INTERNATIONAL STANDARD

ISO 21909-1

First edition
2015-12-15

Corrected version
2015-12-15

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

Reference number
ISO 21909-1:2015(E)

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Contents

Page

Foreword

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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 meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

This first edition of ISO 21909-1 cancels and replaces ISO 21909:2005, which has been technically revised. It also incorporates the Technical Corrigendum ISO 21909-1:2005/Cor:2007.

ISO 21909 consists of the following parts, under the general title *Passive neutron dosimetry systems*:

— *Part 1: Performance and test requirements for personal dosimetry*

This corrected version of ISO 21909-1:2015 includes various editorial corrections and Figure 2 has been modified.

Introduction

ISO 21909-1 gives 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 an 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) packed together, incorporating some means of identification;

c) treatment to prepare the dosemeter before irradiation and/or before reading;

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

This part of ISO 21909 aims at covering all passive neutron detectors that can be used as a personal dosemeter in part or in all of the above-mentioned neutron energy range. This part of ISO 21909 does not focus on any technique in particular, but intends to be general, including when new techniques emerge. When distinctions are necessary, they are defined in as generic way as possible: disposable/reusable dosemeters and photon-sensitive dosemeters. In conclusion, no performance tests are dedicated to one particular technique, unless it is absolutely necessary, in order for this part of ISO 21909 to reach a global coherence between the different available techniques. Consequently, this part of ISO 21909 aims to define performance tests leading to similar results independent of the techniques used.

The main objective of this part of ISO 21909 is to achieve correspondence between performance tests and conditions of use at workplaces. Dosimetry systems complying with this part of ISO 21909 are wanted to give consistent annual dosimetry in standard workplace environments. Reaching such an objective means that this part of ISO 21909 takes into account the various situations of exposure in terms of dose levels and neutron energy distributions.

Annual exposures of many workers usually consist of the sum of several low doses close to the minimal recording value. The dosemeter needs therefore to be well characterized, not only for relatively high dose measurement but also for low doses, to make sure the annual dose is given with an adequate uncertainty. In this part of ISO 21909, there is no description of test aiming at determining the detection threshold by measuring the background signal of the dosemeter when it is not irradiated. But all the tests aiming at characterizing the dosimetric performance of the system (coefficient of variation and linearity, energy and angular responses) are required at two levels of dose: around 1 mSv and close to the minimal 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.

In other words, the main goal of this part of ISO 21909 is to ensure that a dosemeter is reliable enough 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 mean energies of the dose equivalent distributions of the most common reference radiations (e.g. ^{241}Am-Be or ^{252}Cf neutron sources) as used for calibration are generally higher than the ones encountered in workplaces. The performance of the dosemeters for energies situated between a few tens and a few hundreds of keV needs notably 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 part of ISO 21909.

For the performance tests aiming at characterizing stability of dosimetric performances of the dosimetry systems in the range of realistic conditions of use of the dosemeters (influence of fading, ageing, radiation other than neutrons, harsh climatic conditions, light exposure, physical damage, and sealing), it is considered to be sufficient to use only one neutron source (e.g. ^{241}Am-Be or ^{252}Cf neutron sources).

This part of ISO 21909 does not present performance tests aiming at 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.

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.

Moreover, to deal with dosimetry systems whose energy and direction dependences of response do not fulfil all the requirements of this part of ISO 21909, another document would be needed to complete this part of ISO 21909, giving complementary specific recommendations. In this case, a study at the workplace where the dosemeters are used is necessary to complete all the tests performed according to this part of ISO 21909. This new part would give recommendations to qualify the dosimetry system at the workplace, giving a methodology. Even when the dosimetry system fulfils the requirements of this part of ISO 21909, it may still be desirable to make a similar study at the workplace (this will be the subject of a future part of ISO 21909.

This part of ISO 21909 also needs to 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 part of ISO 21909 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)]. No distinction between the different techniques available in the market place is made in the description of the tests. Only generic distinctions, as disposable or reusable dosemeters for instance, are considered. This part of ISO 21909 gives information for extremity dosimetry, based on recommendations given by ICRU Report 66 in Annex A.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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*

ISO 8529-1:2001, *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*

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

3 Terms, definitions, and symbols

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

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]

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. The present standard 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.

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
dosemeter worn by a person for determining the personal dose equivalent received

[SOURCE: IEC 60050-394:2007, 394-31-11 modified — Notes 1 and 2 were removed.]

3.2 Terms relating to quantities

3.2.1
absorbed dose
D
quotient of $d\bar{\varepsilon}$ by *dm*, where $d\bar{\varepsilon}$ is the mean energy imparted to matter of mass *dm* thus

$$D = \frac{d\bar{\varepsilon}}{dm}$$

Note 1 to entry: The unit of absorbed dose is joule per kilogram ($J \cdot kg^{-1}$). The special name for the unit of absorbed dose is Gray (Gy).

[SOURCE: ICRU 60, 4.2.5]

3.2.2
quality factor
Q
number by which the *absorbed dose* (3.2.1) (*D*) is multiplied to reflect the relative biological effectiveness of the radiation, the result being the *dose equivalent* (3.2.3)

[SOURCE: ISO 12749-2:2013, 4.1.6.6]

3.2.3
dose equivalent
H
product of *D* and *Q* at a point in tissue, where *D* is the *absorbed dose* (3.2.1) and *Q* is the *quality factor* (3.2.2) for the specific radiation at this point, thus

$$H = D \cdot Q$$

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: ICRP 103:2007]

3.2.4
ICRU sphere
sphere of 30 cm diameter made of tissue equivalent material with a density of 1 g/cm^3 and a mass composition of 76,2 % oxygen, 11,1 % carbon, 10,1 % hydrogen, and 2,6 % nitrogen

[SOURCE: ISO 12749-2:2013, 4.1.6.4, modified]

3.2.5
fluence
quotient of dN divided by da, where dN is the number of incident particles on a sphere of cross-sectional area da

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

[SOURCE: ISO 8529-1:2001, modified]

3.2.6
personal dose equivalent
$H_p(d)$
dose equivalent (3.2.3) in soft tissue at an appropriate depth, d, below a specified point where the dosemeter is worn/mounted, i.e. on the human body or a calibration phantom

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 dosemeter is worn.

[SOURCE: ISO 12749-2:2013, 4.1.6.8.3, modified]

3.2.7
conversion coefficient
$h_{p\Phi}(d,E,\alpha)$
quotient of the personal dose equivalent, $H_p(d)$, and the neutron fluence, Φ, at a point in the radiation field used to convert neutron fluence into the personal dose equivalent at d 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 Terms relating to 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 quantity value
H^0

quantity value attributed by agreement to a quantity for a given purpose

Note 1 to entry: The conventional value H^0 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.

[SOURCE: ISO/IEC Guide 99:2007, 2.12, 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 indications 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^0, divided by the *reading, M* (3.3.15), derived under standard conditions, given by the following formula:

$$N = \frac{H^0}{M}$$

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

Note 1 to entry: For the purpose of this part of ISO 21909, the calibration quantity is the personal dose equivalent at 10 mm depth in the ICRU tissue slab phantom, $H_p(10)$.

3.3.6
sample standard deviation
s

parameter for a series of n measurements, x_i, characterizing the dispersion and given by the following formula:

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

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:

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

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

3.3.8
detection threshold
minimum measured dose equivalent which is significantly higher (at the 95 % confidence level) than the mean dose equivalent of a sample of unirradiated dosemeters

3.3.9
minimal recording value
$H_{\min}$
minimal value of dose which is recorded, i.e the lower limit of the dose range, defined by the dosimetry laboratory

Note 1 to entry: $H_{\min}$ would be logically at least equal or lower to the legal threshold of the country. Depending on the country or the dosimetry laboratory, $H_{\min}$ is different: 0,10; 0,20 or 0,30 mSv, for example.

Note 2 to entry: In this part of ISO 21909, $H_{\min}$ shall be equal to 0,3 mSv at maximum: $H_{\min} \leq 0{,}3$ mSv.

3.3.10
in-field calibration
procedure to calibrate neutron dosemeters in neutron fields representative of a working environment for which the personal dose equivalent rates or neutron spectra and angle distributions have been determined by appropriate methods and hence are sufficiently well known

3.3.11
influence quantity
quantity (parameter) that may have a bearing on the results of a measurement without being the objective of the measurement

[SOURCE: ISO 8529-3:1998, 3.2.1, modified]

3.3.12
measured dose equivalent
H^{M}
product of the reading, M, and the calibration factor, N:

$$H^{\mathrm{M}} = M \cdot N$$

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

3.3.13
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 exceptional cases of very non-uniform irradiations, the method described in the ICRU report 66, to perform a dosimetry for irradiations of the extremities, may be used. Therefore, a pillar or rod phantom may be employed.

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

3.3.14
read out
process of determining the indication of a detector or dosemeter reader

3.3.15
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

3.3.16
reference conditions
set of influence quantities for which the calibration factor is valid without any correction

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

3.3.17
response
R
measured dose equivalent, H^{M}, divided by the *conventional quantity value* (3.3.2) of the dose equivalent, H^{0}, as given by the following formula:

$$R = \frac{H^{\mathrm{M}}}{H^{0}}$$

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 part of ISO 21909, the quantity is personal dose equivalent: $R = \frac{H_{\mathrm{p}}^{\mathrm{M}}(10)}{H_{\mathrm{p}}^{0}(10)}$.

Note 3 to entry: In this part of ISO 21909, for the sake of shortness, $H^{\mathrm{M}} = H$ is used.

Note 4 to entry: For the specified reference conditions, the response is the reciprocal of the calibration factor.

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]

3.3.18
standard test conditions
range of values of a set of influence quantities under which a calibration or a determination of response is carried out

3.4 List of symbols

The list of the symbols used in this part of ISO 21909 is given in Table 1.

Table 1 — List of symbols

Symbol	Meaning	Unit
C	Coefficient of variation	-
D	Absorbed dose	Gy
$D_{\max}^{\text{ageing}}$	T_2 - T_1	days
$D_{\max}^{\text{fading}}$	Maximal period of storage in days between irradiation and read out	days
d	Depth in ICRU 4-element or soft tissue. Recommended depths are 0,07 mm, 3 mm and 10 mm.	mm
H	Dose equivalent	Sv
H_{HD}	Personal dose equivalent whose value is chosen in the following range: 0,8 mSv < H_{HD} < 2 mSv	Sv
H^{M}	Measured dose equivalent	Sv
$H_{\min}$	Minimal recording value	Sv
$H_{\text{p}}(d)$	Personal dose equivalent at a depth d	Sv
$H_{\text{p}}(10)$	Personal dose equivalent at a depth 10 mm	Sv
H_{p}^{0}	Personal dose equivalent of the conventional quantity value	Sv
$h_{\text{p}\Phi}(10;E,\alpha)$	Conversion coefficient	Sv·m^2
H^0	Conventional quantity value (of a quantity)	Sv
H^0_{neutron}	Conventional quantity value for neutron irradiations only	Sv
H^0_{photon}	Conventional quantity value for photon irradiations only	Sv
$H^*(10)$	Ambient dose equivalent at depth 10 mm	Sv
i	Designator for a group subjected to a specific influence quantity	-
j	Designator for a group subjected to a specific dosemeter out of n dosemeters irradiated equally	-
k	Designator for a group subjected to a specific series of irradiation	-
M	Reading	Sv
N	Calibration factor	-
n	Number of dosemeters in one group that are equally irradiated	-
Q	Quality factor	-
R	Response	-
R^0	Reference response	-
r	Permitted value	-
$r_{\max}$	Maximal permitted value	-
$r_{\min}$	Minimal permitted value	-
s	Sample (experimental) standard deviation	-
T_1	Minimal period between the manufacturing date for disposable dosemeter or the day when the reset is done for reusable dosemeters and the first day of possible irradiation	days
T_2	Maximal period between the manufacturing date for disposable dosemeter or the day when the reset is done for reusable dosemeters and last day of possible irradiation	days
$t_{\text{n-1}}$	Student t-factor for n measurements	-

Table 1 *(continued)*

Symbol	Meaning	Unit
U	Expanded uncertainty	-
U^0	Expanded uncertainty of conventional quantity values	-
ϕ	Fluence	m^{-2}
$\bar{x}$	Arithmetic mean	-

This part of ISO 21909 uses SI units. However, the following units of practical importance for time and energy are used when necessary:

— days (d) and hours (h) for time;

— electron-volt (eV) knowing that 1 eV = 1,602 × 10^{-19} J.

The SI unit of dose equivalent is J·kg^{-1} but the dedicated name for the unit of dose equivalent is Sievert (Sv).

4 General test conditions

4.1 Test conditions

All tests shall be performed under standard test conditions (see Annex B), except if otherwise is stated. The actual conditions should be indicated in the test report. These conditions should not undergo large or rapid changes during a series of measurements.

4.2 Reference radiation

The reference radiation fields defined in ISO 8529-1 shall be used. The performance tests aimed at characterizing the intrinsic properties of the dosimetry system (coefficient of variation, linearity, energy and angular dependences) shall be carried out for different energy distributions (e.g. ^{241}Am-Be or ^{252}Cf neutron sources, mono-energetic fields at different energies). For the performance tests aimed at assessing changes to characteristics due to internal or external conditions (fading, influence of photons, etc.), it is sufficient to use only one neutron field (e.g. ^{241}Am-Be or ^{252}Cf neutron sources). Information on irradiation conditions is found in Annex C.

Moreover, a specific section dedicated to extremity dosimetry is given in Annex A.

NOTE 1 No tests are performed using simulated workplace neutron fields defined in ISO 12789-1 because of the very limited availability of facilities delivering such fields.

NOTE 2 For dosimetry systems calibrated using in-field calibration, some tests can also be performed in these fields. See Annexes C and D.

4.3 Tests requirements

Tests focus on the dosimetric performance of the dosimetry systems in all conditions of use of the dosemeters. The objective is to test that any dosemeter gives results with sufficient accuracy when going through all the processes in the laboratory (storage, packaging, possible preparative treatments, unpackaging, possible treatments before reading and the read out itself), delivery to the customer and use by the customer in any realistic situation.

No tests are proposed for the parameters of the systems and processes operated in the laboratory capable of influencing the reproducibility and stability of dosimetric performance, mainly because systems and processes can be strongly dependent on the dosimetric technique used. Nevertheless, the importance of treating this question, taking into account specifications of the manufacturer and

conditions of use in the laboratory, is underlined. The critical parameters for processing of dosemeters have to be described.

5 Tests and performance requirements

The following general requirements apply to the tests for all dosimetry systems:

a) The tests are performed on a specified number of dosemeters randomly selected among dosemeters used in the routine process;

b) Type tests are made to assess the basic characteristics of the dosimetry systems and are often ensured by recognized national laboratories. This part of ISO 21909 describes type tests only;

c) The performance requirements are listed in Tables 2 and 3. They are divided into two categories:

   1) requirements testing the dosimetric performances of the dosimetry systems (coefficient of variation and linearity, energy and angle dependence of the response);

   2) requirements testing the stability of dosimetric performances of the dosimetry systems in the range of realistic conditions of use of the dosemeters (influence of fading, ageing, radiation other than neutrons, harsh climatic conditions, light exposure, physical damage, sealing).

d) The global processing to store, prepare and analyse the dosemeters shall be performed in accordance with the routine process. More specifically, in case background dosemeters are used to evaluate and to subtract the background noise, these dosemeters would need to be used as in the routine procedure;

e) The laboratory should explain how the total $H_p(10)$ as well as the specific neutron component are get.

Table 2 — Requirements for the dosimetric performances of the dosimetry systems

No.	Characteristic under test	Personal dose equivalent H_p^0 (mSv)	Number of dosemeters	Performance requirement		Performance requirement for the coefficient of variation C	Types of dosimetry systems and components
				r_{min}	r_{max}	r	
7.4.2	Coefficient of variation and linearity	0,1	12	−30 %	+35 %	40 %	All
		0,2 to 0,4	12			30 %	
		0,5	6			20 %	
		0,8	6			15 %	
		≥1	6			10 %	

No.	Characteristic under test	Personal dose equivalent H_p^0 (mSv)	Performance requirement at 0°		Performance requirement at 30°		Performance requirement at 60°	
			r_{min}	r_{max}	r_{min}	r_{max}	r_{min}	r_{max}
7.4.3	Energy and angle dependence of the response	0,1	−60 %	+150 %	−70 %	+230 %	−80 %	+300 %
		0,2	−55 %	+120 %	−60 %	+150 %	−70 %	+230 %
		0,3 ; 0,4	−50 %	+100 %	−55 %	+120 %	−65 %	+190 %
		≥0,5	−40 %	+70 %	−50 %	+100 %	−60 %	+150 %

Table 3 — Performance requirements testing the evolution of the dosimetry systems in function of internal or external conditions

No.	Performance characteristics	Performance requirements	Types of dosimetry systems and components
8.1	Fading (stability of the latent image)	The response of dosimetry systems irradiated at the beginning of a storage period shall not change by more than −15 % +18 % for a storage period under standard test conditions corresponding to the maximal period of storage D_{max}^{fading} between irradiation and read out in the laboratory.	All
8.2	Ageing	The response of dosimetry systems irradiated at the end of a storage period shall not vary by more than −15 % +18 % for a storage period D_{max}^{ageing} under standard test conditions.	All, but the definition of D_{max}^{ageing} before irradiation storage depends on whether the dosemeters are disposable or reusable.

Table 3 *(continued)*

No.	Performance characteristics	Performance requirements	Types of dosimetry systems and components
8.3	Effect of storage for unexposed dosemeters	A maximum of 10 % of unirradiated dosemeters present a measured dose equivalent H_M higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent H_M higher than H_{min} + 0,2 mSv. If one or more dosemeters present a measured dose equivalent H_M higher than H_{min} + 0,2 mSv, a second test with a lot of 50 dosemeters is necessary: a maximum of one dosemeter shall present a measured dose equivalent H_M higher than H_{min} + 0,2 mSv.	All
8.4	Exposure to radiation other than neutrons: photon radiation	The measured dose equivalent shall not change by more than the value of H_{min} for dosimetry systems exposed to 10 mSv with a ^{137}Cs source compared to the measured dose equivalent for dosimetry systems which are unirradiated and stored in standard test conditions.	All
		The measured dose equivalent shall not change by more than the value of 0,1 mSv for dosimetry systems exposed to ^{137}Cs photons and to an ^{241}Am-Be or ^{252}Cf neutron source compared to the measured dose equivalent for dosimetry systems exposed to an ^{241}Am-Be or ^{252}Cf neutron source, in the different configurations in terms of ratio: $H^0_{neutron}/H^0_{photon}$ = 0,3; 1 and 3.	Photon sensitive dosimetry systems
	Exposure to radiation other than neutrons: radon	The measured dose equivalent shall not change by more than 0,5 mSv for dosimetry systems exposed to 3 MBq·h/m^3 of radon at 50 % equilibrium with daughters, compared to the measured dose equivalent of dosemeters stored in standard test conditions.	All
8.5	Stability under various climatic conditions: Effect on the dose response	The measured dose equivalent shall not differ from the measured dose equivalent of dosemeters stored in standard test conditions by more than −15 % +18 % for 48 h storage at 40 °C ± 2 °C and 90 % relative humidity when the dosimetry systems are irradiated either at the beginning or at the end of the storage period.	All
	Stability under various climatic conditions: Effect for unexposed dosemeters	A maximum of 20 % of the dosemeters stored for a 48 h period in a climatic chamber in which the temperature is 40 °C ± 2 °C and the relative humidity is at least 90 % shall present a measured dose equivalent higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent higher than H_{min} + 0,1 mSv.	
8.6	Effect of light exposure (opacity to light): Effect on the dose response	The measured dose equivalent shall not differ from the measured dose equivalent of dosemeters stored in standard test conditions by more than −15 % +18 % for dosemeters exposed to a xenon lamp equivalent to bright sunlight (295 nm to 769 nm) to 1 000 W/m^2 for one week.	All
	Effect of light exposure (opacity to light): Effect for unexposed dosemeters	A maximum of 20 % of unirradiated dosemeters exposed to 1 000 W/m^2 of light for one week presents a measured dose equivalent higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent higher than H_{min} + 0,1 mSv.	

Table 3 *(continued)*

No.	Performance characteristics	Performance requirements	Types of dosimetry systems and components
8.7	Drop test: Effect on the dose response	The measured dose equivalent shall not differ from the measured dose equivalent of dosemeters stored in standard test conditions by more than −15 % +18 % for dosemeters dropped from a height of 1 m.	All
	Drop test: Effect for unexposed dosemeters	A maximum of 20 % of the unirradiated dosemeters dropped from a height of 1 m presents a measured dose equivalent higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent higher than H_{min} + 0,1 mSv.	
8.8	Distance to the phantom	The measured dose equivalent shall not differ from the measured dose equivalent of dosemeters by more than −15 % +18 % for dosemeters situated at 0,5 cm far from the phantom.	All
8.9	Sealing	Precautions to prevent ingress to be stated	All

6 Test methods

Tests to demonstrate compliance with the specified performance requirements are detailed in the following clauses. These provide guidance. Specific details pertaining to similar tests by various national regulatory agencies may differ from those described here.

The performance tests are divided into two categories: first, the tests to quantify the intrinsic characteristics of the dosimetry systems are described. Then, the requirements in terms of changes to the dosimetry systems due to external or internal conditions (time, temperature, humidity, exposure to radiations other than neutrons...) are specified. Before the performance tests, a preliminary test is proposed to reduce the number of irradiations. This test concerns the qualification for eliminating the use of the full neutron and photon package.

7 Performance tests: intrinsic characteristics

7.1 General

This part of ISO 21909 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.

7.2 Irradiations

The tests shall be performed with neutrons of several energies:

a) thermal beam as described in ISO 8529-1;

b) mono-energetic beams at 144 keV; 250 keV; 565 keV; 1,2 MeV; 14,8 MeV described in ISO 8529-1:2001, Table 2;

c) the moderated ^{252}Cf neutron source described in ISO 8529-1:2001, Table 1;

d) ^{241}Am-Be or ^{252}Cf neutron sources.

During the tests, the dosemeter shall be irradiated on the ISO slab water phantom and under the conditions described in ISO 8529-3 and in ISO 29661.

No test for determining the detection threshold by measuring the background signal of unirradiated dosemeters is described in this part of ISO 21909. However, the tests for “coefficient of variation”, “energy

response" and "angular response" are all done at two levels of dose: close to the minimal recording value and in the dose range (0,5 mSv ; 2 mSv). The criteria applied at these two levels of dose can differ.

To perform the tests characterizing the intrinsic properties of the neutron dosimetry system, several irradiations are mandatory. They are summarized in Table 4. To reduce the number of irradiations, the same irradiation may be used for several tests. For instance, the irradiation with a ^{241}AmBe or ^{252}Cf source to a conventional quantity value of personal dose equivalent of 1 mSv is used for three tests: linearity, energy and angular tests.

Table 4 — Series of irradiation needed to perform the tests dedicated to characterize the intrinsic properties of the dosimetry system

Energy range	Thermal			Fast												14,8 MeV
Angle of incidence from normal	0°	60°	85°[a]	0°								30°			60°	0°
Series	A	B	P	C	D	E	F	G	H	I	J	K	L	M	N	O
Dose (mSv)	Thermal spectra			144 keV	250 keV	565 keV	1,2 MeV	^{252}Cf or ^{241}Am-Be with a 144 keV or 250 keV field (in dose $H_p(10)$ proportion of 50 %)	^{252}Cf or ^{241}Am-Be with a thermal field (in dose $H_p(10)$ proportion of 50 %)	Moderated ^{252}Cf	^{252}Cf or ^{241}Am-Be (or any energy between 2 and 10 MeV for linearity)	144 keV	250 keV	^{252}Cf or ^{241}Am-Be (or any energy between 2 and 10 MeV for linearity)	^{252}Cf or ^{241}Am-Be (or any energy between 2 and 10 MeV for linearity)	14,8 MeV
H_{min}	TE TL				TE					TE	TE TL			TA		
H_{min} + 0,1 mSv	TE TL	TA	TA[a]	TE	TE	TE	TE	TE	TE	TE	TE TL	TA	TA	TA	TA[c]	TE
0,5	TE TL[b]	TA[b]									TL					
0,8 mSv < H_{HD} < 2 mSv	TE[b]	TA[b]		TE	TE	TE	TE	TE	TE	TE	TE TL	TA	TA	TA	TA	TE
2	TL[b]										TL					
5											TL					
10											TL					
20											TL					

NOTE The irradiations used for each test are represented by a specific sign: TL for the test of coefficient of variation/linearity, TA for the angular (≠0) test and TE for the energy test.

[a] For thermal neutrons, a specific test is done at 85°, for dose above 0,5 mSv, to check if the reading of the dosemeter at this angle is not higher by a factor of 3 (+200 %) than the reading of the dosemeter at 0°, irradiated by the same fluence of thermal neutrons. This is asked to check a problem which could exist because of a lack of shielding on the side of the dosemeter. The irradiation is performed at the maximal level of dose of the series A. Moreover, the neutron fluence corresponding to $H_p(10,0°)$ as used in series A should be taken for irradiation.

[b] All these irradiations are optional depending of the maximal dose value stated in the accompanying documentation for the thermal field. If the maximal stated value is at least 0,8 mSv, then energy and angular tests do not have to be done at 0,5 mSv.

[c] Mandatory irradiation but criteria just informative. The test would just have to be performed and the result given.

H_{HD} corresponds to a conventional quantity value of personal dose equivalent chosen in the range: 0,8 mSv < H_{HD} < 2 mSv. Defining a range of dose instead of an exact conventional quantity value of personal dose equivalent of 1 mSv was preferred. The laboratory in charge of the irradiations or in charge of the characterization of the dosimetry system, according to the present standard, has to choose a value included in this range, which would not be known by the dosimetry laboratory.

H_{min} corresponds to the minimal value of dose which is recorded. H_{min} is then the lower limit of the dose range, defined by the dosimetry laboratory. H_{min} would be logically at least equal or lower to the legal threshold of the country. Depending on the country or the dosimetry laboratory, H_{min} is different: 0,10; 0,20 or 0,30 mSv, for example. To comply with this standard, H_{min} shall be equal to 0,3 mSv at maximum:

$$H_{min} \leq 0{,}3 \text{ mSv}$$

The criteria of the different tests, coefficient of variation, linearity, energy and angular responses, are functions of the value of the chosen H_{min}. The value of H_{min} should be specified in the accompanying documentation.

Although H_{min} corresponds to the minimal value of dose which is recorded, the value of the personal dose equivalent below this value should not be truncated, contrary to how it is done in the routine process.

The dosimetry laboratory should state the energy range in which the dosimetry system should be characterized:

a) thermal + fast;

b) fast only;

c) fast + 14,8 MeV;

d) thermal + fast + 14,8 MeV.

This energy range shall be clearly stated in the documentation.

For dosimetry systems whose stated range does not include thermal energies, it is important to check that the dosimetry system does not over-respond to thermal fields even if the thermal contribution at the workplace is very low. The mandatory "H" irradiation series has been designed for that purpose (see Table 4) for all dosemeters.

Table 5 — Mandatory series of irradiation as a function of the stated energy range of the dosimetry systems

Stated energy range of the dosimetry systems	Mandatory series of irradiation
Thermal + fast	(A, B, P) + (C, D, E, F, G, H, I, J, K, L, M, N)
Fast only	(C, D, E, F, G, H, I, J, K, L, M, N)
Fast + 14,8 MeV	(C, D, E, F, G, H, I, J, K, L, M, N) + (O)
Thermal + fast + 14,8 MeV	(A, B, P) + (C, D, E, F, G, H, I, J, K, L, M, N) + (O)

Table 5 gives the mandatory series of irradiations as a function of the stated energy range of the dosimetry systems.

The maximum dose, 2 mSv, for thermal neutron tests is a proposal to take into account the reality of the potential exposures with thermal neutrons and to take into account the dose rates of the available reference thermal fields. This may also be adapted according to the dosimetry laboratory. This maximal value should be stated in the accompanying documentation. However, this maximal value cannot be lower than H_{min} + 0,1 mSv.

A minimal value of four dosemeters is required for each test except for the test for the coefficient of variation/linearity (see 7.4.2) and the test for eliminating the use of the full neutron and photon package (see 7.3). Except for the test for the coefficient of variation/linearity, the number of dosemeters per lot

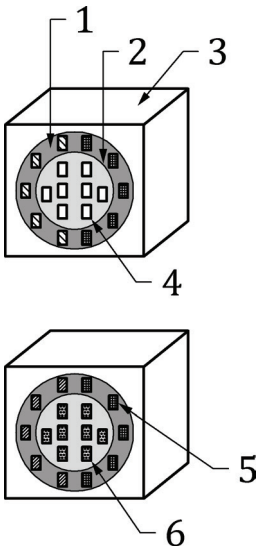
may be increased to be adapted to the associated applied dose. The maximal number of dosemeters should not be higher than 25, except for the test 8.3 where the number can be increased to 50.

In case of irradiations with neutrons at non-normal incidence, the angle of incidence for the n irradiations is varied positive and negative in two planes perpendicular to each other and to the plane of the dosemeter. It means, in case of $n = 8$, that two dosemeters are irradiated in each case to the same angle of incidence. This variation is not necessary in cases where the dosemeter design is symmetrical in its essential sensitive parts and this is stated by the manufacturer. The chosen source for irradiations with an ^{241}Am-Be or ^{252}Cf neutron source shall be the same than the one used to calibrate the dosimetry system.

Prepare for each of the mandatory series of irradiation function of the state energy range of the dosimetry system j lots (j corresponding to the number of dose values given in Table 4) of $i = 1$ to at least 4 dosemeters and irradiate them with neutrons of energy and angle as stated in Table 4 to the conventional quantity value of personal dose equivalents, $H^0_{k,j}$, as given in the first column of Table 4.

In the cases of the series "G" and "H", mixed-field irradiations are performed with half of the dose delivered by a radionuclide source (^{252}Cf or ^{241}Am-Be) and half of the dose delivered by low-energy (144 keV or 250 keV) in case "G" and by thermal neutrons in case "H".

NOTE To limit the number of irradiations and to take into account mixed field situations, dosemeters could be irradiated at the border of the allowed usual surface of irradiation of the phantom and half of them would be irradiated in both fields of the mixed field and half only in one of the fields, then adding values of that last dosemeters (see Figure 1). Using the same methodology, a test in a mixed field (fast + thermal) is proposed to detect nonlinearity of algorithm and over response of dosemeters for thermal neutrons. In the case of simultaneous irradiation of several dosemeters on a phantom effects as described in ISO 29661 (inscattered neutrons from adjacent dosemeters, changes in the properties of the backscattered field) need special attention and can lead to a reduction of the number of dosemeters irradiated together.



First irradiation[a]

Second irradiation[b]

Key

1 bordure of the allowed usual surface of irradiation
2 allowed usual surface of irradiation
3 phantom
4 dosemeters used for the irradiation J
5 dosemeters used for the test of mixing two different fields: ▨ + ▧ = ■
6 dosemeters used for the irradiation C

[a] All dosemeters irradiated with an ^{241}Am-Be or ^{252}Cf neutron source.

[b] All dosemeters irradiated with a 144 keV monoenergetic field.

NOTE The positions and number of dosemeters are just given for example.

Figure 1 — Principle of optimization of the irradiations that could be performed to take into account mixed field situations

7.3 Qualification for eliminating the use of the full neutron and photon package

7.3.1 Aim of the test

This test is not mandatory if the full neutron and photon package is used.

Many configurations of irradiations are required for the performance tests. Moreover, the number of dosemeters per configuration may be significantly high, especially for configurations at the minimal recording value. Neutron dosemeters can be combined with photon dosemeters, working independently, but packaged together. Neutron dosemeters (especially when they are integral with photon dosemeters) can take up a lot of space on the phantom, limiting the number of dosemeters that can be irradiated at one time. The number of dosemeters that can be placed on the phantom per irradiation is limited by the size of the dosemeters. That is why several irradiations may be needed per configuration.

This test aims at characterizing the influence of the photon dosemeters and of the package on the response of the neutron dosemeter. If the criterion of this test is met, then the influence of the photon dosemeter and the package on the neutron response can be considered negligible. Then the following performance tests can be done using only the neutron component of the combined dosemeter. The overall number of irradiations can then be reduced, if the size of the neutron dosemeter is smaller than that of the combined dosemeter.

If this test fails, all the performance tests shall be performed with the whole dosemeters (combined photon and neutron components as packaged together). Moreover, even if this requirement is met, the responsible regulatory, licensing or accrediting body may not accept this clause. Then to respect the regulatory rules, the full neutron and photon package may be mandatory.

NOTE For the tests to establish the "stability in the range of realistic conditions of use of the dosemeters", the package can be considered necessary by dosimetry laboratory.

7.3.2 Method of test

Prepare four lots numbered j = 1 to 4 of i = 1 to at least 6 dosemeters. The two first lots are composed of the whole dosimetry system as used by the participant and the last two lots are composed of neutron dosemeters only. Irradiate the four lots at a conventional quantity value of personal dose equivalent H_j^0 = 1 mSv, with a ^{241}Am-Be or ^{252}Cf neutron source for lots 1 and 3, and with a mono-energetic neutron beam at 144 keV for lots 2 and 4.

7.3.3 Interpretation of results

Read out and determine the measured dose equivalent for each dosemeter, H_{ij}. Calculate the arithmetic mean, H_j, and the experimental standard deviation, s_j, for the four lots. Show that the criteria defined by Formulae (1) and (2) are met:

for the irradiations with a ^{241}Am-Be or ^{252}Cf neutron source,

$$0,95 \leq \left[\left(\frac{H_1}{H_3}\right) \pm U_{1,3}\right] \cdot \frac{H_3^0}{H_1^0} \leq 1,05 \tag{1}$$

for the irradiations with a mono-energetic neutron beam at 144 keV,

$$0,9 \leq \left[\left(\frac{H_2}{H_4}\right) \pm U_{2,4}\right] \cdot \frac{H_4^0}{H_2^0} \leq 1,11 \tag{2}$$

where $U_{m,n}$ is the uncertainty for the quotient of the experimental arithmetic means, H_m and H_n, calculated in accordance with Formula (E.5).

If the criterion of this test is met, the influence on the neutron response of the photon dosemeter and the package is considered negligible. Then, the performance tests may be done using only the neutron dosemeters. If this test fails, all of the performance tests shall be led with the photon and neutron dosemeters packed together.

This test could be replaced by a study based on Monte-Carlo calculations, if such method is validated by measurements.

7.4 Performances tests

7.4.1 General

The tests described in 7.4 (coefficient of variation/linearity, energy and angular responses) are mandatory for all dosimetry systems.

7.4.2 Coefficient of variation/linearity

7.4.2.1 General

This test aims at checking whether both the statistical fluctuations of the indicated value and the dose response are acceptable from low to high dose exposures. The test shall be performed with 12 dosemeters for doses below 0,5 mSv and 6 dosemeters for doses ≥0,5 mSv.

7.4.2.2 Method of test

Read out the i = 12 dosemeters for doses below 0,5 mSv and 6 dosemeters for doses ≥0,5 mSv of the lots corresponding to the k series of irradiations named "A" and "J" in Table 4.

For every conventional dose $H^0_{k,j}$, determine the measured dose equivalent, $H_{k,j,i}$. Calculate the arithmetic mean, $H_{k,j}$, for each lot j of each series k and the respective experimental standard deviation, $s_{k,j}$. Calculate the response $R_{k,j} = H_{k,j}/H^0_{k,j}$. Then, determine the mean response R_k of all the calculated response values for each series.

7.4.2.3 Interpretation of results

Show that the coefficient of variation, $C_{k,j} = \frac{s_{k,j}}{H_{k,j}}$, of the 12 dosemeters for doses below 0,5 mSv or 6 dosemeters above 0,5 mSv for each series does not exceed the figure in Table 2, according to Formula (3):

$$\frac{s_{k,j}}{H_{k,j}} \leq r \tag{3}$$

For each series, show that the response weighted by the mean response R_k, $R_{k,j}/R_k$ does not exceed the values given in Table 2, according to Formula (4):

$$1 + r_{min} \leq \left[\left(\frac{R_{k,j}}{R_k} \right) \pm U_{k,j} \right] \leq 1 + r_{max} \tag{4}$$

with r_{min} and r_{max} defined in Table 2,

with $R_k = \frac{H_k}{H^0_k}$,

where $U_{k,j}$ is the uncertainty related to the measurements of the personal dose equivalent $H_{k,j}$ for the combined quantity in brackets, $\left(\frac{R_{k,j}}{R_k} \right)$, calculated in accordance with GUM.

If the inequalities in Formulae (3) and (4) are valid, then the requirements are considered to be met.

7.4.3 Energy and angle dependence of the response

7.4.3.1 General

This test uses the series of irradiations defined in Table 4 and corresponding to the energy and angle ranges in which the dosimetry system should be characterized (see Table 5).

The test regarding the energy dependence of response raises the question of dosimetry systems with a strong variable energy dependence of its response, as some thermoluminescent albedo dosemeters for instance, for which a qualification has to be completed directly at the workplaces they are used.

If the former test is not fulfilled by the dosimetry system, this dosimetry system shall be qualified at the work situations where it is used. A second part of this standard will give complementary specific recommendations to deal with dosimetry systems whose response is highly energy dependent. This part will give recommendations to the dosimetry laboratory to establish a calibration coefficient at the workplace and to establish whether this coefficient is adaptable for the workplaces where the dosemeters are used, to maintain the same limit of variation: −50 % to +100 %.

For dosimetry systems that are unable to fulfil the criteria of this test, dose monitoring can also be done if workplace spectrometry at all workplaces where the dosemeter is likely to be used shows that the dose contributions at the neutron energies at which the dosemeters do not comply the test are negligible.

7.4.3.2 Method of test

Read out each dosemeter of the lots of all the series of irradiations, corresponding in Table 4 either to the energy test (tests noted "TE" in Table 4) or the angular test (tests noted "TA"). Determine the measured dose equivalent, $H_{k,j,i}$, and calculate the arithmetic mean, $H_{k,j}$, for each lot j of each series k and the respective experimental standard deviations, $s_{k,j}$.

7.4.3.3 Interpretation of results

Show that for each lot and for dose $H^0_{k,j}$, equal to H_{min}, H_{min} + 0,1 mSv and H_{HD}, the following criterion is met:

$$1 + r_{min} - U^0_{rel,k,j} \leq \left[\left(\frac{H_{k,j}}{H^0_{k,j}} \right) \pm U_{k,j} \right] \leq 1 + r_{max} + U^0_{rel,k,j} \quad (5)$$

where

r_{min} is defined in Table 2;

r_{max} is defined in Table 2;

$U_{k,j}$ is the uncertainty for the combined quantity in brackets, $\left(\frac{H_{k,j}}{H^0_{k,j}} \right)$, calculated in accordance with Formula (E.5);

$U^0_{rel,k,j}$ is the relative uncertainty related to the conventional quantity value of the personal dose equivalent $H^0_{k,j}$.

If the inequality in Formula (5) is valid, then the requirement is considered to be met.

The response at normal incidence in the stated energy range for the dosimetry system shall respect the limit of variation defined in Table 2.

This criteria is not mandatory for the series "N" but just informative. The test would just have to be performed and the result given.

7.4.4 Specific test for thermal neutrons

7.4.4.1 General

This test aims at checking if there is an over response by more than a factor of 3 (+200 %) at 85° compared to reading at normal incidence, for thermal neutrons and for doses above 0,5 mSv. This test should be performed by dosimetry laboratories which have stated that thermal energies are encompassed by the energy range of their dosimetry system.

7.4.4.2 Method of test

Read out each dosemeter of the lot corresponding to the series of irradiations named "P" in Table 4. Determine the measured dose equivalent, $H_{P,i}$, and calculate the arithmetic mean, H_P, and the respective experimental standard deviations, s_P.

Read out each dosemeter of the lot corresponding to the series of irradiations named "A" in Table 4 and the personal dose equivalent H_{HD}. Determine the measured dose equivalent, $H_{A,i}$, and calculate the arithmetic mean, H_A and the respective experimental standard deviations, s_A.

7.4.4.3 Interpretation of results

Show that, the following criterion is met:

$$\left[\left(\frac{H_P}{H_A}\right) \pm U_{P,A}\right] \cdot \frac{H_A^0}{H_P^0} \leq 3 \tag{6}$$

where $U_{P,A}$ is the uncertainty for the quotient of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (6) is valid, then the requirement is considered to be met.

8 Performance tests: stability in the range of realistic conditions of use of the dosemeters

8.1 Fading

8.1.1 General

If a loss of signal could appear during a long period of storage after irradiation, a correction function could be needed to avoid strong effect on the dose determination. This test aims at checking that, if needed, this potential loss of signal is correctly taken into account.

Define the maximal period of storage in days between irradiation and read out, denoted D_{max}^{fading}. For example, for a wearing period of three months and a maximal storage in the laboratory before reading of one month, D_{max}^{fading} is equal to four months, i.e. 120 days.

8.1.2 Method of test

Prepare two lots of i = 1 to at least 4 dosemeters (25 dosemeters at maximum). Irradiate these lots with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional quantity value of personal dose equivalent, H^0, between 1 mSv and 3 mSv on day D_0.

Process the first lot of dosemeters in two weeks just following the irradiation. Store and keep dosemeters of the second lot under normal test conditions. Process them on day $D_0 + D_{max}^{fading} + 1$.

Read out each dosemeter, determine the measured dose equivalent for each dosemeter, $H_{j,i}$, and calculate the arithmetic mean H_j for each lot and the standard deviation s_j.

8.1.3 Interpretation of results

Show that the criterion in the Formula (7) is met:

$$0,85 \leq \left[\left(\frac{H_2}{H_1}\right) \pm U_{2,1}\right] \cdot \frac{H_1^0}{H_2^0} \leq 1,18 \tag{7}$$

where $U_{2,1}$ is the uncertainty for the quotient of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (7) is valid, then the requirement is considered to be met.

8.2 Ageing

8.2.1 General

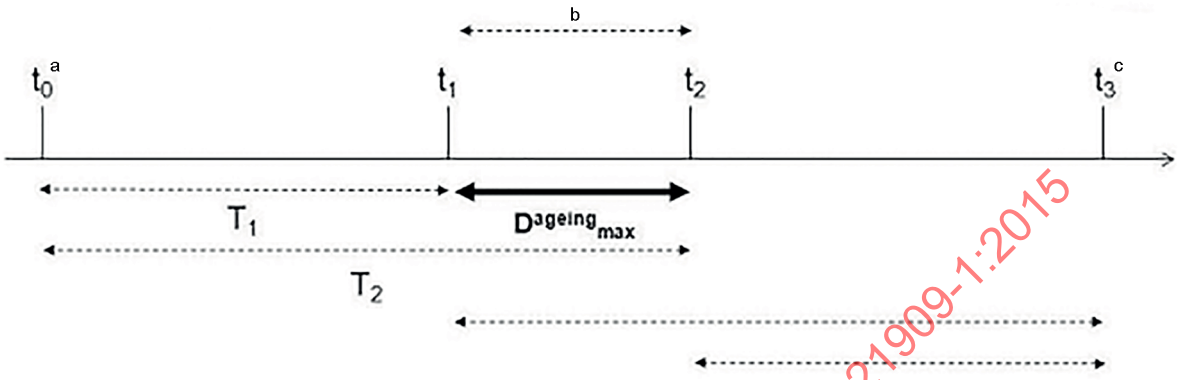
A modification of the response may appear after a long period of storage before irradiation. A correction function may then be needed to avoid strong effect on the dose determination. This test aims at checking that, if needed, this modification of response is correctly taken into account.

To determine the maximal period of storage before irradiation, denoted $D_{\text{max}}^{\text{ageing}}$, determine first the following two periods, T_1 and T_2 (see Figure 2):

— T_1: minimal period between the manufacturing date for disposable dosemeter or the day when the reset is done for reusable dosemeters and the first day of possible irradiation;

— T_2: maximal period between the manufacturing date for disposable dosemeter or the day when the reset is done for reusable dosemeters and last day of possible irradiation.

Then, calculate $D_{\max}^{\text{ageing}} = T_2 - T_1$.



a For usable dosemeter, day of the reception of the detector element from the manufacturer; for reusable dosemeter, day when the reset is done.

b Possible range of first days of use.

c Irradiation.

Figure 2 — Definition of $D_{\max}^{\text{ageing}}$

If the manufacturing date is not well known, the uncertainty on this date should be taken into account in a penalizing way.

8.2.2 Method of test

Prepare two lots of $i = 1$ to at least 4 dosemeters (25 dosemeters at maximum). The first lot of dosemeters corresponds to dosemeters stored in standard test conditions in the laboratory for T_1 days. Irradiate this lot with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional quantity value of the personal dose equivalent, H^0, between 1 mSv and 3 mSv. Process this first lot of dosemeters in two weeks just following the irradiation.

Choose a second lot of dosemeters stored in standard test conditions for T_2 days. Irradiate this lot with a ^{241}Am-Be or ^{252}Cf neutron source to the same conventional quantity value of the personal dose equivalent, H^0.

Read out, determine the measured dose equivalent for each dosemeter, $H_{j,i}$, and calculate the arithmetic mean, H_j, and the experimental standard deviation, s_j for lots 1 and 2.

8.2.3 Interpretation of results

Show that the criterion in Formula (8) is met:

$$0{,}85 \leq \left[\left(\frac{H_2}{H_1}\right) \pm U_{2,1}\right] \cdot \frac{H_1^0}{H_2^0} \leq 1{,}18 \tag{8}$$

where $U_{2,1}$ is the uncertainty for the quotient of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (8) is valid, then the requirement is considered to be met.

8.3 Effect of storage for unexposed dosemeters

8.3.1 General

This test aims at checking that there is no strong influence of the ageing on the background signal of the dosemeters.

8.3.2 Method of test

Define the maximal period, D_{max}, between manufacturing time of the detector or the day when reusable dosemeters were reset or zeroed and the first day of use.

Store a lot of at least 10 dosemeters, which are unirradiated, under standard test conditions during D_{max}. Read out and determine the measured dose equivalent for each dosemeter, H.

NOTE The number of dosemeters can be increased, if wanted by the laboratory.

8.3.3 Interpretation of results

Show that a maximum of 10 % of the unirradiated dosemeters present a measured dose equivalent H_M higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent H_M higher than H_{min} + 0,2 mSv.

If one or more dosemeters present a measured dose equivalent H_M higher than H_{min} + 0,2 mSv, a second test with a lot of 50 dosemeters is necessary: a maximum of one dosemeter shall present a measured dose equivalent H_M higher than H_{min} + 0,2 mSv.

If these conditions are valid, then the requirement is considered to be met.

8.4 Exposure to radiation other than neutrons

8.4.1 General

Two mandatory tests are needed for all dosimetry systems to check whether the system is sensitive to radon or photon radiation. If so, complementary tests are required to characterize more precisely the influence of these two types of radiations on the dose response.

8.4.2 Photon radiation

8.4.2.1 All dosimetry systems

8.4.2.1.1 General

This test applies to all dosimetry systems. The purpose of this test is to determine whether the dosimetry system is photon-sensitive. If this test is successfully passed, then the dosimetry system is not considered to be sensitive to photons. If not, the dosimetry system is considered photon-sensitive. Supplementary performance tests shall then be performed (see 8.4.2.2).

8.4.2.1.2 Method of test

Prepare two lots numbered j = 1 and 2 of i = 1 to at least 4 dosemeters (25 dosemeters at maximum) and irradiate the first lot with a ^{137}Cs source to a conventional quantity value of the personal dose equivalent, H^0, 10 mSv. Store lot 2 under standard test conditions.

Read out and determine the measured neutron personal dose equivalent for each dosemeter, $H_{j,i}$.

Calculate the arithmetic mean H_j for each of the two lots and the experimental standard deviation, s_j.

8.4.2.1.3 Interpretation of results

Show that the criterion, expressed in milliSieverts, in Formula (9) is met:

$$\left|\left(\overline{H_1} - \overline{H_2}\right)\right| \pm U_{1,2} \leq H_{\min} \tag{9}$$

where $U_{1,2}$ is the uncertainty for the difference of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (9) is valid, then the requirement is considered to be met.

8.4.2.2 Photon-sensitive dosimetry systems only

8.4.2.2.1 General

For photon-sensitive dosemeters, supplementary performance tests shall be done and these dosemeters shall comply to the tests as described below.

8.4.2.2.2 Method of test

Prepare three series named k = Q, R and S of two lots numbered j = 1 and 2 of i = 1 to at least 4 dosemeters (25 dosemeters at maximum). Irradiate all the dosemeters with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional quantity value of the personal dose equivalent, H^0_{neutron} of 0,5 mSv for series "Q", 1 mSv for series "R" and 2 mSv for series "S".

In addition, irradiate the second lot of each series with a ^{137}Cs source to a conventional quantity value of the personal dose equivalent, H^0_{photon} of 1,5 mSv for series "Q", 1 mSv for series "R" and 0,6 mSv for series "S".

Read out and determine the measured dose equivalent for each dosemeter, $H_{\text{k,j,i}}$, calculate the arithmetic mean $H_{\text{k,j}}$ and the experimental standard deviation, $s_{\text{k,j}}$, for the six lots.

8.4.2.2.3 Interpretation of results

Show that the criterion in Formula (10) is met for each series k:

$$\left|H_{2,\text{k}} - H_{1,\text{k}}\right| \pm U_{1,2,\text{k}} \leq 0,1 \text{ mSv} \tag{10}$$

where $U_{1,2,\text{k}}$ is the uncertainty for the difference of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (10) is valid, then the requirement is considered to be met.

Table 6 gives a summary of the required tests for the photon-sensitive dosemeters.

Table 6 — Performance tests for photon-sensitive dosemeters

Series	Neutron irradiation	Photon irradiation
	H^0_{neutron} (mSv)	H^0_{photon} (mSv)
Q	0,5	1,5

Table 6 *(continued)*

Series	Neutron irradiation	Photon irradiation
	H^{0}_{neutron} (mSv)	H^{0}_{photon} (mSv)
R	1	1
S	2	0,6

8.4.3 Radon

8.4.3.1 Method of test

Prepare two lots numbered j = 1 and 2 of i = 1 of at least 4 dosemeters (25 dosemeters at maximum) and expose lot 1 to 3 MBq·h/m^3 of radon at 50 % equilibrium with daughters (F = 0,5). Store lot 2 in standard test conditions with no radon in excess of background.

Read out, determine the measured dose equivalent for each dosemeter, $H_{j,i}$, and calculate the arithmetic mean, H_j, for each of the two lots and the respective experimental standard deviations, s_j.

8.4.3.2 Interpretation of results

Show that the criterion, expressed in milliSieverts, in Formula (11) is met:

$$\left|\left(\overline{H_1} - \overline{H_2}\right)\right| - U_{1,2} \leq 0,5 \text{ mSv} \tag{11}$$

where $U_{1,2}$ is the uncertainty for the difference of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (11) is valid, then the requirement is considered to be met.

8.5 Stability under various climatic conditions

8.5.1 General

The dosemeters could be exposed to many different climatic conditions at workplaces. They are not controlled by the dosimetry laboratories. This test aims at qualifying their performances in harsh conditions. It gives requirements in harder conditions representative to incidental conditions, for instance.

It is not mandatory to fulfil the criteria of this test but if the requirements are not fulfilled, the laboratory shall specify to customers the uncertainty added to the dose estimation in these conditions of exposure.

8.5.2 Effect on the dose response

8.5.2.1 General

This test aims at characterizing the stability of the response of the dosimetry system as a function of climatic conditions.

8.5.2.2 Method of test

Prepare three lots numbered j = 1, 2 and 3 of i = 1 to at least 4 dosemeters (25 dosemeters at maximum). Store lot 3 in standard test conditions. Irradiate lot 1 with a ^{241}Am-Be or ^{252}Cf neutron source to a

conventional quantity value of the personal dose equivalent, H^0, between 1 mSv and 3 mSv. Store both lots 1 and 2 of dosemeters in a climatic chamber in which the temperature is 40 °C ± 2 °C and the relative humidity is at least 90 %. After a continuous period of 48 h, remove both lots of dosemeters from the climatic chamber. Irradiate lots 2 and 3 to the same conventional quantity value of the personal dose equivalent as lot 1.

Read out and determine the measured dose equivalent for each dosemeter, $H_{j,i}$, and calculate the arithmetic mean, H_j, for each of the two lots and the respective experimental standard deviations, s_j.

8.5.2.3 Interpretation of results

Show that for each lot, the following criterias are met:

$$0{,}85 \leq \left[\left(\frac{H_1}{H_3}\right) \pm U_{1,3}\right] \cdot \frac{H_3^0}{H_1^0} \leq 1{,}18 \tag{12}$$

$$0{,}85 \leq \left[\left(\frac{H_2}{H_3}\right) \pm U_{2,3}\right] \cdot \frac{H_3^0}{H_2^0} \leq 1{,}18 \tag{13}$$

where $U_{m,n}$ is the uncertainty for the quotient of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequalities in Formulae (12) and (13) are valid, then the requirement is considered to be met.

8.5.3 Effect for unexposed dosemeters

8.5.3.1 General

This test aims at checking that there is no strong influence of harsh climatic conditions on the background signal of the dosemeters.

8.5.3.2 Method of test

Store a lot of 10 dosemeters, which are unirradiated, in a climatic chamber in which the temperature is 40 °C ± 2 °C and the relative humidity is at least 90 %. After a continuous period of 48 h, remove this lot of dosemeters from the climatic chamber. Read out and determine the measured dose equivalent for each dosemeter, H_i.

NOTE The number of dosemeters can be increased to 20, if wanted by the laboratory.

8.5.3.3 Interpretation of results

Show that a maximum of 20 % of the dosemeters (2 dosemeters for a total of 10 dosemeters, 4 dosemeters for a total of 20 dosemeters) presents a measured dose equivalent higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent higher than H_{min} + 0,1 mSv.

If these two conditions are valid, then the requirement is considered to be met.

8.6 Effect of light exposure (insensitivity to light)

8.6.1 Effect on the dose response

8.6.1.1 Method of test

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to at least 4 dosemeters (25 dosemeters at maximum) and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional quantity value of the personal dose equivalent, H^0, of at least 1 mSv and 3 mSv. Expose lot 2 to 1 000 W/m^2 of light for one week. Store the dosemeters of lot 1 in the dark in an otherwise identical environment.

Read out and determine the measured dose equivalent for each dosemeter, $H_{j,i}$, and calculate the arithmetic mean, H_j, for each of the two lots and the respective experimental standard deviations, s_j, for the two lots.

8.6.1.2 Interpretation of results

Show that the criterion in Formula (14) is met:

$$0{,}85 \leq \left[\left(\frac{H_2}{H_1}\right) \pm U_{2,1}\right] \cdot \frac{H_1^0}{H_2^0} \leq 1{,}18 \tag{14}$$

where $U_{1,2}$ is the uncertainty for the quotient of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (14) is valid, then the requirement is considered to be met.

8.6.2 Effect for unexposed dosemeters

8.6.2.1 General

This test aims at checking that there is no strong influence of light exposure on the background signal of the dosemeters.

8.6.2.2 Method of test

Expose a lot of 10 dosemeters, which are unirradiated, to 1 000 W/m^2 of light for one week. Read out and determine the measured dose equivalent for each dosemeter, H.

NOTE The number of dosemeters can be increased to 20, if wanted by the laboratory.

8.6.2.3 Interpretation of results

Show that a maximum of 20 % of the dosemeters (2 dosemeters for a total of 10 dosemeters, 4 dosemeters for a total of 20 dosemeters) presents a measured dose equivalent higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent higher than H_{min} + 0,1 mSv.

If these two conditions are valid, then the requirement is considered to be met.

8.7 Drop test

This test aims at checking if there is a change in response due to physical damage.

8.7.1 Effect on the dose response

8.7.1.1 Method of test

Prepare two lots numbered j = 1 and 2 of i = 1 to at least 4 dosemeters (25 dosemeters at maximum) and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional quantity value of the personal dose equivalent, H^0, between 1 mSv and 3 mSv. Then drop the dosemeters of the second lot on a representative floor of the working area from a height of 1 m.

Read out each dosemeter and determine the measured dose equivalent, $H_{j,i}$. Calculate the arithmetic mean, H_j, and the respective experimental standard deviations, s_j, for the two lots.

8.7.1.2 Interpretation of results

Show that the criterion in Formula (15) is met:

$$0{,}85 \leq \left[\left(\frac{H_2}{H_1}\right) \pm U_{2,1}\right] \cdot \frac{H_1^0}{H_2^0} \leq 1{,}18 \qquad (15)$$

where $U_{1,2}$ is the uncertainty for the quotient of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (15) is valid, then the requirement is considered to be met.

8.7.2 Effect for unexposed dosemeters

8.7.2.1 General

This test aims at checking that there is no strong influence of physical damage on the background signal of the dosemeters.

8.7.2.2 Method of test

Drop a lot of 10 dosemeters, which are unirradiated, on a representative floor of the working area from a height of 1 m. Read out and determine the measured dose equivalent for each dosemeter, H.

NOTE The number of dosemeters can be increased to 20, if wanted by the laboratory.

8.7.2.3 Interpretation of results

Show that a maximum of 20 % of the dosemeters (2 dosemeters for a total of 10 dosemeters, 4 dosemeters for a total of 20 dosemeters) presents a measured dose equivalent higher than H_{min}. Moreover, no dosemeter shall present a measured dose equivalent higher than H_{min} + 0,1 mSv.

If these two conditions are valid, then the requirement is considered to be met.

8.8 Distance to the phantom

8.8.1 General

This test aims at checking the influence of the distance to the phantom on the dosimetry report.

8.8.2 Method of test

Prepare 2 lots of i = 1 to at least 4 dosemeters (25 dosemeters at maximum). Irradiate these lots with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional quantity value of the personal dose equivalent, H^0, between 1 mSv and 3 mSv. The dosemeters of the second lot are placed 0,5 cm far from the phantom.

Process the two lots of dosemeters.

Read out each dosemeter, determine the measured dose equivalent for each dosemeter, $H_{j,i}$, and calculate the arithmetic mean H_j for each lot and the standard deviation s_j.

8.8.3 Interpretation of results

Show that the criterion in Formula (16) is met:

$$0{,}85 \leq \left[\left(\frac{H_2}{H_1}\right) \pm U_{2,1}\right] \cdot \frac{H_1^0}{H_2^0} \leq 1{,}18 \tag{16}$$

where $U_{1,2}$ is the uncertainty for the quotient of the arithmetic means, calculated in accordance with Formula (E.5).

If the inequality in Formula (16) is valid, then the requirement is considered to be met.

8.9 Sealing

The manufacturer shall state the precautions to be taken to prevent the ingress of moisture. The effectiveness of the sealing and the associated precautions should be demonstrated by the manufacturer.

9 Identification and accompanying documentation

9.1 Individual marking

Dosemeters and detectors shall have simple, unique and secure means of identification. The marking shall not damage the useful portion of the detector, either directly or indirectly, nor shall it change its behaviour in any significant manner. Dosemeters shall carry any necessary markings for determining their origin, expiry date (if relevant). Moreover, dosemeters shall carry a marking stating that they are intended for neutron dosimetry and front/back side should be clearly stated on the package.

9.2 Collective marking

The following information shall be indicated on each box (or other collective packing) of detectors or dosemeters or, failing this, on an accompanying note:

— name or trademark of the manufacturer;

— complete designation;

— serial number or manufacturer's batch number;

— expiry date, if relevant.