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Passive neutron dosimetry systems —

Part 1: Performance and test requirements for personal dosimetry

Systèmes dosimétriques passifs pour les neutrons —

Partie 1: Exigences de fonctionnement et d'essai pour la dosimétrie individuelle

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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, *Radiological protection*.

This second edition cancels and replaces ISO 21909:2015, which has been technically revised.

The main changes compared to the previous edition, based on feedbacks from laboratories applying ISO 21909-1, are as follows:

— link between ISO 21909-1 and ISO 21909-2 improved by the addition of a flow chart explaining the link between the two parts;

— irradiations qualities for the energy test modified:

  — fast energy range enlarged to a range between 10 MeV and 19 MeV;

  — modification of the possible relative contribution of the thermal field in the mixed field composed of 252Cf or 241Am-Be with a thermal one;

— modification in the tests and/or criteria for:

  — the test to potentially eliminates the use of the full neutron and photon package;

  — the test of the coefficient of variation: criteria given by a function;

  — the linearity test: modifications in the equation and associated criteria consequently;

  — the energy and angle dependence of the response test: modification of the performance limits using trumpet curves;

  — alignment of the criteria for the following 3 tests: Stability under various climatic conditions/ effect of light exposure (opacity to light) / effect of storage, all for unexposed dosemeters.

A list of all 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

This document gives laboratory-based performance and test requirements for passive dosimetry systems to be used for the determination of personal dose equivalent, $H_p(10)$, in neutron fields with energies ranging from thermal to approximately 20 MeV.

A dosimetry system may consist of the following elements:

a) a passive device, referred to here as a detector, which, after the exposure to radiation, stores information (signal) for use in measuring one or more quantities of the incident radiation field;

b) a dosemeter, made up of one or more detector(s) incorporated together and with some means of identification;

c) a reader which is used to read out the stored signal from the detector, and the associated algorithm, if applicable, aiming to determine the personal dose equivalent.

A treatment to prepare the dosemeter before irradiation and/or before reading is also part of the process and is considered in the document.

This document does not focus on any technique in particular, but intends to be general, including new techniques as they emerge. When distinctions are necessary, they are defined as generically as possible, e.g., disposable/reusable dosemeters and photon-sensitive dosemeters. In conclusion, no performance tests are dedicated to one particular technique, unless it is absolutely necessary. Consequently, this document aims to define performance tests leading to similar results, independently of the techniques used.

The main objective of this document is to achieve correspondence between performance tests and conditions of use at workplaces. Dosimetry systems complying with this document exhibit consistent annual dosimetry results in workplace environments. Reaching such an objective means that this document accounts for the various situations of exposure in terms of dose levels and neutron energy distributions.

Annual exposures of many workers comprise the sum of several low doses close to the minimum recording value. The dosemeter needs therefore to be well characterized, not only for use in relatively high dose situations but also for use in low dose situations, to ensure that the annual dose is determined with an adequate uncertainty. In this document, false positive events when there is not any irradiation, are considered but there is no test of the detection threshold by measuring the background signal of the dosemeter when it is not irradiated. However, all the tests aimed at characterizing the dosimetric performance of the system (coefficient of variation and linearity, energy and angle dependence of the responses) are required at two levels of dose: around 1 mSv and close to the minimum recording value. The criteria applied at these two levels of dose could differ. This choice is made to ensure that dosimetric systems are adapted to the range of doses usually encountered at workplaces.

The main goal of this document is to ensure that a dosemeter is reliable enough to use in most workplaces. Reference neutron radiation characteristics and methodologies for the proper calibration of the dosemeters are reported in ISO 8529 (all parts), ISO 12789-1 and ISO 29661. The dose equivalent distributions of the most common reference radiation sources (e.g. ^{241}Am-Be or ^{252}Cf) as used for calibration are generally higher in energy (where the fluence-to-dose-equivalent conversion coefficients are greater) than the ones encountered in workplaces. The performance of the dosemeters for neutron energies between a few tens and a few hundreds of keV specifically needs to be determined to ensure good response in most of the workplaces. To address this need, some performance tests with mono-energetic neutrons fields at low energies are required in this document.

One well-characterized neutron field (e.g., ^{241}Am-Be or ^{252}Cf) is sufficient to test the stability of dosimetric performances for influencing factors (e.g., fading, ageing, the impact of non-neutron radiation on the neutron signal, harsh climatic conditions, light exposure, physical damage, and sealing).

This document does not present performance tests for characterizing any type of potential degradation (see Scope). However, to ensure the stability of the dosimetry system, it is necessary for the laboratory to evaluate the potential degradation and/or set adapted controls on processing.

For the case that a dosimetry system does not comply with the full range of requirements of this document with regard to the dependence of the response on the energy and direction distributions of the neutron fluence, it is necessary to evaluate the performance for the conditions of the selected workplace. This is addressed in ISO 21909-2 which gives methodologies and criteria to qualify the dosimetry system at the workplace. Even when the dosimetry system fulfils the requirements of this document, it may still be desirable to make a similar study at the workplace.

This document may be extended in the future to another part for the ambient dose equivalent $H^*(10)$ for ambient and environmental dosimetry.

Passive neutron dosimetry systems —

Part 1: Performance and test requirements for personal dosimetry

1 Scope

This document provides performance and test requirements for determining the acceptability of neutron dosimetry systems to be used for the measurement of personal dose equivalent, $H_p(10)$, for neutrons ranging in energy from thermal to 20 MeV[1)].

This document applies to all passive neutron detectors that can be used within a personal dosemeter in part or in all of the above-mentioned neutron energy range. No distinction between the different techniques available in the marketplace is made in the description of the tests. Only generic distinctions, for instance, as disposable or reusable dosemeters, are considered.

This document describes type tests only. Type tests are made to assess the basic characteristics of the dosimetry systems and are often ensured by recognized national laboratories

This document does not present performance tests for characterizing the degradation induced by the following:

— intrinsic temporal variability of the quality of the dosemeter supplied by the manufacturer;

— intrinsic temporal variability of preparation treatments (before irradiation and/or before reading), if existing;

— intrinsic temporal variability of reading process;

— degradation due to environmental effects on the preparation treatments, if existing;

— degradation due to environmental effects on the reading process.

This document gives information for extremity dosimetry in the Annex C, based on recommendations given by ICRU Report 66. This document addresses only neutron personal monitoring and not criticality accident conditions.

The links between this document and ISO 21909-2 are given in Annex A.

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

1) This maximal limit of the energy range is only an order of magnitude. The reference radiation fields used for the performance tests are those defined in ISO 8529-1. This means that the maximal energies could only be 14,8 MeV or 19 MeV. This document gives performance requirements to 14,8 MeV which is the typical neutron energy encountered for fusion. For fission spectra, the highest energies are around 20 MeV but the contribution to dose equivalent coming from neutrons with energy higher than 14,8 MeV is negligible.

ISO 21909-2, *Passive neutron dosimetry systems — Part 2: Methodology and criteria for the qualification of personal dosimetry systems in workplaces*

ISO 8529-1, *Reference neutron radiations — 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 8529-3, *Reference neutron radiations — Part 3: Calibration of area and personal dosimeters and determination of response as a function of energy and angle of incidence*

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

JCGM 100, *GUM 1995 with minor corrections, Evaluation of measurement, data — Guide to the expression of uncertainty in measurement*

3 Terms and definitions

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 https://www.iso.org/obp

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

3.1 General terms and definitions

3.1.1
ageing
change with time of physical, chemical or electrical properties of a component or module under specified operating conditions, which could result in degradation of significant performance characteristics

[SOURCE: IEC 60050-393:2007, 393-18-41]

3.1.2
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.]

3.1.3
fading
loss of signal under certain circumstances such as storage, transmission, humidity or temperature change

[SOURCE: IEC 60050-393:2007, 393-38-54]

3.1.4
dosemeter
dosimeter
device having a reproducible, measurable response to radiation that can be used to measure the *absorbed dose* (3.2.1) or *dose equivalent* (3.2.3) quantities in a given system

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

3.1.5
personal dosemeter
meter designed to measure the *personal dose equivalent (rate)* (3.2.5)

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]

3.1.6
dosimetry system
system used for measuring *absorbed dose* (3.2.1) or *dose equivalent* (3.2.3), 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 — Definition slightly reworded.]

3.2 Quantities

3.2.1
absorbed dose
D
differential quotient of $\bar{\varepsilon}$ with respect to *m*, where $\bar{\varepsilon}$ is the mean energy (ISO 80000-5) imparted by ionizing radiation to matter of mass, *m*:

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$

Note 1 to entry: The gray is a special name for joule per kilogram, to be used as the coherent SI unit for absorbed dose. 1 Gy = 1 J/kg

$$\bar{\varepsilon} = \int D \, \mathrm{d}m$$

where d*m* is the element of mass of the irradiated matter.

In the limit of a small domain, the mean specific energy $\bar{z} = \frac{\Delta\bar{\varepsilon}}{\Delta m}$ is equal to the absorbed dose *D*.

The absorbed dose can also be expressed in terms of the volume of the mass element by:

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m} = \frac{\mathrm{d}\bar{\varepsilon}}{\rho \, \mathrm{d}V}$$

[SOURCE: ISO 80000-10:2019, 10-81.1]

3.2.2
quality factor
Q
factor in the calculation and measurement of *dose equivalent* (item 3.2.3), by which the *absorbed dose* (item 3.2.1) is to be weighted in order to account for different biological effectiveness of radiations, for radiation protection purposes

[SOURCE: ISO 80000-10:2019, 10-82]

3.2.3
dose equivalent
H

product of the absorbed dose D (3.2.1) to tissue at the point of interest and the quality factor Q (3.2.2) 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.]

3.2.4
neutron fluence
Φ
differential quotient of N with respect to a, where N is the number of neutrons incident on a sphere of cross-sectional area a:

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

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 — Note 1 to entry added.]

3.2.5
personal dose equivalent
$H_p(d)$
dose equivalent (3.2.3) 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 (3.2.3) 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* (3.2.5) *at 10 mm depth*, $H_p(10)$, and the *neutron fluence*, Φ (3.2.4), 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
arithmetic mean
$\bar{x}$
average of a series of n measurements, x_i, given by the following formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

3.3.2
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 — Term and notes to entry modified.]

3.3.3
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]

3.3.4
calibration factor
N
quotient of the *conventional quantity value* (3.3.2), H^{conv}, divided by the *reading, M* (3.3.14), derived under standard conditions, given by the following 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.

3.3.5
calibration quantity
physical quantity used to establish the calibration of the dosemeter

Note 1 to entry: For the purpose of this document, the calibration quantity is the personal dose equivalent at 10 mm depth in the ICRU tissue slab phantom, $H_p(10)$.

3.3.6
standard deviation
s
parameter for a series of *n* measurements, x_i, characterizing the dispersion and given by the following formula:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where $\bar{x}$ is the arithmetic mean of the results of *n* measurements.

3.3.7
coefficient of variation
C
ratio of the standard deviation *s* to the arithmetic mean $\bar{x}$ of a set of *n* measurements x_i given by the following formula:

$$C = \frac{s}{\bar{x}} = \frac{1}{\bar{x}}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

[SOURCE: IEC 60050-394, 394-40-14]

3.3.8
minimum recording value
$H_{\min}$
minimum value of dose which is recorded, i.e the lower limit of the dose range, defined by the dosimetry laboratory

Note 1 to entry: $H_{\min}$ can be equal to 0,10 mSv or 0,20 mSv or even 0,30 mSv for example. The choice depends on the country of the dosimetry laboratory. Indeed, $H_{\min}$ would be logically at least equal or lower to the legal threshold of the country.

Note 2 to entry: In this document, $H_{\min}$ cannot exceed 0,3 mSv : $H_{\min} \leq 0{,}3$ mSv.

3.3.9
influence quantity
quantity (parameter) that may have a bearing on the result of a measurement without being the subject of the measurement

[SOURCE: ISO 8529-3:1998, 3.2.1, modified – by adding the word “parameter” and removing Note 1 to entry.]

3.3.10
measured dose equivalent
H_M
product of the *reading* (3.3.13), *M*, and the *calibration factor* (3.3.4), *N:*

$$H_M = M \cdot N$$

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

3.3.11
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 × 30 cm × 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, 4.1.6.1 modified — Notes 1 and 2 to entry added.]

3.3.12
reference conditions
set of influence quantities for which the *calibration factor* (3.3.4) is valid without any correction

[SOURCE: ISO 8529-3: 1998, 3.2.2]

3.3.13
reading
M
quantitative indication of a *detector* (3.1.2) or *dosemeter* (3.1.4) when it is read out, generally corrected for background, ageing, fading and non-linearity of the process or the read out system

3.3.14
read out
process of determining the indication of a *detector* (3.1.2) or dosemeter reader

3.3.15
dose equivalent response
response
R
measured dose equivalent (3.3.10), H_M, divided by the *conventional quantity value* (3.3.2) of the dose equivalent, H^{conv}, as given by the following formula:

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

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: $R = \dfrac{H_{\text{p}}^{M}(10)}{H_{\text{p}}^{\text{conv}}(10)}$

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 — Term and definition reworded.]

3.3.16
standard test conditions
conditions represented by the range of values for the *influence quantities* (3.3.9) under which a *calibration* (3.3.3) or a determination of the *response* (3.3.15) is carried out

3.4 List of symbols

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