frac{d^2\Phi}{dE\Omega}$$

Note 1 to entry: The SI unit of the energy and direction distribution of the neutron fluence is $m^{-2} \cdot J^{-1} \cdot sr^{-1}$; a widely-used unit is ($cm^{-2} \cdot MeV^{-1} \cdot sr^{-1}$).

Note 2 to entry: The energy and direction distribution of the neutron fluence rate $\Phi_{E,\Omega}$ is the quotient of $d\Phi_{E,\Omega}$ by dt, where $d\Phi_{E,\Omega}$ is the increment of the energy and direction distribution of the fluence in time interval dt. The unit is ($m^{-2} \cdot J^{-1} \cdot sr^{-1} \cdot s^{-1}$); a widely-used unit is ($cm^{-2} \cdot MeV^{-1} \cdot sr^{-1} \cdot s^{-1}$).

3.2.5
personal dose equivalent
$H_p(d)$
dose equivalent in soft tissue at an appropriate depth, d, below a specified point on the human body

Note 1 to entry: The unit of personal dose equivalent is joule per kilogram ($J \cdot kg^{-1}$) and its special name is sievert (Sv).

Note 2 to entry: The specified point is usually given by the position where the individual's dosimeter is worn.

[SOURCE: ICRP 103:2007]

3.2.6
ambient dose equivalent
$H^*(10)$, $H'(0,07)$ or $H'(3)$
dose equivalent that would be produced by the corresponding aligned and expanded field in the *ICRU sphere* at a depth, d, on the radius opposing the direction of the aligned field

[SOURCE: IAEA – Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards - Interim Edition IAEA Safety Standards Series GSR Part 3, 2011]

3.2.7
conversion coefficient
$h_{p\Phi}(10,E,\alpha)$
quotient of the personal dose equivalent at 10 mm depth, $H_p(10)$, and the *neutron fluence*, Φ, at a point in the radiation field used to convert neutron fluence into the personal dose equivalent at 10 mm depth in the ICRU tissue slab phantom, where E is the energy of the incident neutrons impinging on the phantom at an angle α

Note 1 to entry: The unit of the conversion coefficient is $Sv \cdot m^2$. A commonly used unit of the conversion coefficient is $pSv \cdot cm^2$.

3.3 Calibration and evaluation

3.3.1
conventional true value for the neutron personal dose equivalent
H^{conv}
quantity value attributed by agreement to a quantity for a given purpose

Note 1 to entry: The conventional value H^{conv} is the best estimate of the quantity to be measured, determined by a primary standard or a secondary or working measurement standard which are traceable to a primary standard.

Note 2 to entry: in this document, the quantity is the neutron personal dose equivalent.

[SOURCE: ISO/IEC Guide 99:2007, 2.12, modified — the term was changed.]

3.3.2
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding readings with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1 to entry: Calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called “self-calibration”, or with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[SOURCE: ISO/IEC Guide 99:2007, 2.39]

3.3.3
calibration factor
N
quotient of the *conventional quantity value*, H^{conv}, (3.3.1) divided by the reading, *M*, derived under standard test conditions, given by the formula:

$$N = \frac{H^{conv}}{M}$$

Note 1 to entry: mathematical functions, in some cases families of functions, can be used to provide calibration factors over a range of conditions. Several different calibration functions can be defined for the same dosimetry system and possibly be used for different conditions of exposure.

3.3.4
correction factor or function
numerical value or function by which the indication is multiplied to compensate for the deviation of measurement conditions from reference conditions or for a systematic effect

Note 1 to entry: In this document, it corresponds to the factor or function, noted $k_{n,E,\Omega}$, defined for a specific workplace field, that is applied to the value of the measured dose equivalent in order to take into account the systematic effect induced by the dose response of the dosimetry system.

[SOURCE: ISO 29661:2012, 3.1.9, modified — the wording of the definition was slightly modified.]

3.3.5
measured dose equivalent
H_M
product of the reading, *M*, and the calibration factor, *N*:

$$H_M = M \cdot N$$

Note 1 to entry: More elaborate algorithms may also be used.

Note 2 to entry: This definition is only valid for a calibration field. To extend it to any other field, the correction factor of function $k_{n,E,\Omega}$, needs to be added. In that case, the formula becomes:

$$H_M = M \cdot N \cdot k_{n,E,\Omega}$$

3.3.6
phantom
object constructed to simulate the scattering and absorption properties of the human body for a given ionizing radiation

Note 1 to entry: For calibrations for whole body radiation protection considerations, the ISO water slab phantom is employed. It is made with polymethyl metacrylate (PMMA) walls (front wall 2,5 mm thick, other walls 10 mm thick), of outer dimensions 30 cm x 30 cm x 15 cm and filled with water.

Note 2 to entry: In the cases of very non-uniform irradiation conditions, an extremity cylinder, pillar or rod phantom may be used as described in ICRU report 66.

[SOURCE: ISO 12749-2: 2013, 4.1.6.1 modified — Notes 1 and 2 to entry added]

3.3.7
reading
M
quantitative indication of a detector or dosemeter when it is read out, generally corrected for background, ageing, fading and non-linearity of the process or the read out system

3.3.8
dose equivalent response
response
R
measured dose equivalent, H_M, divided by the *conventional quantity value*, H^{conv}, (3.3.1) of the dose equivalent, as given by the following formula:

$$R = \frac{H_M}{H^{conv}}$$

Note 1 to entry: The reading, *M*, is converted into dose equivalent, H_M, by multiplying *M* by an appropriate conversion coefficient or by using a more elaborate algorithm.

Note 2 to entry: In this document, the quantity is personal dose equivalent: $R = \frac{H_p^M(10)}{H_p^{conv}(10)}$

Note 3 to entry: In this document, for the sake of brevity, $H_M = H$ is used.

Note 4 to entry: The reciprocal of the response at *reference conditions* is equal to the calibration coefficient.

Note 5 to entry: In radiation metrology, the term response, abbreviated for this application from “response characteristic” (VIM), is defined as the ratio of the reading, *M*, of the instrument, to the value of the quantity to be measured by the instrument, for a specified type, energy and direction distribution of radiation. It is necessary, in order to avoid confusion, to state the quantity to be measured, e.g. the “fluence response” is the response with respect to the fluence, the “dose equivalent response” is the response with respect to dose equivalent.

[SOURCE: ISO 8529-3:1998, 3.2.10, modified]

3.4 Symbols

The list of the symbols used in this document is given in Table 1.

Table 1 — List of symbols

Symbol	Meaning	Unit
α	angle of incidence of the irradiation field	degree
d	Depth in ICRU 4-element or soft tissue. Recommended depths are 0,07 mm, 3 mm, and 10 mm.	mm
E	Neutron energy	eV
Φ	Neutron fluence	m^{-2}
H	Dose equivalent	Sv
$H^*(10)$	Ambient dose equivalent at 10 mm depth	Sv
H^{conv}	Conventional true value for the neutron personal dose equivalent	Sv
H_{HD}	Personal dose equivalent whose value is chosen in the range: 0,8 mSv < H_{HD} < 2 mSv	Sv
H_M	Measured dose equivalent	Sv
$H_p(d)$	Personal dose equivalent at a depth *d*	Sv
$H_p(10)$	Personal dose equivalent at 10 mm depth	Sv
H_p^{conv}	Conventional true value for the neutron personal dose equivalent.	Sv
$h_p(d,E,\alpha)$	Fluence-to-personal-dose-equivalent conversion factor	Sv·m²
R	Dose-equivalent response	-
U_{H_M}	Expanded uncertainty of the measured personal dose equivalent	As quantity
$U_{H^{conv}}$	Expanded uncertainty of the conventional true value for the personal dose equivalent	As quantity