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Passive personal neutron dosemeters — Performance and test requirements

Dosimètres individuels passifs pour les neutrons — Exigences de fonctionnement et d'essai

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 21909 was prepared by Technical Committee ISO/TC 85*, Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

Introduction

ISO 21909 contains performance and test requirements for dosemeters to be used for the determination of personal dose equivalent, $H_p(10)$, in neutron fields with energies ranging from thermal to 20 MeV. In this energy range, reference neutron radiation are reported in ISO 8529-3. Reference radiation are required for the proper calibration of the dosemeters. This International Standard covers the following five classes of passive neutron detectors that can be used as a personal dosemeter in part or all of the above-mentioned neutron energy range:

— nuclear track emulsion dosemeters (NTED);

— solid state nuclear track dosemeters (SSNTD);

— thermoluminescence albedo dosemeters (TLAD);

— superheated emulsion dosemeters (SED);

— ionization chamber dosemeters (ICD).

Passive personal neutron dosemeters — Performance and test requirements

1 Scope

This International Standard provides performance and test requirements for determining the acceptability of personal neutron dosemeters to be used for the measurement of personal dose equivalent, $H_p(10)$, for neutrons ranging in energy from thermal to 20 MeV.

2 Normative references

The following referenced documents are indispensable for the application 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 5-2:2001, *Photography — Density measurements — Part 2: Geometric conditions for transmission density*

ISO 8529-1:2001, *Reference neutron radiations — Part 1: Characteristics and methods of production*

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

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

ISO 12789:2000, *Reference neutron radiations — Characteristics and methods of production of simulated workplace neutron fields*

3 Terms and definitions

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

3.1 General terms

3.1.1
ageing
changes occurring in an unirradiated dosemeter with time

3.1.2
batch
⟨detectors or dosemeters⟩ grouping of detectors or dosemeters manufactured according to the same specification and usually at the same time

NOTE 1 Detectors from a batch are intended and supposed to have the same performance characteristics, consistent with the appropriate requirements of this International Standard, and to be used in type or quality test procedures.

NOTE 2 In the case of SSNTD, a batch under this definition can be as small as one single sheet.

3.1.3
detector
device or substance that indicates the presence of a phenomenon without necessarily providing a value of an associated quantity

NOTE In particular, in the presence of radiation, such devices or substances provide by either a direct or indirect means a signal or other indication suitable for measuring one or more quantities.

3.1.4
fading
changes occurring in an irradiated dosemeter with time

3.1.5
personal dosemeter
device comprising one or more detectors positioned in a holder, suitable for the measurement of personal dose equivalent

3.2 Quantities

3.2.1
absorbed dose
D
$d\bar{\varepsilon}$ divided by dm, where $d\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter with mass dm

NOTE 1 The SI unit of absorbed dose is the J/kg. The special name for the unit of absorbed dose is gray (Gy)[20].

NOTE 2 In quoting values of absorbed dose, it is necessary to specify the material. e.g. soft tissue.

3.2.2
ambient dose equivalent
$H^*(d)$
dose equivalent at a point in a radiation field that would be produced by the corresponding expanded and aligned field in the ICRU sphere at a depth, d, on the radius opposing the direction of the aligned field

NOTE 1 The SI unit of ambient dose equivalent is J/kg. The special name for the unit of ambient dose equivalent is sievert (Sv).

NOTE 2 For strongly penetrating radiation, a depth of 10 mm is currently recommended. The ambient dose equivalent for this depth is then denoted by $H^*(10)$[20].

3.2.3
dose equivalent
H
product of Q and D at a point in soft tissue, where D is the absorbed dose and Q is the quality factor at that point

NOTE The SI unit of dose equivalent is J/kg. The special name for the unit of dose equivalent is sievert (Sv)[20].

3.2.4
neutron fluence
Φ_{n}
dN divided by da, where dN is the number of neutrons incident on a sphere of cross-sectional area da

NOTE The SI unit of neutron fluence is m^{-2}, a frequently unit used is cm^{-2} (ISO 8529-1).

3.2.5
personal dose equivalent
$H_{\mathrm{p}}(d)$
dose equivalent in soft tissue, at an appropriate depth, d, below a specified point on the body

NOTE 1 The SI unit of personal dose equivalent is J/kg. The special name for the unit of personal dose equivalent is sievert (Sv)[20].

NOTE 2 Soft tissue in this context is the ICRU 4-element tissue.

3.2.6
conversion coefficient
$h_{p\Phi}(10;E,\alpha)$
quotient of the personal dose equivalent, $H_p(10)$, and the neutron fluence, Φ_n, at a point in the radiation field and used to convert from 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 The SI 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
$\overline{x}$
average of a series of n measurements, x_i, given by the equation

$$\overline{x} = (1/n)\sum_{i=1}^{n} x_i$$

3.3.2
calibration
set of operations which establish, under a controlled set of standard test conditions, the relationship between the reading given by a dosemeter and the quantity to be measured

3.3.3
calibration factor
N
quotient of the conventional true value, H_t, divided by the reading, M (see 3.3.16), derived under standard conditions, given by the equation

$$N = \frac{H_t}{M}$$

3.3.4
calibration quantity
physical quantity used to establish the calibration of the dosemeter

NOTE For the purpose of this International Standard, the calibration quantity is the personal dose equivalent at 10 mm depth in the ICRU tissue slab phantom, $H_p(10)$.

3.3.5
coefficient of variation
V
measure of dispersion for a series of n measurements, x_i, given by the equation

$$V = s/\overline{x}$$

where s is the experimental standard deviation and $\overline{x}$, the arithmetic mean of n measurements.

3.3.6
control specimens
lot of reference detectors or dosemeters of the same type and batch as those used in the test procedures

3.3.7
conventional true value of a quantity
H_t
⟨dose equivalent⟩ best estimate of a value of a quantity, as determined by a primary or secondary standard or by a reference instrument that has been calibrated against a primary or secondary standard

NOTE A *conventional true value* is regarded as being sufficiently close to the *true value* such that the difference is considered as insignificant for the given purpose.

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

3.3.9
experimental standard deviation
s
parameter for a series of n measurements, x_i, characterizing the dispersion and given by the equation

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

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

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

3.3.11
influence quantity
quantity (parameter) that can have a bearing on the results of a measurement without being the objective of the measurement (ISO 8529-3)

3.3.12
measured dose equivalent
H_M
product of the reading, M, and the calibration factor, N

$$H_M = M \cdot N$$

NOTE In the case of TLAD, elaborate algorithms are generally required (see E.3).

3.3.13
phantom
specified object used to simulate the human body or parts thereof in terms of scattering and absorption properties

NOTE For calibrations, the ISO water slab phantom is employed. It is made with polymethylmetaacrylate (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.

3.3.14
quality test
QT
test performed on a number of detectors or dosemeters of a given batch or production designed to assure their quality

NOTE These tests are usually carried out by the user.

3.3.15
read out
process of determining the indication of a detector or dosemeter reader

NOTE For the NTEDs and SSNTs, the reading is usually the number of tracks recorded per unit area; for TLADs, it is the integrated current from the reader; for SEDs, it is the number of bubbles detected or the change in volume; and for ICDs, it is the electric charge collected.

3.3.16
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

3.3.17
reference conditions
set of influence quantities for which the calibration factor is valid without any correction (ISO 8529-3)

3.3.18
response
R
measured dose equivalent, H_{M}, divided by the conventional true value of the dose equivalent, H_{t} (see 3.3.7), as given by the following equation

$$R = \frac{H_{\mathrm{M}}}{H_{\mathrm{t}}}$$

NOTE 1 The reading, M, is converted into dose equivalent, H_{M}, by multiplying M by an appropriate conversion coefficient. In the case of TLAD, elaborate algorithms are generally required (see E.3).

NOTE 2 In this International Standard, the quantity is personal dose equivalent: $R = H_{\mathrm{p,M}}(10)/H_{\mathrm{p,t}}(10)$.

NOTE 3 In this International Standard for the sake of shortness, $H_{\mathrm{M}} = H$ will be used in Annex C.

NOTE 4 For the specified reference conditions, the response is the reciprocal of the calibration factor.

NOTE 5 In radiation metrology, the term response, abbreviated for this application from "response characteristic"[15] 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 (ISO 8529-3).

3.3.19
standard test conditions
range of values of a set of influence quantities under which a calibration or a determination of response is carried out

3.3.20
type test
TT
performance test of one or more devices that are made to a certain design to show that the design meets given specifications

3.4 Terms with respect to nuclear track emulsion dosemeters (NTED)

3.4.1
film packet
ensemble containing the emulsion wrapped in a light tight envelope that is placed in a sealed pouch, generally filled with dry nitrogen or air, meant to protect the emulsion against fading

3.4.2
latent image
invisible change occurring within the photographic emulsion when it is exposed to actinic radiation, i.e. visible light, ultraviolet or radiation that is directly or indirectly ionizing and that will be converted upon processing into a visible image like a nuclear track

3.4.3
nuclear tracks
tracks created in a nuclear emulsion following the interaction of neutrons with the nuclei in the emulsion, base, wrapping and holder giving rise to protons [by $^{14}N(n,p)^{14}C$] or recoil nuclei

3.4.4
nuclear track emulsion
photographic emulsion capable of recording nuclear tracks in a latent form

NOTE These tracks become visible after the chemical development and can be counted under a microscope or any other appropriate scanning device.

3.4.5
nuclear track emulsion dosemeter
passive device consisting of a film packet mounted in a holder (appropriate for the application), intended to be worn on a person's body, detecting neutrons for the purpose of assessing the appropriate personal dose equivalent at or near the position where it is placed

3.4.6
optical density
S
logarithm to the base 10 of the ratio of aperture flux [ISO 5-2] to the flux transmitted by the sample under the same beam geometric conditions

3.4.7
scanning
process of evaluating a nuclear track emulsion by counting the visible tracks under a microscope either by an operator or by an automatic scanning device

3.4.8
stability of latent image
degree to which a nuclear track emulsion is capable of producing a developed image of a nuclear interaction irrespective of the time elapsed between the formation of the latent image and the development of the emulsion and irrespective of the ambient conditions that have prevailed during this time (temperature or humidity)

3.4.9
track density
number of tracks scanned per unit area

3.5 Terms with respect to solid state nuclear track dosemeters (SSNTD)

3.5.1
chemical etch bath
configuration containing the etching solution for etching detectors under a defined temperature

3.5.2
converter material
material in which neutrons undergo nuclear reactions and produce charged particles that can be detected by SSNT

NOTE Examples are hydrogen compounds for fast neutrons, and ^{10}B, ^{6}Li or nitrogen-containing compounds for thermal and epithermal neutrons.

3.5.3
etch chamber
device containing the detectors in a geometry allowing their proper etching under defined temperature conditions and an applied voltage (if applicable)

3.5.4
etching
process to develop the radiation induced tracks in detectors to make them countable

NOTE Etching could be chemical by putting the detectors into a proper chemical solution under defined temperature conditions. When an alternating high voltage is applied across the detector, then etching is called electro-chemical.

3.5.5
solid state nuclear track dosemeter
passive device consisting of one or more track etch detectors mounted in a holder (appropriate for the application), intended to be worn on a person's body to detect neutrons for the purpose of assessing the appropriate personal dose equivalent at or near the position where it is placed

3.5.6
track etch detector
material, usually plastic in nature, carefully manufactured under controlled conditions for the purpose of radiation measurements

3.5.7
track etch reader
device used to establish the number of tracks per unit area

3.6 Terms with respect to thermoluminescence albedo dosemeters (TLAD)

3.6.1
albedo
fraction of incident radiation scattered from a surface

NOTE Neutrons scattered back from a body following interactions within the body are called albedo neutrons.

3.6.2
annealing
controlled thermal treatment of a TL detector or dosemeter during or after readout

3.6.3
apparent photon dose equivalent
H_a
measured dose equivalent of each detector evaluated as if it had been irradiated by reference photon radiation

3.6.4
preparation
normal treatment of annealing, cleaning, etc., of detectors or dosemeters that are intended for routine use

3.6.5
thermoluminescence
TL
emission of light exhibited by certain substances or materials when the substance is heated following its exposure to ionizing radiation or U.V.

NOTE Strictly, the property should be referred to as radiothermoluminescence, but the abbreviated form is usually adequate.

3.6.6
thermoluminescence albedo neutron dosemeter
albedo dosemeter
passive device, consisting of two or more TL detectors, mounted in a holder (appropriate for the application), intended to detect incident and albedo neutrons when worn on a person's body for the purpose of assessing the appropriate personal dose equivalent at or near the position where it is placed

3.6.7
thermoluminescent detector
specified quantity of TL material, or such material incorporated with other non-luminescent material into a matrix, being defined by mass, shape or size or the mass of material incorporated in the matrix

3.6.8
thermoluminescence dosemeter reader
TL reader
instrument used to measure the light emitted from the detectors of thermoluminescence dosemeters, consisting essentially of a heating device, a light measuring device and the associated electronics

3.6.9
zero point
reading of unirradiated TLDs expressed in apparent photon dose equivalent

3.7 Terms with respect to superheated emulsion dosemeters (SED)

3.7.1
activation
procedure to render superheated emulsions ready for use

NOTE 1 Bubble detectors (BD) are typically stored and kept inactive under pressure, which is applied keeping their screw caps on. They are activated by removing the screw cap.

NOTE 2 Superheated drop detectors (SDD) are typically stored and kept inactive at reduced temperature. They are activated by allowing them to reach ambient temperature.

3.7.2
bubble reading
reading of a dosemeter based on superheated emulsions

NOTE In bubble detectors (BD), the number of visible bubbles, that comprise the measurement, is obtained by optical counting or by use of an automatic electro-optical instrument. In the superheated drop detectors, the volume of evolved gas is measured with the help of a calibrated scale.

3.7.3
depletion
decrease in the number of superheated drops due to their transformation into bubbles after being struck by neutrons

NOTE In the bubble detectors (BD), the initial sensitivity is restored by repressurization and no depletion correction is necessary. In the superheated drop detectors, the bubbles separate permanently from the detector and a depletion correction is necessary with prolonged use.

3.7.4
resetting
clearing of bubbles from the visco-elastic matrix

NOTE In the bubble detectors (BD), this is done by the application of external pressure using a piston assembly. In the superheated drop detectors, resetting is unnecessary because the bubbles leave the medium by rising to the top of the dosemeter due to their buoyancy.

3.7.5
superheated drops
drops of superheated liquid, generally of 5 µm to 100 µm diameter

NOTE These drops dispersed throughout a visco-elastic matrix represent the radiation-sensitive sites of the detector.

3.7.6
superheated emulsion
SE
superheated drops dispersed within a clear visco-elastic matrix

NOTE Superheated emulsions are typically contained in a device consisting of a transparent, cylindrical holder. Visible bubbles are formed throughout the device when irradiated with neutrons. The number of bubbles provides a measure of the neutron dose.

3.7.7
superheated liquid
fluid above its normal boiling point that is still in the liquid phase

3.7.8
visco-elastic matrix
⟨gel⟩ aqueous or polymer gel in which immiscible superheated drops are uniformly emulsified

NOTE In bubble detectors, the visco-elastic matrix typically keeps bubbles immobilized at the location of their formation. In superheated drop detectors (SDD), the visco-elastic matrix typically allows bubbles to rise out of the detector by buoyancy.

3.8 Terms with respect to ion chamber dosemeters with direct ion storage (ICD)

3.8.1
apparent photon dose equivalent
H_a
measured dose equivalent of each detector evaluated as if it had been irradiated by reference photon radiation

3.8.2
direct ion storage
DIS
permanent storage of an electric charge in a MOSFET with an open floating gate connected to an ion chamber

3.8.3
ion chamber detector
air volume surrounded by conductive wall material with applied electric field to collect ions produced by ionizing radiation

NOTE The neutron sensitivity of an ion chamber strongly depends on the wall material. Pairs of ion chambers with different neutron sensitivities are used to differentiate between neutron and photon radiation.

4 Units

This International Standard uses SI units. However the following units of practical importance for time are used where necessary: days (d) and hours (h).

5 General test conditions

5.1 Test conditions

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

Irradiation of dosemeters shall be performed on a phantom in terms of personal dose equivalent for the energy and angle dependence of response tests. For the other tests, dosemeters may be irradiated free-in-air and reference quantity could be neutron fluence.

5.2 Reference radiation

The reference radiation fields defined in ISO 8529-1 shall be used. In addition, simulated workplace neutron fields may be used (ISO 12789). For many of the tests, it is sufficient to use only one neutron source (e.g. ^{241}Am-Be or ^{252}Cf neutron sources). Information on irradiation conditions is found in Annex D.

NOTE For TLADs, any neutron source with adequate low-energy neutron intensity, the more moderated the better, can be used for the tests.

5.3 Test requirements

All detectors and dosemeters shall be subjected to the preparation, handling and read-out recommended by the manufacturer. Packaging, handling and processing of the detectors and dosemeters govern their performance that is generally assessed under laboratory conditions. As these conditions can never adequately simulate the conditions actually experienced in practical personal dosimetry, caution is therefore necessary when applying the results of these performance tests in real situations.

6 Performance requirements

The following general requirements apply to the tests for all detectors and dosemeters.

a) The tests are performed on a specified number of dosemeters randomly selected from one batch.

b) Type tests are made to assess the basic characteristics of the detectors or dosemeters and are often assured by recognized national laboratories, while quality tests are usually done by dosimetry services that intend to use dosemeters for routine neutron personal dosimetry.

c) The performance requirements are listed in Tables 6.1 to 6.5 as type tests (TT) or quality tests (QT).

d) The number of dosemeters used in each test shall be such to demonstrate that the requirements are met at the 95 % confidence level.

e) The reader used in the evaluation of the detectors and dosemeters shall be subjected to routine tests to establish consistency of operation.

Information on the characteristics of detectors and dosemeters is given in Annex E.

Table 1 — Performance requirements for nuclear track emulsion dosemeters

No.	Performance characteristics	Performance requirements	Test
1	Batch homogeneity	The coefficient of variation of the reading for n dosemeters shall not exceed 30 % for a given personal dose equivalent greater than 1 mSv.	QT C.1.1
2	Reproducibility	Not applicable	—
3	Linearity	The response to neutrons shall not vary by more than 20 % over the personal dose equivalent range from 0,5 mSv to 20 mSv.	TT C.1.2
4	Detection threshold	The detection threshold shall not exceed a personal dose equivalent of 0,2 mSv.	QT C.1.3
5	Fading (stability of the latent image)	The fading of tracks under normal test conditions shall not be greater than 10 %, 15 %, 20 % and 30% for periods of 3 days, 10 days, 30 days and 90 days, respectively, when comparing the test samples with control specimens.	QT C.1.4
6	Ageing	Not applicable	—
7	Residual signal	Not applicable	—
8	Self-irradiation	Not applicable	—
9	Exposure to radiation other than neutrons	The arithmetic mean of the response to neutrons shall differ by less than 10 % for a personal dose equivalent between 1 mSv and 2 mSv and an additional exposure to 3 mSv of photon radiation from a ^{137}Cs source compared with dosemeters not subjected to photon radiation.	TT C.1.5
10	Stability under various climatic conditions	The fading of tracks at a temperature of 40 °C and a humidity of 100 % shall not be greater than 15 %, 30 % and 50 % for periods of 3 days, 10 days and 30 days when comparing the test samples with control specimens.	TT C.1.6
11	Effect of light exposure (opacity to light)	No streaks shall be observed on the processed test film when exposed to 1 000 W/m^2 for one hour using a xenon lamp equivalent to bright sunlight (295 nm to 769 nm). The mean optical density over the useful area of the film shall not differ by more than three experimental standard deviations in comparison with the mean optical density of the control specimen.	TT C.1.7
12	Physical damage	Not applicable	—
13	Energy dependence of response	The response at normal incidence in the stated energy range for the dosimetry system shall not vary by more than ± 50 % for a personal dose equivalent of a least 1 mSv.	TT C.1.8
14	Angle dependence of response	The arithmetic mean of the response of a dosemeter at angles of incidence of 0°, 15°, 45° and 60° from normal shall not differ by more than 30 % from the corresponding response at normal incidence.	TT C.1.9

Table 2 — Performance requirements for solid state nuclear track dosemeters

No.	Performance characteristics	Performance requirements	Test
1	Batch homogeneity	The coefficient of variation of the reading for n dosemeters shall not exceed 15 % for any given personal dose equivalent greater than 1 mSv.	QT C.2.1
2	Reproducibility	Not applicable	—
3	Linearity	The response to neutrons shall not vary by more than 10 % over the personal dose equivalent range from 1 mSv to 10 mSv.	TT C.2.2
4	Detection threshold	The detection threshold shall not exceed a personal dose equivalent of 0,3 mSv.	QT C.2.3
5	Fading	The response of dosemeters irradiated at the beginning of a storage period shall not vary by more than 30 % for a 90-day storage period under standard test conditions. (The period from the manufacture of the detectors to the beginning of the test shall not exceed 90 days.)	TT C.2.4
6	Ageing	The response of dosemeters irradiated at the end of a storage period shall not vary by more than 30 % for a 90-day storage period under standard test conditions. (The period from the manufacture of the detectors to the beginning of the test shall not exceed 90 days.)	TT C.2.5
7	Residual signal	Not applicable	—
8	Self-irradiation	Not applicable	—
9	Exposure to radiation other than neutrons	The response to radiation other than neutrons, in particular ^{137}Cs photons, shall be less than 10 % in terms of $H_p(10)$. The zero point shall not change by more than 0,5 mSv for dosemeters exposed to 3 MBq · h/m^3 of radon at 50 % equilibrium with daughters ($F = 0{,}5$).	TT C.2.6
10	Stability under various climatic conditions	The measured dose equivalent shall not differ from the conventional true value by more than 20 % for 48-h storage at 40 °C and 90 % relative humidity when the dosemeters are irradiated either at the beginning or at the end of the storage period.	TT C.2.7
11	Effect of light exposure	The zero point shall not change by more than 1 mSv when exposed to a xenon lamp equivalent to bright sunlight (295 nm to 769 nm) to 1 000 W/m^2 for one day. For exposure of one week, the reading shall not differ from the reading of a dosemeter kept in the dark by more than 10 %.	TT C.2.8
12	Physical damage	Not applicable	—
13	Energy dependence of response	The response at normal incidence in the stated energy range for the dosimetry system shall not vary by more than ± 50 % for a personal dose equivalent of at least 1 mSv.	TT C.2.9
14	Angle dependence of response	The arithmetic mean of the response of a dosemeter at angles of incidence of 0°, 15°, 45° and 60° from normal shall not differ by more than 40 % from the corresponding response at normal incidence. The personal dose equivalent should be at least 1 mSv.	TT C.2.10

Table 3 — Performance requirements for thermoluminescence albedo dosemeters

No.	Performance characteristics	Performance requirements	Test
1	Batch homogeneity	The coefficient of variation of the apparent photon dose equivalent for n dosemeters shall not exceed 20 %.	QT C.3.1
2	Reproducibility	The coefficient of variation of the apparent photon dose equivalent for n dosemeters shall not exceed 20 % for each dosemeter separately when irradiated ten times.	QT C.3.2
3	Linearity	The response shall not vary by more than 10 % when dosemeters are irradiated with neutrons and photons producing readings of apparent photon dose equivalents between 1 mSv and 100 mSv.	TT C.3.3
4	Detection threshold	The detection threshold shall not exceed an apparent photon dose equivalent of 0,3 mSv.	QT C.3.4
5	Fading	The response of dosemeters irradiated at the beginning of a storage period shall not change by more than 10 % for a 90-day storage period under standard test conditions.	TT C.3.5
6	Ageing	Not applicable	—
7	Residual signal	The residual signal shall not exceed an apparent photon dose equivalent to 0,3 mSv following an irradiation corresponding to an apparent photon dose equivalent to 10 mSv.	TT C.3.6
8	Self-irradiation	After a storage period of 60 days, the zero point shall not change by an apparent photon dose equivalent of more than 0,3 mSv.	TT C.3.7
9	Exposure to radiation other than neutrons	Not applicable (see E.3)	—
10	Stability under various climatic conditions	The apparent photon dose equivalent shall not differ from the conventional true value by more than 5 % after 30 days storage under standard test conditions or 10 % for 48-h storage at 40 °C and 90 % relative humidity, when the dosemeters are irradiated either at the beginning or at the end of the storage period.	TT C.3.8
11	Effect of light exposure	The zero point shall not change by more than an apparent photon dose equivalent of 0,3 mSv when exposed with a xenon lamp equivalent to bright sunlight (295 nm to 769 nm) to 1 000 W/m^2 for one day. For exposure of one week, the apparent photon dose equivalent shall not differ from the apparent photon dose equivalent of a dosemeter kept in the dark by more than 10 %.	TT C.3.9
12	Physical damage	Not applicable	—
13	Energy dependence of response	Not applicable (see E.3)	—
14	Angle dependence of response	The arithmetic mean of the response of a dosemeter at angles of incidence of 0°, 15°, 45° and 60° from normal shall not differ by more than 30 % from the corresponding response at normal incidence. The personal dose equivalent should be about 1 mSv.	TT C.3.10

Table 4 — Performance requirements for superheated emulsions

No.	Performance characteristics	Performance requirements	Test
1	Batch homogeneity	The coefficient of variation of the reading for n dosemeters shall not exceed 25 % for a personal dose equivalent greater than 0,1 mSv.	QT C.4.1
2	Reproducibility	The coefficient of variation of the reading for n irradiations shall not exceed 25 % for any given personal dose equivalent less than 1 mSv.	QT C.4.2
3	Linearity	The response to neutrons shall not vary by more than 25 % over the personal dose equivalent range from 0,1 mSv to 1 mSv.	TT C.4.3
4	Detection threshold	The detection threshold shall not exceed a personal dose equivalent of 0,1 mSv.	QT C.4.4
5	Fading	Not applicable	—
6	Ageing	Bubble detectors shall not change in response by more than 25 % over up to 3 months, if used and reset and stored in an inactivated state following daily use.	TT C.4.5
7	Residual signal	Following an irradiation of up to 1 mSv, no bubble should be present in the detector after the resetting procedure.	QT C.4.6
8	Self-irradiation	Not applicable	—
9	Exposure to radiation other than neutrons	Not applicable	—
10	Stability under various climatic conditions	The response shall not vary by more than 25 % over the temperature range from 20 °C to 40 °C.	TT C.4.7
11	Effect of light exposure	Not applicable	—
12	Physical damage	A drop from a height of 1 m should not produce more than four bubbles.	QT C.4.8
13	Energy dependence of response	The response shall not vary by more than 25 % upon irradiation with mono-energetic neutrons (ISO 8529-1) over the energy range specified for the detector.	TT C.4.9
14	Angle dependence of response	The arithmetic mean of the response of a dosemeter at angles of incidence of 0°, 15°, 45° and 60° from normal shall not differ by more than 30 % from the corresponding response at normal incidence. The personal dose equivalent should be such that at least 100 bubbles are formed in a detector.	QT C.4.10

Table 5 — Performance requirements for ion chamber detectors with direct ion storage

No.	Performance characteristics	Performance requirements	Test
1	Batch homogeneity	The coefficient of variation of the apparent photon dose equivalent for n dosemeters shall not exceed 20 %.	QT C.5.1
2	Reproducibility	The coefficient of variation of the apparent photon dose equivalent for n dosemeters shall not exceed 20 % for each dosemeter separately when irradiated ten times.	QT C.5.2
3	Linearity	The response shall not vary by more than 10 % when dosemeters are irradiated with neutrons and photons producing readings corresponding to apparent photon dose equivalents between 1 mSv and 100 mSv.	TT C.5.3
4	Detection threshold	The detection threshold shall not exceed an apparent photon dose equivalent of 0,3 mSv.	QT C.5.4
5	Fading	The response of dosemeters irradiated at the beginning of a storage period shall not vary by more than 10 % for a 90-day storage period under standard test conditions.	TT C.5.5
6	Ageing	The response of dosemeters irradiated at the end of a storage period shall not vary by more than 10 % for a 90-day storage period under standard test conditions.	TT C.5.6
7	Residual signal	Not applicable	—
8	Self-irradiation	Not applicable	—
9	Exposure to radiation other than neutrons	The arithmetic mean of the response to neutrons shall differ by less than 20 % for a personal dose equivalent between 1 mSv and 2 mSv and an additional exposure to 3 mSv of photon radiation from a ^{137}Cs source compared with dosemeters not subjected to photon radiation.	TT C.5.7
10	Stability under various climatic conditions	The apparent photon dose equivalent shall not differ from the conventional true value by more than 10 % for 48-h storage at 40 °C and 90 % relative humidity when the dosemeters are irradiated either at the beginning or at the end of the storage period.	TT C.5.8
11	Effect of light exposure	Not applicable	—
12	Physical damage	Not applicable	—
13	Energy dependence of response	The response at normal incidence in the stated energy range for the dosimetry system shall not vary by more than ± 50 % for a personal dose equivalent of a least 1 mSv.	TT C.5.9
14	Angle dependence of response	The arithmetic mean of the response of a dosemeter at angles of incidence of 0°, 15°, 45° and 60° from normal shall not differ by more than 30 % from the corresponding response at normal incidence. The personal dose equivalent should be at least 1 mSv.	TT C.5.10

7 Test methods

Tests to demonstrate compliance with the specified performance requirements are detailed in Annex C. These provide guidance; specific details pertaining to similar tests by various national regulatory agencies shall take precedence over those described here.

8 Identification and accompanying documentation

8.1 Individual marking

Dosemeters and detectors shall have simple, unique and secure means of identification. The marking shall not impair 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, and that they are intended for neutron dosimetry.

8.2 Collective marking

The following information shall be indicate 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;

— series number or manufacturer's batch number;

— expiry date, if relevant.

8.3 Accompanying documentation

The note attached to each box or other packing container shall carry at least the following information, if it is not provided on the container:

— complete designation;

— name and trademark of manufacturer;

— neutron energy range for which the detectors or dosemeters are designed;

— method of processing.

9 Certification

An acknowledged testing laboratory will make the certification. Some basic requirements are suggested for manufacturers claiming compliance (or partial compliance) with the performance requirements of this International Standard:

a) name and address of the manufacturer;

b) name and address of the testing laboratory or laboratories, when more than one is involved;

c) description/specification of the dosemeters under consideration, including how the dosemeter is assembled; drawings or photos are encouraged;

d) description of reader, procedures and ancillary equipment used (model No., etc.);

e) statements giving the dates and the outcome of each test (test reports shall be available for inspection by the purchaser);

f) details of conversion coefficients and phantoms agreed between the manufacturer and the purchaser, when those proposed in this International Standard are not used;

g) any deviations from the recommended testing procedures should be justified.

Annex A
(normative)

Reference and standard test conditions

Table A.1

Influence	**Reference conditions (unless otherwise stated by the manufacturer)**	**Standard test conditions (unless otherwise stated by the manufacturer)**
Reference neutron radiation	Conforming to ISO 8529-3	Conforming to ISO 8529-3 and ISO 12789
Ambient temperature	$T = 20$ °C	$T = 18$ °C to 22 °C
Relative humidity	65 %	50 % to 75 %
Atmospheric pressure	$p = 101{,}3$ kPa	$p = 86$ to 106 kPa
Radiation background	$H^*(10) \leqslant 0{,}1$ μSv/h	$H^*(10) \leqslant 0{,}25$ μSv/h
Contamination by radioactive elements	Negligible	Negligible
Light intensity	50 W/m^2	$<$ 100 W/m^2

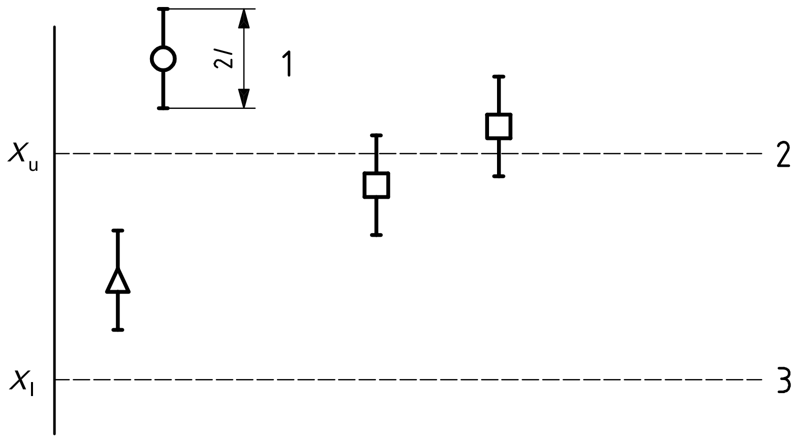
Annex B
(normative)

Confidence limits

B.1 General

The magnitude of the uncertainty of a measured value due to random effects is a significant fraction of the allowed tolerances of this measured value. This uncertainty is considered by taking more than one measurement.

In fact, the number of measurements should be large enough to ensure that the arithmetic mean, $\bar{x}$, of a series of measurements provides a reliable estimate of the "true" mean, μ, and that in addition the experimental standard deviation, s, is a reliable estimate of the standard deviation, σ[10]. In this International Standard, the number of measurements or the sample size shall be chosen in such a way that, for a confidence level of 95 %, the confidence interval obtained for each arithmetic mean, $\bar{x}$, lies either within the limits of variation of the measured value allowed in the test (test passed, point Δ in Figure B.1) or outside of these limits (test failed, point ○ in Figure B.1). If one of the allowed limits of variation, x_u or x_l, lies within the confidence interval of the arithmetic mean (points □ in Figure B.1), the number of measurements or the sample size can be increased to reduce the width $2l$ of the confidence interval of the arithmetic mean, $\bar{x}$, in order to reach one of the two cases mentioned above that are necessary for an unequivocal decision of passing the test or not.



Key

1 confidence interval of the arithmetic mean $\bar{x}$ of width $2l$

2 allowed upper limit of variation, x_u

3 allowed lower limit of variation, x_l

Figure B.1 — Test for confidence interval

The test is passed if the confidence interval of width $2l$ around $\bar{x}$ lies between the allowed upper and lower limits of variation x_u and x_l as given by Equation (B.1):

$$x_l + l < \bar{x} < x_u - l \quad \text{(B.1)}$$

In each test, it is recommended to start with 10 measurements and to increase the number of measurements or dosemeters if it turns out to be necessary to reduce the width $2l$ of the confidence interval.

B.2 Confidence interval for the arithmetic mean, $\bar{x}$

The confidence interval for the arithmetic mean, $\bar{x}$, is ($\bar{x} - l_i$, $\bar{x} + l_i$), where l_i is the half width of the confidence interval of $\bar{x}$ relative to the ith series of measurements. When calculating $\bar{x}$ from n_i measurements, the half width of the confidence interval is given by Equation (B.2):

$$l_i = t_n \cdot s_i \big/ \sqrt{n_i} \tag{B.2}$$

where

s_i is the experimental standard deviation for the ith series of measurements;

t_n is taken from Table B.1 for n_i measurements.

EXEMPLE For $n_i = 10$; $l_i = 2{,}26 \cdot s_i / \sqrt{10} = 0{,}71 \cdot s_i$.

Table B.1 — Two-sided Student's *t* values for 95 % confidence interval for sample size n_i

n_i	t_n	n_i	t_n
2	12,71	15	2,15
3	4,30	20	2,09
4	3,18	25	2,06
5	2,78	30	2,05
6	2,57	40	2,02
7	2,45	50	2,00
8	2,37	60	1,98
9	2,31	120	1,96
10	2,26	∞	1,96

B.3 Confidence interval for the experimental standard deviation, s

The confidence interval for the experimental standard deviation, s, of the arithmetic mean, $\bar{x}$, is given by the expressions

$(s - l_s, s + l_s)$

where l_s is the half width of the confidence interval of s. If s is calculated from n measurements for which the probability distribution is close to normal, the upper limit of l_s at a confidence level of 95 % is approximated by Equation (B.3):

$$l_s(n) = t_n \cdot s\sqrt{0{,}5/(n-1)} \tag{B.3}$$

EXAMPLE $l_s(10) = 0{,}53 \cdot s$ is obtained for $n = 10$ measurements and t_n is taken from Table B.1.

B.4 Confidence interval for a combined quantity

If the limits of variation are stated for a quantity, the arithmetic mean, $\bar{x}$, calculated from k means $\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$, … $\bar{x}_k$ is given by Equation (B.4):

$$\bar{x} = f(\bar{x}, \bar{x}_2, \bar{x}_3, ..., \bar{x}_k) \tag{B.4}$$

and the half width of the confidence interval of the ith arithmetic mean is l_i. The half width, l, of the confidence interval for $\bar{x}$ is given by Equation (B.5):

$$l = \sqrt{\sum_{i=1}^{k} \left[\delta f\left(\bar{x}_1, \bar{x}_2, \bar{x}_3, ... \bar{x}_k\right) \delta x_i\right]^2 \cdot l_i^2} \tag{B.5}$$

EXAMPLES

a) $\bar{x} = \bar{x}_1 \pm \bar{x}_2$ hence $l = \sqrt{l_1^2 + l_2^2}$

In general, $\bar{x} = \sum_{i=1}^{n} \bar{x}_i$ hence $l = \sqrt{\sum_{i=1}^{n} l_i^2}$

b) $\bar{x} = \bar{x}_1 / \bar{x}_2$ hence $l = \left(\bar{x}_1 / \bar{x}_2\right) \sqrt{\left(l_1 / \bar{x}_1\right)^2 + \left(l_2 / \bar{x}_2\right)^2}$

c) $\bar{x} = \left(\bar{x}_1 - \bar{x}_2\right) / \left(\bar{x}_1 + \bar{x}_2\right)$ hence $l = \frac{2}{\left(\bar{x}_1 + \bar{x}_2\right)^2} \sqrt{\left(\bar{x}_2 \cdot l_1\right)^2 + \left(\bar{x}_1 \cdot l_2\right)^2}$

B.5 Confidence interval for detection threshold

In the case for the calculation of the detection threshold according to the following formula (used elsewhere to define the critical level of the decision limit [27]):

$$t_n \cdot s \tag{B.6}$$

The Student's t values to be used are the ones reported in the following table belonging to the one-sided Student's t distribution.

Table B.2 — One-sided Student's t values for 95 % confidence interval for sample size n_i

n_i	t_n	n_i	t_n
2	6,32	15	1,76
3	2,92	20	1,73
4	2,35	25	1,71
5	2,13	30	1,70
6	2,01	40	1,68
7	1,94	50	1,68
8	1,89	60	1,67
9	1,86	120	1,66
10	1,83	∞	1,64

Annex C
(normative)

Performance tests

C.1 Nuclear track emulsions (NTE)

C.1.1 Batch homogeneity

Prepare and irradiate a lot of $i = 1$ to n dosemeters of the same emulsion with a ^{241}Am-Be or ^{252}Cf neutron source to the same conventional true value of the personal dose equivalent, H_t, of at least 1 mSv.

Develop, read out (scan at least 100 tracks), determine the track density for each dosemeter, M_i, and show that the coefficient of variation, V, for the reading, M_i, of the n dosemeters does not exceed 30 %.

C.1.2 Linearity

Prepare six lots numbered $j = 1$ to 6 of $i = 1$ to n dosemeters and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional true value of personal dose equivalents, $H_{t,j}$, of 0,5 mSv, 1 mSv, 2 mSv, 5 mSv, 10 mSv and 20 mSv, respectively.

Develop, read out (scan at least 100 tracks) each dosemeter, determine the measured dose equivalent, $H_{i,j}$, calculate the arithmetic mean, $\bar{H}_j$, for each lot j and the respective experimental standard deviations, s_j. Show that for each personal dose equivalent, H_t meets the criterion given in Equation (C.1):

$$0{,}8 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) \big/ H_{t,j} \leqslant 1{,}2 \qquad \text{(C.1)}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.1.3 Detection threshold

Develop and read out (scan) n unirradiated dosemeters. Use the conversion coefficient for a ^{241}Am-Be or ^{252}Cf neutron source to transform the number of tracks into measured dose equivalent, H_i, and calculate the experimental standard deviation, s, for the n dosemeters. Show that the criterion in Equation (C.2) is met:

$$t_n \cdot s \leqslant 0{,}2 \text{ mSv} \text{ [27]} \qquad \text{(C.2)}$$

where the values for t_n are listed in Table B.2.

C.1.4 Fading (stability of the latent image)

Prepare five lots numbered $j = 1$ to 5 of $n + 2$ dosemeters. Irradiate $i = 1$ to n dosemeters of each lot with a ^{241}Am-Be or ^{252}Cf neutron source to the same value of the conventional true value of the personal dose equivalent, H_t, between 1 mSv and 2 mSv at days D_o (lot 1), $D_o + 60$ (lot 2), $D_o + 80$ (lot 3), $D_o + 87$ (lot 4) and $D_o + 90$ (lot 5) and keep two dosemeters of each lot as background samples. Following irradiation, store and keep all dosemeters under normal test conditions. Develop all dosemeters together on days $D_o + 91$ or $D_o + 92$ and consider the dosemeters of lot five as the control specimens.

Read out (scan at least 100 tracks) each dosemeter, determine the track density, $M_{i,j}$, and check the background dosemeters for an undue increase of tracks. Determine the arithmetic mean of the reading, $\bar{M}_j$, and the experimental standard deviation, s_j, for each of the five lots. Show that the criterion of Equation (C.3) is met:

$$\left(\bar{M}_j/\bar{M}_5\right) \pm l \geqslant Q_{\mathrm{R},j} \tag{C.3}$$

where $j = 1$ to 4, the Q_{R1} to Q_{R4} are 0,7, 0,8, 0,85 and 0,9, respectively, and l for the quotient of the arithmetic means is calculated in accordance with Equation (B.5).

C.1.5 Exposure to radiation other than neutrons

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional true value of the personal dose equivalent, H_{t}, between 1 mSv and 2 mSv. In addition irradiate the second lot with 3 mSv of photon radiation from a ^{137}Cs source.

Develop, read out (scan at least 100 tracks) and determine the track density for each dosemeter, $M_{i,j}$. Determine the arithmetic mean of the reading, $\bar{M}_j$, and the experimental standard deviation, s_j, for the two lots. Show that the criterion in Equation (C.4) is met:

$$0{,}9 \leqslant \left(\bar{M}_1/\bar{M}_2\right) \pm l \leqslant 1{,}1 \tag{C.4}$$

where l for the quotient of the arithmetic means is calculated in accordance with Equation (B.5).

C.1.6 Stability under various climatic conditions

Prepare four lots of $n + 2$ dosemeters each and identify the lots by numbers $j = 1$ to 4. Irradiate $i = 1$ to n dosemeters of each lot with a ^{241}Am-Be or ^{252}Cf neutron source to the same conventional true value of the personal dose equivalent, H_{t}, between 1 mSv and 2 mSv at days D_{o} (lot 1), $D_{\mathrm{o}} + 20$ (lot 2), $D_{\mathrm{o}} + 27$ (lot 3) and $D_{\mathrm{o}} + 30$ (lot 4) and keep two dosemeters of each lot as background samples. Following irradiation, store and keep all dosemeters at 40 °C and a relative humidity of 100 %.

Develop all dosemeters together on days $D_{\mathrm{o}} + 31$ or $D_{\mathrm{o}} + 32$ and consider the dosemeters of lot 4 as the control specimens. Read out (scan at least 100 tracks) and determine the track density for each dosemeter, $M_{i,j}$, and check the background dosemeters for an undue increase of tracks in the samples. Determine the arithmetic mean of the reading, $\bar{M}_j$, and the experimental standard deviation, s_j, for each of the four lots. Show that the criterion in Equation (C.5) is met:

$$\left(\bar{M}_j/\bar{M}_4\right) \pm l \geqslant Q_{\mathrm{R},j} \tag{C.5}$$

where the Q_{R1} to Q_{R3} are 0,5, 0,7 and 0,85, respectively, and l for the quotient of the arithmetic means is calculated in accordance with Equation (B.5).

C.1.7 Effect of light exposure (opacity to light)

Expose film packets randomly selected from a batch to an illumination from a xenon lamp of 1 000 W/m^2 for 1 h at a sufficiently large distance from the light source to avoid the film packets exceeding a temperature of 30 °C. Set the face of the film packets perpendicular to the luminous radiation. Then expose the other face of the film packets under the same conditions for 1 h. Then expose each edge of the film packets under the same conditions for 1 h.

Process films simultaneously with an unexposed control specimen and compare their optical densities with respect to streaks or lack of homogeneity of the optical density. The optical density, $S_{k,j}$, is measured at ten different points on each film j. Calculate the mean optical density, $\overline{S}_j$, and the experimental standard deviation, s_j, for each film and compare the values with those of the control specimen, S_c. Show that the criterion in Equation (C.6) is met:

$$\left|\left(\overline{S}_j - \overline{S}_C\right)\right| + l \leqslant 3 \cdot s_j \qquad \text{(C.6)}$$

where l for the difference of the arithmetic means is calculated in accordance with Equation (B.5).

C.1.8 Energy dependence of response

Prepare m lots numbered $j = 1$ to m of $i = 1$ to n dosemeters and irradiate them with m neutron energies in the applicable energy range for which compliance with this standard is sought. These neutron energies should be taken from ISO 8529-1:2001, Table 2.The dosemeters shall be irradiated on the ISO slab water phantom to a conventional true value of the personal dose equivalent, $H_{\rm t}$, between 1 mSv and 2 mSv.

Develop, read out (scan at least 100 tracks), determine the measured dose equivalent for each dosemeter, $H_{i,j,}$ and calculate for each lot j (energy), the arithmetic mean, $\overline{H}_j$, and the respective experimental standard deviation, s_j. Show that the criterion in Equation (C.7) is met:

$$0{,}5 \leqslant \left(\overline{H}_j \pm l_{i,j}\right) \big/ H_{{\rm t},j} \leqslant 1{,}5 \qquad \text{(C.7)}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.1.9 Angle dependence of response

Prepare four lots numbered $j = 1$ to 4 of four dosemeters each numbered $i = 1$ to 4. Irradiate all dosemeters with neutrons to a value of the conventional true value of the personal dose equivalent, H_t, between 1 and 2 mSv on the ISO slab water phantom under the following conditions (ISO 8529-3):

— lot 1: normal incidence;

— lot 2: 15° off normal;

— lot 3: 45° off normal;

— lot 4: 60° off normal.

For lots 2 to 4, the angle of incidence for the dosemeters $i = 1$ to 4 irradiated is varied positive and negative in two planes perpendicular to each other and to the plane of the dosemeter. Determine the conventional true value of the personal dose equivalent employing the appropriate conversion coefficient for the neutrons used in the test at the respective angles j, H_t.

Develop, read out (scan at least 100 tracks), determine the measured dose equivalent for each dosemeter, $H_{i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the four lots (angles), the respective experimental standard deviation, s_j, and the response, R_j. Show that the criterion in Equation (C.8) is met:

$$0{,}7 \leqslant \left[0{,}25\sum_{j=1}^{4}\left(R_j/R_1\right)\right] \pm l \leqslant 1{,}3 \tag{C.8}$$

where l for the sum of the ratios is calculated in accordance with Equation (B.5).

C.2 Solid state nuclear track detectors (SSNT)

C.2.1 Batch homogeneity

Prepare and irradiate a lot of $i = 1$ to n dosemeters belonging to the same batch (sheet or material) with a ^{241}Am-Be or ^{252}Cf neutron source to the same conventional true value of the personal dose equivalent, H_t, of at least 1 mSv.

Etch, read out each dosemeter and show that the coefficient of variation, V, for the reading, M_i, of n dosemeters does not exceed 15 %.

C.2.2 Linearity

Prepare five lots numbered $j = 1$ to 5 of $i = 1$ to n dosemeters each and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional true value of personal dose equivalents, $H_{t,j}$, of 1 mSv, 2 mSv, 5 mSv, 10 mSv and 20 mSv, respectively.

Etch, read out, determine the measured dose equivalent for each dosemeter, $H_{i,j,}$ calculate the arithmetic mean, $\bar{H}_j$, for each lot j and the respective experimental standard deviations, s_j. Show that for each personal dose equivalent, $H_{t,j}$, the criterion in Equation (C.9) is met:

$$0{,}85 \leqslant \left(\bar{H}_j \pm l_{i,j}\right)\big/H_{t,j} \leqslant 1{,}15 \tag{C.9}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.2.3 Detection threshold

Etch and read out $i = 1$ to n unirradiated dosemeters. Use the conversion coefficient for a ^{241}Am-Be or ^{252}Cf neutron source to transform the number of tracks into measured dose equivalent, H_i, and calculate the experimental standard deviation, s, for the n dosemeters. Show that the criterion, expressed in millisieverts, in Equation (C.10) is met:

$$t_n \cdot s \leqslant 0{,}3 \text{[27]} \tag{C.10}$$

where the values for t_n are listed in Table B.2.

C.2.4 Fading

Prepare and irradiate $i = 1$ to n dosemeters with a ^{241}Am-Be or ^{252}Cf neutron source to the same value of the conventional true value of the personal dose equivalent, H_t, of at least 1 mSv. Store the dosemeters under standard test conditions for 90 days.

Following storage, etch, read out, determine the measured dose equivalent for each dosemeter, H_i, and calculate the arithmetic mean, $\bar{H}$, and the experimental standard deviation, s. Show that the criterion in Equation (C.11) is met:

$$0{,}7 \leqslant \left(\bar{H} \pm l_i\right) / H_t \leqslant 1{,}3 \tag{C.11}$$

where l_i is calculated in accordance with Equation (B.2).

C.2.5 Ageing

Prepare and store $i = 1$ to n dosemeters under standard test conditions for 90 days. Following storage irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to the same conventional true value of the personal dose equivalent, H_t, of at least 1 mSv.

Etch, read out, determine the measured dose equivalent for each dosemeter, H_i, and calculate the arithmetic mean, $\bar{H}$, and the experimental standard deviation, s. Show that the criterion in Equation (C.12) is met:

$$0{,}7 \leqslant \left(\bar{H} \pm l_i\right) / H_t \leqslant 1{,}3 \tag{C.12}$$

where l_i is calculated in accordance with Equation (B.2).

C.2.6 Exposure to radiation other than neutrons

C.2.6.1 Photon radiation

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional true value of the personal dose equivalent, H_t, between 1 mSv and 2 mSv. In addition, irradiate the second lot with 3 mSv of photon radiation from a ^{137}Cs source.

Etch, read out and determine the measured dose equivalent for each dosemeter, $H_{i,j}$, calculate the arithmetic mean, $\bar{H}_j$, and the experimental standard deviation, s_j, for the two lots. Show that the criterion in Equation (C.13) is met:

$$0{,}9 \leqslant \left(\bar{H}_1 / \bar{H}_2\right) \pm l \leqslant 1{,}1 \tag{C.13}$$

where l for the quotient of the arithmetic means is calculated in accordance with Equation (B.5).

C.2.6.2 Radon

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters 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 free of radon.

Etch, read out, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the two lots and the respective experimental standard deviations, s_j. Show that the criterion, expressed in millisieverts, in Equation (C.14) is met:

$$\left|\left(\bar{H}_1 - \bar{H}_2\right)\right| \pm l \leqslant 0{,}5 \tag{C.14}$$

where l for the difference of the arithmetic means is calculated in accordance with Equation (B.5).

C.2.7 Stability under various climatic conditions

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters. Store both lots for 24 h under standard test conditions. Irradiate lot 1 with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional true value of the personal dose equivalent, H_t, of at least 1 mSv. Store both lots 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 lot 2 to the same conventional true value of the personal dose equivalent as lot 1.

Etch, read out, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the two lots and the respective experimental standard deviations, s_j. Show that for each lot the criterion in Equation (C.15) is met:

$$0{,}8 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) / H_t \leqslant 1{,}2 \qquad \text{(C.15)}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.2.8 Effect of light exposure

C.2.8.1 Effect on zero point

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters and expose lot 1 to 1 000 W/m^2 of light for 1 day. Store dosemeters of lot 2 in the dark in an otherwise identical environment.

Etch, read out, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the two lots and the respective experimental standard deviations, s_j. Show that the criterion, expressed in millisieverts, in Equation (C.16) is met:

$$\left|\left(\bar{H}_1 - \bar{H}_2\right)\right| \pm l \leqslant 1 \qquad \text{(C.16)}$$

where l for the difference of the arithmetic means is calculated in accordance with Equation (B.5).

C.2.8.2 Effect on the reading

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source to a conventional true value of the personal dose equivalent, H_t, of at least 1 mSv. Exposure lot 1 to 1 000 W/m^2 of light for 1 week. Store the dosemeters of lot 2 in the dark in an otherwise identical environment.

Etch, read out each dosemeter, $M_{i,j}$, and calculate the arithmetic mean of the reading, $\bar{M}_j$, and the experimental standard deviation, s_j, for the two lots. Show that the criterion in Equation (C.17) is met:

$$0{,}9 \leqslant \left(\bar{M}_1 / \bar{M}_2\right) \pm l \leqslant 1{,}1 \qquad \text{(C.17)}$$

where l for the quotient of the arithmetic means is calculated in accordance with Equation (B.5).

C.2.9 Energy Dependence of Response

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n dosemeters and irradiate them with four neutron energies taken from ISO 8529-1:2001, Table 2, in the applicable energy range for which compliance with this standard is sought. The dosemeters shall be irradiated on the ISO slab water phantom to a conventional true value of the personal dose equivalent, H_t, of at least 1 mSv.

Etch, read out, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, calculate the arithmetic mean, $\bar{H}_j$, for each of the four lots (energies) and the respective experimental standard deviation, s_j. Show that the criterion in Equation (C.18) is met:

$$0{,}5 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) / H_{t,j} \leqslant 1{,}5 \tag{C.18}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

NOTE These are the minimum requirements to fully comply with this International Standard. It is possible to use additional reference neutron radiation energies and their use is encouraged.

C.2.10 Angle dependence of response

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n dosemeters. For this test, a series of mono-energetic neutron energies could be used. It is however convenient that the dosemeters are irradiated on an ISO water slab phantom using a ^{241}Am-Be, ^{252}Cf or other neutron source according to the methods of production described in ISO 8529-1. The conventional true value of the personal dose equivalent, H_t, shall be at least 1 mSv and the irradiation conditions shall be the following (ISO 8529-3):

- lot 1: normal incidence;
- lot 2: 15° off normal;
- lot 3: 45° off normal;
- lot 4: 60° off normal.

For lots 2 to 4, 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. Determine the conventional true value of the personal dose equivalent by employing the appropriate conversion coefficient for the neutrons used at the respective angles j, $H_{t,j}$.

Etch, read out, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the four lots (angles), the respective experimental standard deviation, s_j, and the response, R_j. Show that the criterion in Equation (C.19) is met:

$$0{,}6 \leqslant \left[0{,}25 \sum_{j=1}^{4} \left(R_j / R_1\right)\right] \pm l \leqslant 1{,}4 \tag{C.19}$$

where l for the sum of the ratios is calculated in accordance with Equation (B.5).

C.3 Thermoluminescence albedo dosemeters (TLAD)

C.3.1 Batch homogeneity

Prepare and identically irradiate each dosemeter from a lot of $i = 1$ to n, dosemeters to a combined neutron/photon field which gives an apparent photon dose equivalent, $H_{ap,i}$, of about 1 mSv to the photon-sensitive detector element and an apparent photon dose equivalent, $H_{an,i}$, of about 2 mSv to the neutron-sensitive element.

Read out and determine the apparent photon dose equivalent, $H_{a,i} = H_{an,i} - H_{ap,i}$, for each dosemeter and show that the coefficient of variation, V, for the n dosemeters does not exceed 20 %.

C.3.2 Reproducibility

Prepare and identically irradiate each dosemeter from a lot of $i = 1$ to n dosemeters to a combined neutron/photon field which gives an apparent photon dose equivalent, $H_{\text{ap},i}$, of about 1 mSv to the photon-sensitive detector element and an apparent photon dose equivalent, $H_{\text{an},i}$, of about 2 mSv to the neutron-sensitive element. Repeat this 10 times with exactly the same value of the apparent photon dose equivalent, H_{a}, for each of the n dosemeters.

Read out, determine for each of the $i = 1$ to n dosemeters the $j = 1$ to 10 apparent photon dose equivalent, $H_{\text{a},i,j} = H_{\text{an},i,j} - H_{\text{ap},i,j}$, the arithmetic mean, $\bar{H}_{\text{a},i}$, and the experimental standard deviation, s_i. Show that for each of the $i = 1$ to n dosemeters, the criterion in Equation (C.20) is met:

$$(s_i + l_{\text{s},i}) / \bar{H}_{\text{a},i} \leqslant 0{,}2 \qquad \text{(C.20)}$$

where the $l_{\text{s},i}$ are calculated in accordance with Equation (B.3).

C.3.3 Linearity

Prepare five lots numbered $j = 1$ to 5 of $i = 1$ to n dosemeters each and irradiate them with a combined neutron/photon field such that the apparent photon dose equivalent to the neutron sensitive element, $H_{\text{an},i}$, is about twice that to the photon-sensitive element, $H_{\text{ap},i}$, and where the conventional true values of the personal dose equivalent, $H_{\text{t},j}$, are 1 mSv, 3 mSv, 10 mSv, 30 mSv and 100 mSv, respectively.

Read out, determine the apparent photon dose equivalent for each dosemeter, $H_{\text{a},i,j} = H_{\text{an},i,j} - H_{\text{ap},i,j}$, calculate the arithmetic mean, $\bar{H}_j$, for each lot j and the respective experimental standard deviations, s_j. Show that for each apparent photon dose equivalent, $H_{\text{a},i,j}$, the criterion in Equation (C.21) is met:

$$0{,}9 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) / H_{\text{a},i,j} \leqslant 1{,}1 \qquad \text{(C.21)}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.3.4 Detection threshold

Prepare $i = 1$ to n unirradiated dosemeters. Read out, determine the apparent photon dose equivalent, $H_{\text{a},i} = H_{\text{an},i} - H_{\text{ap},j}$, for each dosemeter and calculate the experimental standard deviation, s. Show that the criterion, expressed in millisieverts, in Equation (C.22) is met:

$$t_n \cdot s \leqslant 0{,}3 \text{ [27]} \qquad \text{(C.22)}$$

where the values for t_n are listed in Table B.2.

C.3.5 Fading

Prepare $i = 1$ to n dosemeters and irradiate them all with a combined neutron/photon field such that the apparent photon dose equivalent of the neutron sensitive element, $H_{\text{an},i}$, is about twice that of the photon-sensitive element, $H_{\text{ap},i}$, and where the conventional true value of the personal dose equivalent, H_{t}, is about 1 mSv. Store the dosemeters under standard test conditions for 90 days. Following storage, read out, determine the apparent photon dose equivalent for each dosemeter, $H_{\text{a},i} = H_{\text{an},i} - H_{\text{ap},j}$, and calculate the arithmetic mean, $\bar{H}$, and the experimental standard deviation, s. Show that the criterion in Equation (C.23) is met:

$$0{,}9 \leqslant \left(\bar{H} \pm l_i\right) / H_{\text{a},i} \leqslant 1{,}1 \qquad \text{(C.23)}$$

where l_i is calculated in accordance with Equation (B.2).

C.3.6 Residual signal

Prepare the $i = 1$ to n dosemeters used for the test of the detection threshold (C.3.4) and irradiate them all with a combined neutron/photon field which gives an apparent photon dose equivalent, $H_{\text{ap},i}$, of about 10 mSv to the photon-sensitive detector element and an apparent photon dose equivalent, $H_{\text{an},i}$, of about 20 mSv to the neutron-sensitive element. Anneal and read out the detectors according to the routine procedure.

Anneal and read out the dosemeters a second time, determine the apparent photon dose equivalent for each neutron-sensitive and photon-sensitive detector element, $H_{\text{an},i}$ or $H_{\text{ap},i}$, and calculate the experimental standard deviation, s. Show for each detector element type that the criterion, expressed in millisieverts, in Equation (24) is met:

$$t_n \cdot s \leqslant 0{,}3 \qquad \text{(C.24)}$$

where the values for t_n are listed in Table B.1.

C.3.7 Self-irradiation

Prepare $i = 1$ to n dosemeters. Store them for 60 days under standard test conditions in a location where the background dose rate is known.

Read out, determine the apparent photon dose equivalent for each neutron-sensitive and photon-sensitive detector element, $H_{\text{an},i}$ *or* $H_{\text{ap},i}$, calculate the arithmetic mean, $\bar{H}_j$, and the experimental standard deviation, s. Show for each detector element type that the criterion, expressed in millisieverts, in Equation (C.25) is met:

$$\left(\bar{H}_j + l_i\right) \leqslant 0{,}3 \qquad \text{(C.25)}$$

where l_i is calculated in accordance with Equation (B.2).

C.3.8 Stability under various climatic conditions

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters each. Store both lots for 24 h under standard test conditions. Irradiate lot 1 to a combined neutron/photon field such that the apparent photon dose equivalent of the neutron sensitive element, $H_{\text{an},i,j}$, is about twice that of the photon-sensitive element, $H_{\text{ap},i,j}$. Store both lots of dosemeters in a climatic chamber in which standard test conditions prevail.

After a continuous period of 30 days, remove both lots of dosemeters from the climatic chamber. Irradiate lot 2 in the same way as lot 1. Store both lots for one day under standard test conditions.

Read out, determine the apparent photon dose equivalent, $H_{\text{a},i,j} = H_{\text{an},i,j} - H_{\text{ap},i,j}$, for each dosemeter and calculate the arithmetic mean, $\bar{H}_j$, and the experimental standard deviation, s_j, for the two lots. Show that for each lot the criterion in Equation (C.26) is met:

$$0{,}95 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) \Big/ H_{\text{a},i,j} \leqslant 1{,}05 \qquad \text{(C.26)}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

Repeat the test for a storage period of 48 h, but in a climatic chamber in which the temperature is 40 °C ± 2 °C and the relative humidity is at least 90 %. Show that for each lot the criterion in Equation (C.27) is met:

$$0{,}95 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) \Big/ H_{\text{a},i,j} \leqslant 1{,}1 \qquad \text{(C.27)}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.3.9 Effect of light exposure

C.3.9.1 Effect on zero point

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters. Expose lot 1 to 1 000 W/m^2 of light for one day ensuring that the temperature of the dosemeters is maintained at less than 40 °C. Store the dosemeters of lot 2 in the dark in an otherwise identical environment. Ensure that the temperature of the dosemeters of lot 2 stays within ± 5 °C of the dosemeters of lot 1.

Read out all dosemeters after one day, determine the apparent photon dose equivalent for each neutron-sensitive and photon-sensitive detector element, $H_{\text{an},i,j}$ or $H_{\text{ap},i,j}$, and calculate the arithmetic mean, $\bar{H}_{\text{a},j}$, for each detector element type of the two lots and their respective experimental standard deviations, s_j. Show for each detector element type and for each lot that the criterion, expressed in millisieverts, in Equation (C.28) is met:

$$\left|\bar{H}_{\text{a},1} - \bar{H}_{\text{a},2}\right| \pm l \leqslant 0{,}3 \qquad \text{(C.28)}$$

where l is calculated in accordance with Equation (B.5).

C.3.9.2 Effect on the reading

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters each and irradiate them with neutrons to an apparent photon dose equivalent of about 1 mSv. Expose and store lots 1 and 2, respectively, as described in C.3.9.1.

Read out all dosemeters after one week, determine the apparent photon dose equivalent for each dosemeter, $H_{\text{a},i,j} = H_{\text{an},i,j} - H_{\text{ap},i,j}$, calculate the arithmetic mean, $\bar{H}_j$, for each of the two lots and their respective experimental standard deviation, s_j. Show that the criterion in Equation (C.29) is met:

$$0{,}9 \leqslant \left(\bar{H}_1/\bar{H}_2\right) \pm l \leqslant 1{,}1 \qquad \text{(C.29)}$$

where l for the ratio of the arithmetic means is calculated in accordance with Equation (B.5).

C.3.10 Angle dependence of response

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n dosemeters. Irradiate on an ISO water slab phantom using a simulated workplace neutron field in accordance with the methods of production described in ISO 12789 or D_2O-moderated ^{252}Cf as specified in ISO 8529-1. The conventional true value of the personal dose equivalent, H_t, shall be about 1 mSv and the irradiation conditions shall be the following (ISO 8529-3):

— lot 1: normal incidence;

— lot 2: 15° off normal;

— lot 3: 45° off normal;

— lot 4: 60° off normal.

For lots 2 to 4, 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. Determine the conventional true value of the personal dose equivalent employing the appropriate conversion coefficient for the neutrons used in the tests at the respective angles j, $H_{\text{t},j}$.

Read out, determine the apparent photon dose equivalent for each dosemeter, $H_{a,i,j} = H_{an,i,j} - H_{ap,i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the four lots (angles), the respective experimental standard deviation, s_j, and the response, R_j. Show that the criterion in Equation (C.30) is met:

$$0,7 \leqslant \left[0,25 \sum_{j=1}^{4} \left(R_j / R_1 \right) \right] \pm l \leqslant 1,3 \qquad \text{(C.30)}$$

where l for the sum of the ratios is calculated in accordance with Equation (B.5).

C.4 Superheated emulsions (SE)

C.4.1 Batch homogeneity

Ensure that the room temperature is within the specified operating range of the detectors. Prepare and irradiate each of $i = 1$ to n detectors to a specified conventional true value of the personal dose equivalent, H_t, between 0,1 mSv and 1 mSv (preferably to achieve approximately 100 bubbles in the detector) using one of the recommended ISO neutron sources. If the irradiations are done sequentially at a reproducible location, ensure that the room temperature variation during the irradiation period is kept to a minimum (< 2 °C).

Read out each dosemeter in accordance with the manufacturer's recommendation. Evaluate the coefficient of variation, V, for the reading, M_i, for the n dosemeters and show that it does not exceed 25 %.

C.4.2 Reproducibility

Ensure that the room temperature is within the specified operating range of the detectors (20 °C to 40 °C). Prepare and irradiate each of the n detectors of C.4.1 to a specified conventional true value of the personal dose equivalent H_t of 1 mSv or less and repeat this 10 times. The room temperature during irradiation should not vary by more than 2 °C. Read the detectors out in accordance with the manufacturer's recommendation.

For each of the $i = 1$ to n detectors, determine the $j = 1$ to 10 readings, $M_{i,j}$, the arithmetic mean, $\bar{M}_j$, and the experimental standard deviation, s_j. Show that for each of the $i = 1$ to n dosemeters, the criterion in Equation (C.31) is met:

$$\left(s_j + l_{s,i} \right) / \bar{M}_i \leqslant 0,25 \qquad \text{(C.31)}$$

where the $l_{s,i}$ are calculated in accordance with Equation (B.3).

C.4.3 Linearity

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n dosemeters each and irradiate them to a conventional true value of personal dose equivalents, $H_{t,j}$, within the range of 0,1 mSv to 1 mSv.

Read out, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, calculate the arithmetic mean, $\bar{H}_j$, for each lot j and the respective experimental standard deviations, s_j. Show that for each personal dose equivalent, $H_{t,j}$, the criterion in Equation (C.32) is met:

$$0,75 \leqslant \left(\bar{H}_j \pm l_j \right) / H_{t,j} \leqslant 1,25 \qquad \text{(C.32)}$$

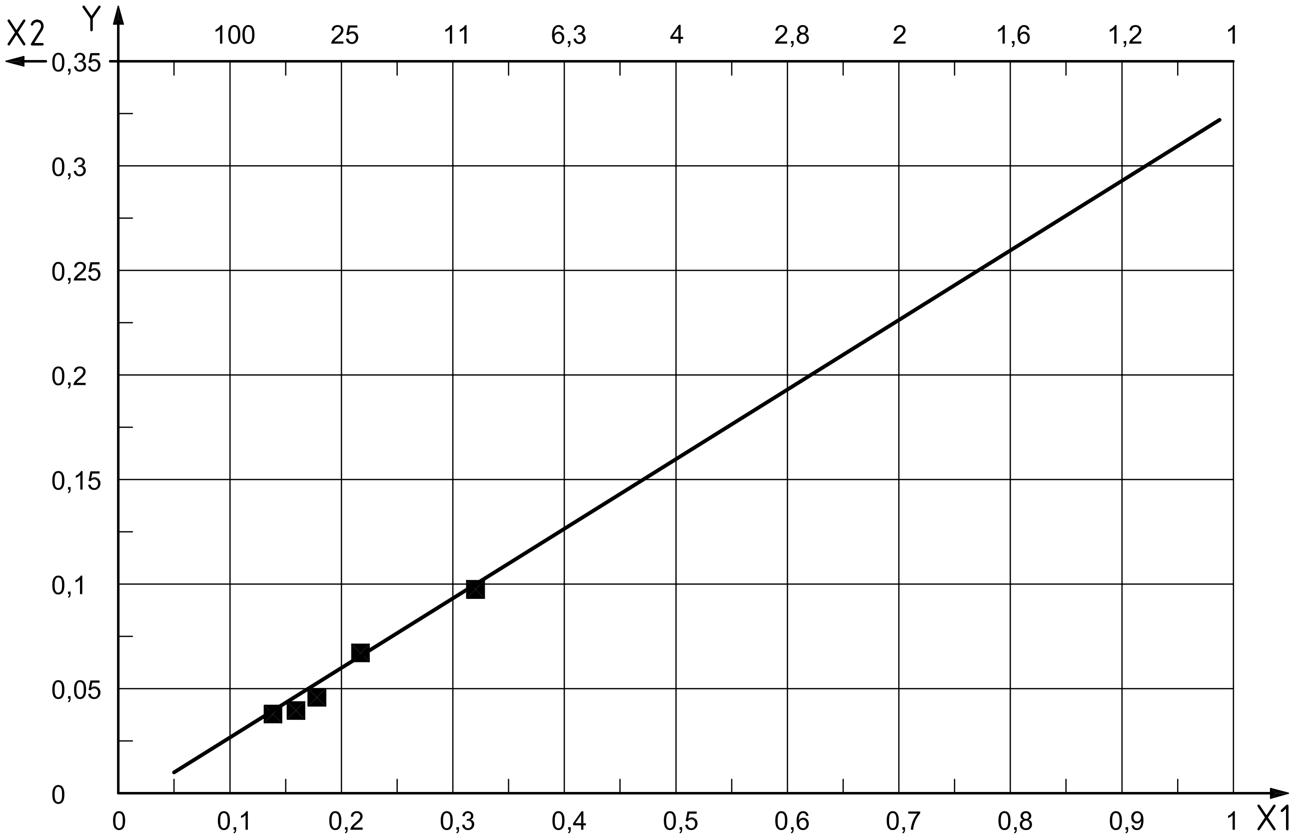
where the l_j are calculated in accordance with Equation (B.2).

C.4.4 Detection threshold

Prepare three lots numbered $j = 1$ to 3 of $i = 1$ to n detectors. Irradiate lot 1 to a conventional true value of the personal dose equivalent, $H_{t,1}$, choosing neutrons in the energy range where the dosemeter is used. The value of $H_{t,1}$ should be approximately 0,05 mSv.

Irradiate lot 2 to approximately $H_{t,2} = 2\,H_{t,1}$ and lot 3 to approximately $H_{t,3} = 4\,H_{t,1}$. Read the detectors, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each lot j and the respective experimental standard deviations, s_j.

Fit a straight line through the function $s_j / H_{t,j}$ versus $1/\sqrt{H_{t,j}}$. The required uncertainty in personal dose equivalent $H_{t,j}$ defines a point on the straight-line fit, which gives the value of $1/\sqrt{H_{t,j}}$, from which the required value of $H_{t,j}$ can be determined. This value of $H_{t,j}$ is the detection threshold and shall not exceed 0,1 mSv.



Key

X1 $1/\sqrt{1/H_{t,j}}$

X2 $H_{t,j}$

1 relative standard deviation

Figure C.1 — Plot of relative standard deviation on the dose readings, $s_j / \bar{H}_{t,j}$ versus $1/\sqrt{H_{t,j}}$ for the determination of the detection threshold[28]

C.4.5 Ageing

C.4.5.1 Superheated drop detectors

Prepare two lots numbered $j = 1$, 2 of $i = 1$ to n superheated drop detectors. Activate the detectors of the first lot and irradiate them under standard conditions to a conventional true value of the personal dose equivalent, H_t, of less than 1 mSv to produce approximately 100 bubbles. Read the detectors, determine the measured dose equivalent for each detector of the first lot, $H_{i,1}$, and calculate the arithmetic mean, $\bar{H}_1$, and the experimental standard deviation, s_1.

Store the detectors of the second lot in a laboratory away from direct sunlight or other sources of heating, as specified by the manufacturer. Leave the detectors inside their containers for a period of one year.

Repeat the experiment that was carried out on detectors of lot 1 with the detectors of lot 2 under identical conditions. For each of the two irradiations, show that the criterion in Equation (C.33) is met:

$$0{,}85 \leqslant (\bar{H}_j \pm l_j)/H_t \leqslant 1{,}15 \qquad \text{(C.33)}$$

where the l_j are calculated in accordance with Equation (B.2).

C.4.5.2 Bubble detectors

Prepare $i = 1$ to n bubble detectors, activate and irradiate the detectors under standard test conditions to a conventional true value of the personal dose equivalent, H_t, of less than 2 mSv to produce approximately 150 bubbles. Following this first irradiation, read the detectors, determine the measured dose equivalent for each detector, $H_{i,1}$, and calculate the arithmetic mean, $\bar{H}_1$, and the experimental standard deviation, s_1. Recompress the bubbles by screwing the cap back on the detectors 8 h after irradiation. Repeat the experiment j times on a daily basis as per normal work schedule (e.g. 5 days per week).

After continuing the experiment for three months, evaluate the coefficient of variation, V, for the response $\bar{H}_j / H_{t,k}$ of all the measurements j. The coefficient should be less than 25 %.

C.4.6 Residual Signal

Prepare $i = 1$ to n detectors, activate and irradiate the detectors under standard test conditions to a conventional true value of the personal dose equivalent, H_t, of less than 1 mSv to produce approximately 100 bubbles. Reset the detectors in accordance with the manufacturer's recommendation; no bubbles should be present afterwards. Ensure that any new bubbles that may form are not the result of response to natural (i.e. cosmic rays) or radioactive neutron sources.

C.4.7 Stability under various climatic conditions

Prepare $i = 1$ to n detectors. The irradiations are to be performed in controlled temperature environments over the range 20 °C to 40 °C and allow the detectors to reach temperature equilibrium by leaving them in the irradiation area for at least 1 hour. Irradiate the activated detectors to a conventional true value of the personal dose equivalent, H_t, producing approximately 100 bubbles in each detector.

Read out the detectors in accordance with the manufacturer's recommendation, evaluate the measured dose equivalent for each detector, H_i, and determine the arithmetic mean, $\bar{H}$, and the experimental standard deviation, s. Repeat the experiment j times at different temperatures over the range 20 °C to 40 °C. Show that the criterion in Equation (C.34) is met:

$$0{,}75 \leqslant \left(\bar{H}_j \pm l_j\right)/H_{t,j} \leqslant 1{,}25 \qquad \text{(C.34)}$$

where the l_j are calculated in accordance with Equation (B.2).

C.4.8 Physical damage

Select a lot of $i = 1$ to n detectors. Activate them and then drop them on a representative floor of the working area from a height of 1 m. No more than four bubbles per detector should form.

C.4.9 Energy dependence of response

Prepare m lots numbered $j = 1$ to m of $i = 1$ to n dosemeters and irradiate them with m neutron energies in the applicable energy range for which compliance with this standard is sought. These neutron energies should be taken from ISO 8529-1:2001, Table 2.

Ensure that the irradiations are done under controlled temperature conditions (< 2 °C variation). Activate the detectors and irradiate them on the ISO slab water phantom to a conventional true value of the personal dose equivalent, $H_{t,j}$, producing approximately 100 bubbles in each detector.

Read out the detectors in accordance with the manufacturer's recommendation, evaluate the measured dose equivalent for each detector, $H_{i,j}$, and calculate for each lot j (energy) the arithmetic mean, $\bar{H}_j$, and the experimental standard deviation, s_j. Show that the criterion in Equation (C.35) is met:

$$0{,}75 \leqslant \left(\bar{H}_j \pm l_j\right) / H_{t,j} \leqslant 1{,}25 \qquad \text{(C.35)}$$

The l_j is calculated in accordance with Equation (B.2).

C.4.10 Angle dependence of response

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n detectors. For this test, a series of mono-energetic neutron energies could be used. It is however convenient that the dosemeters are irradiated on an ISO water slab phantom using ^{241}Am-Be, ^{252}Cf or other neutron source according to the methods of production described in ISO 8529-1. The conventional true value of the personal dose equivalent, H_t, shall be at least 1 mSv and the irradiation conditions shall be the following (ISO 8529-3):

- lot 1: normal incidence;
- lot 2: 15° off normal;
- lot 3: 45° off normal;
- lot 4: 60° off normal.

For lots 2 to 4, 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. Determine the conventional true value of the personal dose equivalent employing the appropriate conversion coefficient for the neutrons used in the test at the respective angles j, $H_{t,j}$.

Read out, determine the measured dose equivalent for each dosemeter, $H_{i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the four lots (angles), the respective experimental standard deviation, s_j, and the response, R_j. Show that the criterion in Equation (C.36) is met:

$$0{,}7 \leqslant \left[0{,}25 \sum_{j=1}^{4} \left(R_j / R_1 \right) \right] \pm l \leqslant 1{,}3 \qquad \text{(C.36)}$$

where l for the sum of the ratios is calculated in accordance with Equation (B.5).

C.5 Ion chamber detectors with direct ion storage

C.5.1 Batch homogeneity

Prepare and identically irradiate each dosemeter from a lot of $i = 1$ to n dosemeters to a combined neutron/photon field which gives an apparent photon dose equivalent, $H_{\text{ap},i}$, of about 1 mSv to the photon-sensitive detector element and an apparent photon dose equivalent, $H_{\text{an},i}$, of about 2 mSv to the neutron-sensitive element.

Read out and determine the apparent photon dose equivalent, $H_{\text{a},i} = H_{\text{an},i} - H_{\text{ap},i}$, for each dosemeter and show that the coefficient of variation, V, for the n dosemeters does not exceed 20 %.

C.5.2 Reproducibility

Prepare and identically irradiate each dosemeter from a lot of $i = 1$ to n dosemeters to a combined neutron/photon field which gives an apparent photon dose equivalent, $H_{\text{ap},i}$, of about 1 mSv to the photon-sensitive detector element and an apparent photon dose equivalent, $H_{\text{an},i}$, of about 2 mSv to the neutron-sensitive element. Repeat this 10 times with exactly the same value of the apparent photon dose equivalent, H_{ap}, for each of the n dosemeters.

Read out, determine for each of the $i = 1$ to n dosemeters the $j = 1$ to 10 apparent photon dose equivalent, $H_{\text{a},i,j} = H_{\text{an},i,j} - H_{\text{ap},i,j}$, the arithmetic mean, $\bar{H}_{\text{a},i}$, and the experimental standard deviation, s_i. Show that for each of the $i = 1$ to n dosemeters the criterion in Equation (C.37) is met:

$$\left(s_i + l_{\text{s},i}\right) / \bar{H}_{\text{a},i} \leqslant 0{,}2 \tag{C.37}$$

where the $l_{\text{s},i}$ is calculated in accordance with Equation (B.3).

C.5.3 Linearity

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n dosemeters each and irradiate them with a combined neutron/photon field such that the apparent photon dose equivalent to the neutron sensitive element, $H_{\text{an},i,j}$, is about twice that to the photon-sensitive element, $H_{\text{ap},i,j}$, and where the conventional true values of the personal dose equivalent, $H_{\text{t},j}$, are 1 mSv, 2 mSv, 5 mSv and 10 mSv, respectively.

Read out, determine the apparent photon dose equivalent for each dosemeter, $H_{\text{a},i,j} = H_{\text{an},i,j} - H_{\text{ap},i,j}$, calculate the arithmetic mean, $\bar{H}_j$, for each lot j and the respective experimental standard deviations, s_j. Show that for each apparent photon dose equivalent, $H_{\text{a},i,j}$, the criterion in Equation (C.38) is met:

$$0{,}9 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) / H_{\text{a},i,j} \leqslant 1{,}1 \tag{C.38}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.5.4 Detection threshold

Prepare $i = 1$ to n unirradiated dosemeters. Read out, determine the apparent photon dose equivalent, $H_{\text{a},i,j} = H_{\text{an},i,j} - H_{\text{ap},i,j}$, for each dosemeter and calculate the experimental standard deviation, s. Show that the criterion, expressed in millisieverts, in Equation (C.39) is met:

$$t_n \cdot s \leqslant 0{,}3 \tag{C.39}$$

[27]

where the values for t_n are listed in Table B.2.

C.5.5 Fading

Prepare $i = 1$ to n dosemeters and irradiate them all with a combined neutron/photon field such that the apparent photon dose equivalent of the neutron sensitive element, $H_{\mathrm{an},i}$, is about twice that of the photon-sensitive element, $H_{\mathrm{ap},i}$, and where the conventional true value of the personal dose equivalent, H_{t}, is about 1 mSv. Store the dosemeters under standard test conditions for 90 days. Following storage, read out, determine the apparent photon dose equivalent for each dosemeter, $H_{\mathrm{a},i} = H_{\mathrm{an},i} - H_{\mathrm{ap},i}$, and calculate the arithmetic mean, $\bar{H}$, and the experimental standard deviation, s. Show that the criterion in Equation (C.40) is met:

$$0{,}9 \leqslant \left(\bar{H} \pm l_j\right) \Big/ H_{\mathrm{a},j} \leqslant 1{,}1 \tag{C.40}$$

where l_i is calculated in accordance with Equation (B.2).

C.5.6 Ageing

Prepare and store $i = 1$ to n dosemeters under standard test conditions for 90 days. Following storage, irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source such that the apparent photon dose equivalent of the neutron sensitive element, $H_{\mathrm{an},i}$, is at least 1 mSv. Read out, determine the apparent photon dose equivalent for each dosemeter, $H_{\mathrm{a},i} = H_{\mathrm{an},l} - H_{\mathrm{ap},l}$, and calculate the arithmetic mean, $\bar{H}$, and the experimental standard deviation, s. Show that the criterion in Equation (C.41) is met:

$$0{,}9 \leqslant \left(\bar{H} \pm l_j\right) \Big/ H_{\mathrm{a},i} \leqslant 1{,}1 \tag{C.41}$$

where l_i is calculated in accordance with Equation (B.2).

C.5.7 Exposure to radiation other than neutrons

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters and irradiate them with a ^{241}Am-Be or ^{252}Cf neutron source such that the apparent photon dose equivalent of the neutron sensitive element, $H_{\mathrm{an},i}$, is between 1 mSv and 2 mSv. In addition, irradiate the second lot with 3 mSv of photon radiation from a ^{137}Cs source.

Read out, determine the apparent photon dose equivalent for each dosemeter, $H_{\mathrm{a},i,j} = H_{\mathrm{an},i,j} - H_{\mathrm{ap},i,j}$, and calculate the arithmetic mean of the reading, $\bar{H}_i$, and the experimental standard deviation, s_j, for the two lots. Show that the criterion in Equation (C.42) is met:

$$0{,}8 \leqslant \left(\bar{H}_1 / \bar{H}_2\right) \pm l \leqslant 1{,}2 \tag{C.42}$$

where l for the quotient of the arithmetic means is calculated in accordance with Equation (B.5).

C.5.8 Stability under various climatic conditions

Prepare two lots numbered $j = 1$ and 2 of $i = 1$ to n dosemeters each. Store both lots for 24 h under standard test conditions. Irradiate lot 1 to a combined neutron/photon field such that the apparent photon dose equivalent of the neutron sensitive element, $H_{\mathrm{an},i}$, is about twice that of the photon-sensitive element, $H_{\mathrm{ap},j}$. Store both lots 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. After waiting for 2 h, irradiate lot 2 in the same way as lot 1.

Read out, determine the apparent photon dose equivalent, $H_{a,i,j} = H_{an,i,j} - H_{ap,i,j}$, for each dosemeter and calculate the arithmetic mean, $\bar{H}_j$, and the experimental standard deviation, s_j, for the two lots. Show that for each lot the criterion in Equation (C.43) is met:

$$0,9 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) / H_{a,i,j} \leqslant 1,1 \tag{C.43}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

C.5.9 Energy dependence of response

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n dosemeters and irradiate them with four neutron energies taken from of ISO 8529-1:2001, Table 2, in the applicable energy range for which compliance with this standard is sought. The dosemeters shall be irradiated on the ISO slab water phantom to a conventional true value of the personal dose equivalent, H_t, of at least 1 mSv, such that the apparent photon dose equivalent of the neutron detector element is at least twice that of the photon detector element.

Read out, determine the apparent photon dose equivalent for each dosemeter, $H_{a,i,j} = H_{an,i,j} - H_{ap,i,j}$, apply the relevant calibration procedure to calculate the neutron personal dose equivalent, H_j, and calculate the arithmetic mean, $\bar{H}_j$, for each of the four lots (energies) and the respective experimental standard deviation, s_j. Show that the criterion in Equation (C.44) is met:

$$0,5 \leqslant \left(\bar{H}_j \pm l_{i,j}\right) / H_t \leqslant 1,5 \tag{C.44}$$

where the $l_{i,j}$ are calculated in accordance with Equation (B.2).

NOTE These are the minimum requirements to fully comply with the standard. It is possible to use additional reference neutron radiation energies and their use is encouraged.

C.5.10 Angle dependence of response

Prepare four lots numbered $j = 1$ to 4 of $i = 1$ to n dosemeters. For this test, a series of mono-energetic neutron energies could be used. It is however convenient that the dosemeters are irradiated on an ISO water slab phantom using a ^{241}Am-Be or ^{252}Cf neutron source or other neutron sources according to the methods of production described in ISO 8529-1. The conventional true value of the personal dose equivalent, H_t, shall be at least 1 mSv and the irradiation conditions shall be the following (ISO 8529-3):

lot 1: normal incidence;

lot 2: 15° off normal;

lot 3: 45° off normal;

lot 4: 60° off normal.

For lots 2 to 4, 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. Determine the conventional true value of the personal dose equivalent employing the appropriate conversion coefficient for the neutrons used at the respective angles j, $H_{t,j}$.

Read out, determine the apparent photon dose equivalent for each dosemeter, $H_{a,i,j}$, and calculate the arithmetic mean, $\bar{H}_j$, for each of the four lots (angles), the respective experimental standard deviation, s_j, and the response, R_j. Show that the criterion in Equation (C.45) is met:

$$0,7 \leqslant \left[0,25 \sum_{j=1}^{4} \left(R_j / R_1\right)\right] \pm l \leqslant 1,3 \tag{C.45}$$

where l for the sum of the ratios is calculated in accordance with Equation (B.5).

Annex D
(informative)

Irradiation conditions

Reference neutron sources, as specified in ISO 8529-1, that can be traced back to appropriate primary and secondary standards shall be used for type and quality testing of detectors and dosemeters. Radionuclide neutron sources are specified in ISO 8529-1:2001, Table 1, whilst nearly mono-energetic neutron radiations primarily used for determining or testing the energy response of neutron detectors and dosemeters are given in ISO 8529-1:2001, Table 2. These “mono-energetic” neutron sources are available only at highly specialized and well-equipped laboratories staffed with experts in radiation spectroscopy. Generally, these laboratories are already certified by national bodies or are recognized as having the required expertise to investigate the properties of neutron detectors and dosemeters.

Irradiation conditions that shall be observed for the calibration of dosemeters are described in ISO 8529-2 and should also be followed in the type and quality testing of neutron detectors and dosemeters. In particular, the calibration facility should meet the following specifications.

— The total neutron scatter from the floor, walls and ceiling of the room should be kept such that its contribution to the dose equivalent intended to be delivered is smaller than 10 %. Therefore, table and supports should have a minimum mass and not be made of material containing hydrogen. Corrections for scattered neutrons can be made using one of several techniques described in ISO 8529-2.

— If several dosemeters are irradiated together on the same phantom, the distance between them should be sufficiently large that the mutual influence on their reading should be such that the difference in the readings of a dosemeter irradiated together with other dosemeters and the same dosemeter irradiated alone in the same position is less than 3 %.

— In order to subject several dosemeters to the same value of the calibration quantity, their supports should be placed on the same dose rate contour. If sufficient homogeneity cannot be achieved, the support may be made to rotate around the source.

When the dosemeter is calibrated or tested on the ISO water slab phantom, it should be positioned with its back face in contact with the phantom and the radiation impinging perpendicularly onto the surface of the dosemeter, except in the case where the angle dependence of the response is determined. The “source to dosemeter” distance is defined as the distance from the equivalent point source to the geometric centre of the sensitive volume of the dosemeter. The necessary neutron fluence-to-dose equivalent conversion coefficients $h_{\mathrm{p}\Phi}(10;E,\alpha)$ are given in ISO 8529-3 for both radionuclide neutron sources and nearly mono-energetic neutron radiations as specified in ISO 8529-1.

Simulated workplace neutron fields as specified and produced in accordance with the methods described in ISO 12789 can also be chosen for testing and calibration, provided these spectra are sufficiently characterized in term of their spectral fluence. This will permit the establishment of a fluence-to-dose equivalent conversion coefficient for the spectrum of interest and define reference dose equivalents at the calibration position. Simulated workplace neutron fields are important in practical radiation protection because they closely resemble neutron fields encountered in routine radiation protection. However, for type tests of angle dependence, simulated workplace neutron fields are only recommended for thermoluminescence albedo dosemeters. Complete information on these fields and the “field” calibration conditions shall be contained in adequate certification documents.

Annex E
(informative)

Performance of neutron dosemeters

All tests are performed on a specified number of dosemeters randomly selected. The detectors shall be chosen from a single production batch, i.e. from one emulsion number in the case of the nuclear track emulsion or material from the same sheet of material in the case of the solid-state nuclear track detectors.

The number of dosemeters used in each test shall be such to demonstrate that the performance requirements are met at the 95 % confidence level. The performance tests proposed take in consideration the particular features of the detectors used. Hence, in the case of the nuclear emulsion and the solid state nuclear track detector, a test on reproducibility is meaningless, as the detectors cannot be reused. On the other hand, the following tests are pertinent to all dosemeters.

Batch homogeneity is determined by observing the variability among the readings of dosemeters subjected to the same value of the calibration quantity under identical conditions, including laboratory and operator.

The read out value of a dosemeter should be linearly related to the personal dose equivalent, $H_p(10)$, over its whole useful dose range.

The detection threshold of any detector is a function of the variability of the background that shall be determined for each batch of detectors or dosemeters.

Temperature, humidity and light influence the response of most dosemeters. Tests with respect to temperature and humidity are performed in climatic chambers. To produce 1 000 W/m^2 of light, use an apparatus which produces light where the spectrum corresponds to that of bright sunlight (295 nm to 769 nm). This is achieved, for example, with a xenon lamp equipped, if necessary, with appropriate filters or by using a daylight fluorescent lamp.

NOTE 1 000 W/m^2 of bright sunlight includes nominally 60 W/m^2 of U.V.

In addition to the angle dependence of the response, the variation in response to personal dose equivalent, $H_p(10)$, with neutron energy is one of the most important performance parameters of the dosemeters to be tested as all known personal neutron dosemeters show a strong dependence of response with neutron energy.

E.1 Nuclear track emulsions

The nuclear track emulsion (NTE), the oldest passive method for neutron detection, is used in personal dosimetry for persons working with radioactive neutron sources and in stray neutron fields outside the biological shielding around accelerators where neutron energies reach up to the maximum energy of the primary beam. The nuclear emulsion is no longer employed around nuclear power reactors where neutron energies are mostly below the detection threshold of the detector.

The loss of latent information or fading with time is the greatest problem in nuclear track emulsions. In order to reduce the fading to a minimum, the nuclear emulsion is, before use, generally desiccated in dry nitrogen and sealed in an air- and moisture-proof pouch called a film packet. The test on fading checks the stability of the latent image under normal test conditions and should assure that the dosimetric information stored stays sufficiently stable during a normal wearing period.

The packaging and the development of the nuclear track emulsion as well as the scanning equipment used influence the performance.

Since fading of nuclear tracks is strongly influenced by temperature and humidity, the quality of the air- and water-tight pouch used to seal the nuclear track emulsion shall be checked at higher temperature and humidity, i.e. conditions that correspond to the most adverse practical wearing practices of the dosemeter.

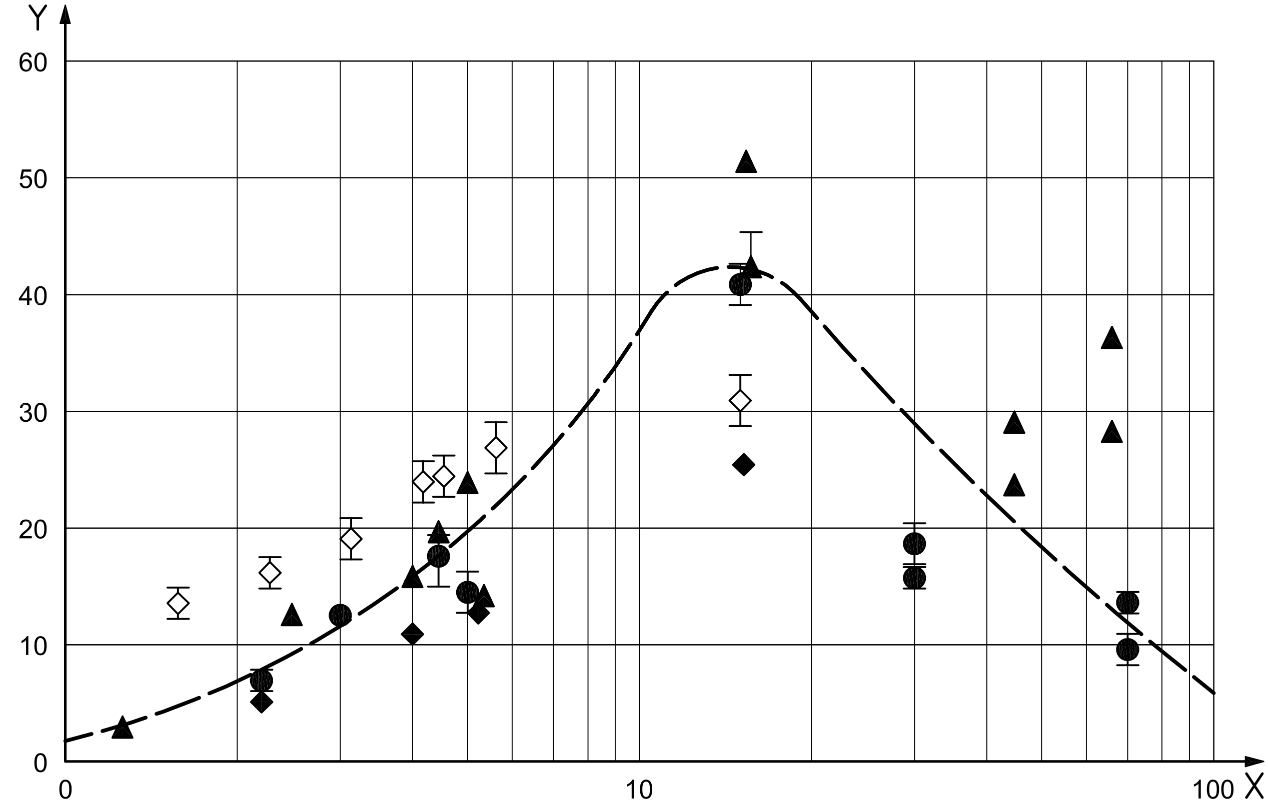
Nuclear track emulsions are carried as personal dosemeters in radiation fields containing photons. A fogging of the emulsion by an important exposure to photons will make the scanning of recorded neutron tracks difficult. For a reasonable exposure to photons, generally in mixed neutron-gamma radiation fields, the loss of information for the neutron component should be negligible.

The film package shall be light-tight and shall be tested accordingly.

Due to the fact that in the case of the nuclear track emulsion at least 100 tracks per dosemeter must be counted to reach a sufficiently low stochastic uncertainty, it is inconvenient to use too many dosemeters. However, all tests should be performed with lots comprising at least five dosemeters.

The tests on the angle and the energy dependence of the response shall prove the compliance of the nuclear track emulsion as a dosemeter measuring the quantity personal dose equivalent, $H_p(10)$, with respect to angle and energy of a neutron exposure with sufficient accuracy.

For nuclear track emulsions, the useful neutron energy range starts between 500 keV and 1 MeV with its response to personal dose equivalent rising to a maximum at 14 MeV, as shown in Figure E.1.



Key

X energy, MeV

Y tracks, $mm^{-2} \cdot mSv^{-1}$

NOTE Open symbols are taken from Reference [4], whilst solid symbols are from Reference [13]. It is evident that for tests, only those neutron sources in the energy range from 2 MeV to 5 MeV and chosen from ISO 8529-1 are meaningful and should be used. However, for convenience, all tests could be made with neutrons from readily available ^{241}Am-Be or ^{252}Cf sources, except the one on energy response.

Figure E.1 — Energy response for the nuclear track emulsion in tracks per mm^2 and per mSv

Due to the energy threshold, nuclear track emulsions should be used as dosemeters only in neutron fields with mean energies well above 1 MeV where, in the energy range from 2 MeV to 5 MeV, the response stays within ± 50 %. However, if nuclear track emulsions are carried as dosemeters in neutron fields that differ considerably from this energy range, such as the energies encountered outside the main shield of high-energy accelerators, in-field calibrations in those realistic workplaces are necessary to determine practical conversion coefficients between the number of tracks recorded and the personal dose equivalent accumulated.

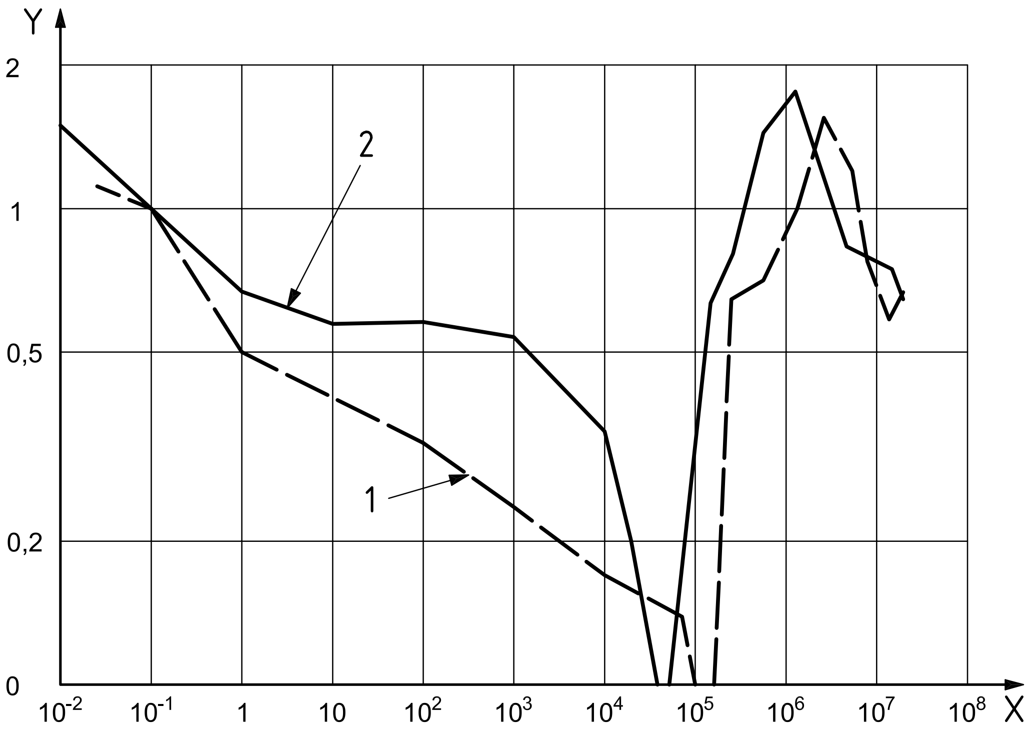
E.2 Solid state nuclear track detectors

Solid state nuclear track detectors (SSNT) use plastic material like polycarbonate or polyallyldiglycol carbonate as a detector. They have successfully replaced the NTE in lower energy neutron fields and are increasingly employed in stray fields around accelerators.

Solid state nuclear track (SSNT) detectors shall be subjected to the preparation, etching and reading procedures that are recommended by the manufacturer unless otherwise justified in writing. SSNT detectors are prepared in the same holders and results are analysed in the same fashion as used for personal dosimetry unless otherwise stated.

In the case of SSNT, batch homogeneity is an important parameter. The variation in response to neutrons between several sheets of material of the same production batch shall be checked and even across one sheet the response can change. The response of SSNT detectors is sensitive to UV and humidity, and the time elapsed since manufacture can also affect their response and is a factor to be understood for a particular type of SSNT material. In addition, sheets of material shall be well protected against the influence of an exposure to radon.

The analysis of SSNT detectors involves the use of caustic chemicals and, in case of electrochemical etching, high voltages, hence proper safety precautions should be observed.



Key

X energy, eV

Y personal equivalent dose response, normalized to the Am-Be source

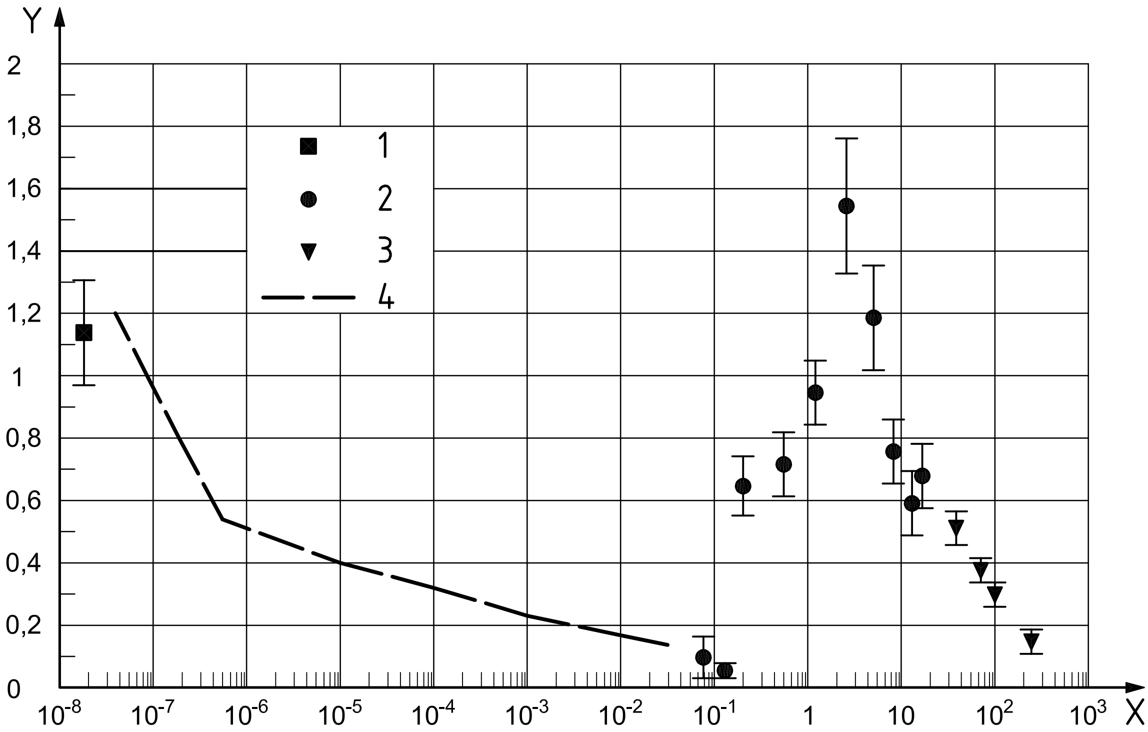
1 chemical etch[7]

2 electrochemical etch[9]

NOTE Curves are normalized to 1 mSv^{-1} for neutrons from an Am-Be source. Electrochemical etch processes result in lower fast-neutron thresholds, but the threshold is also strongly dependent on the read-out method[22].

Figure E.2 — Energy dependence of the personal dose equivalent response for two operational etched-track dosimetry systems using PADC and appropriate converters

SSNT detectors without converter typically have a useful energy response beginning at approximately 200 keV to beyond 20 MeV. Their energy response is greatly influenced by the etching technique in particular the high-voltage when electrochemical etching is applied. As can be seen from Figure E.2, increasing the voltage enhances considerably the response in the energy range from 0,1 MeV to 1 MeV. SSNT detectors with converters for thermal neutrons can give some information on the neutron spectrum if the readings for thermal and fast neutrons are separated. The result of these readings can be used in an algorithm to correct for the energy dependence of the dosemeter. The response of chemically etched SSNT detectors with converters for thermal and fast neutrons is shown in Figure E.3. Usually, SSNT detectors are calibrated with a spontaneous fission source (average energy about 2,5 MeV) or a convenient (α,n)-source (average energy about 5 MeV). For most moderated fission neutron and neutrons from (α,n)-sources encountered in workplaces, SSNT detectors perform adequately as neutron dosemeters with little correction. Often low energy neutrons account for only 10 % or less of the dose equivalent. Therefore, systems with converters for thermal neutrons are not always required. For neutron fields with a substantial high-energy neutron component, greater than about 5 MeV, an additional field correction is needed to account for the drop in SSNT detector response in this region. As with the use of most neutron detectors, some knowledge of the neutron spectrum in the stray field is required such that SSTN detectors can be properly used as personal dosemeters.



Key

X energy, MeV

Y response normalized to Am-Be

1 thermal neutrons

2 mono-energetic neutrons

3 high-energy spectra

4 calculated response

Figure E.3 — Energy response for $H_p(10)$ **of chemically etched SSNT detectors with converters for thermal** (PE/^{6}Li) **and fast** (PE) **neutrons** [7]

E.3 Thermoluminescence albedo dosemeters

Thermoluminescence albedo dosemeters (TLAD) are widely used for neutron personal dosimetry. As detectors they employ thermoluminescent materials (TL) containing nuclides such as ^{6}Li or ^{10}B showing a high response to thermal neutrons. However, the response of these nuclides decreases strongly with increasing neutron energy. The dosimetry of higher energy neutrons nevertheless becomes possible when thermal-neutron-sensitive thermoluminescent materials are carried on the human body where they will respond to low energy neutrons that are scattered from the body surface as the result of the moderation of fast neutrons within the body. These scattered neutrons are called albedo neutrons. Since TL materials are also sensitive to photons, dosemeters generally incorporate pairs of detectors, i.e. one detector with a response to neutrons (e.g. ^{6}LiF) and photons whilst practically the other detector is sensitive only to photons (e. g. ^{7}LiF). Such a combination permits the dosimetry of both neutrons and photons in mixed radiation fields.

Thermoluminescent detectors shall be subjected to the annealing, cleaning and handling procedures that are recommended by the manufacturer, or to the procedures specified by the processor.

TLADs show a strong dependence of response to personal dose equivalent with neutron energy and this can be determined using nearly mono-energetic neutron radiations chosen from ISO 8529-1. However, due to their pronounced energy dependence, TLADs have to be evaluated on the basis of the neutron energy and angle distributions prevailing in the neutron field of the environment in which they are worn. Hence, they are either calibrated in-field or their readings are modified using correction factors. These factors are generally derived in one of the following three ways, or using a combination of the three methods.

a) The correction factors are based on the relative readings of detector elements of the dosemeter combined with an *a priori* information on the type of environment[23].

b) The correction factors are based on the results of environmental surveys[12].

c) The correction factors are based on the relationship between the reading of a dosemeter irradiated on a phantom in the workplace environment, and the measuring result of a wide range neutron survey instrument[5].

E.4 Superheated emulsions

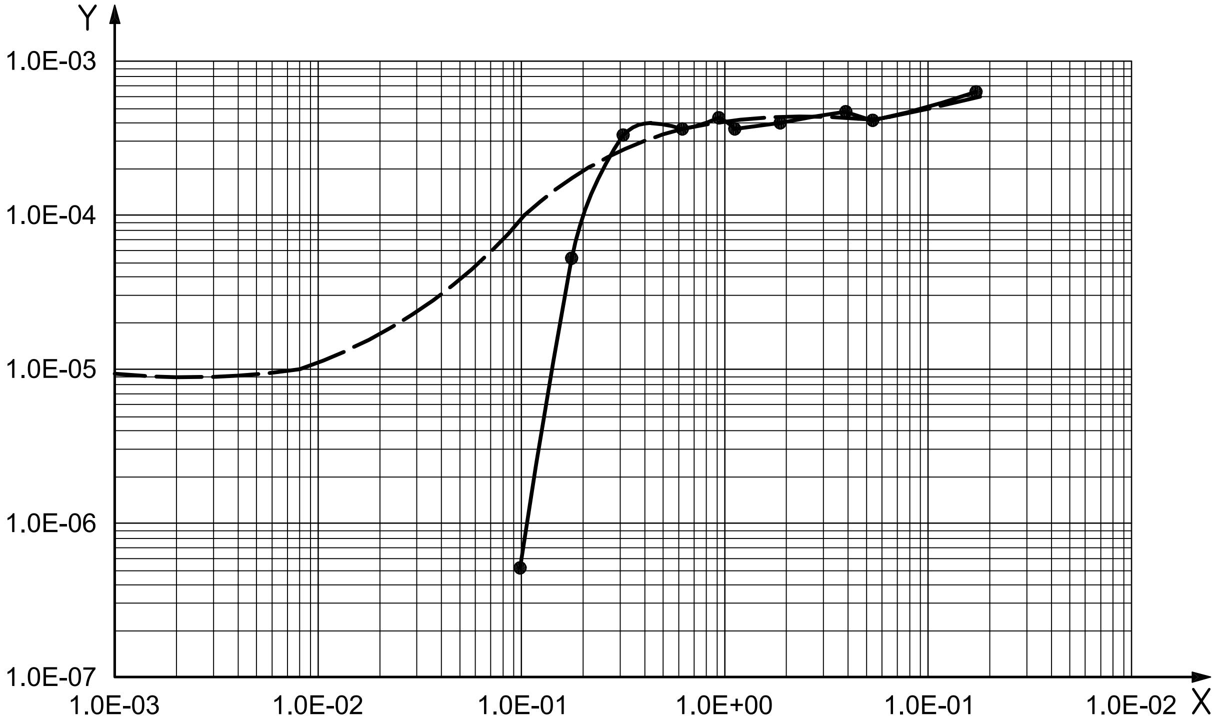
Superheated emulsions (SE), available as bubble detectors (BD) and superheated drop detectors (SDD), are a recent addition to the group of passive neutrons dosemeters. These detectors consist of a visco-elastic matrix in which superheated halocarbon droplets are homogeneously dispersed. The metastable droplets vaporize into bubbles when they are nucleated by neutron-induced charged particles.

The superheated emulsions (SE) should be within the warranty period for good detector operation specified by the manufacturer. Detectors tested should be from the same batch.

Dosemeters shall be subjected to the activation, reading and resetting procedures that are recommended by the manufacturer unless otherwise justified in writing. Dosemeters are prepared and analyzed in the same fashion as used for personal use unless otherwise stated.

Superheated emulsions can be quality tested with neutrons from commonly available ^{241}Am-Be-sources, except when determining their response (type test) as a function of neutron energy where neutron sources are chosen from ISO 8529-1. Details of irradiations and corrections for scattering are given in ISO 8529-2, which recommends setting the distance between the front face of the phantom and the source centre to 75 cm. As the sensitivity of SE detectors to low energy neutrons is very small, they may be irradiated for many of the tests on a phantom or free in air. If detectors are irradiated simultaneously, ensure that the dose-rate at the various detector locations is identical or the variations of dose with location are known.

The Figure E.4 shows the measured energy response of bubble detectors. Their response follows the conversion coefficient for personal dose equivalent of neutrons above 200 keV extremely well.



Key

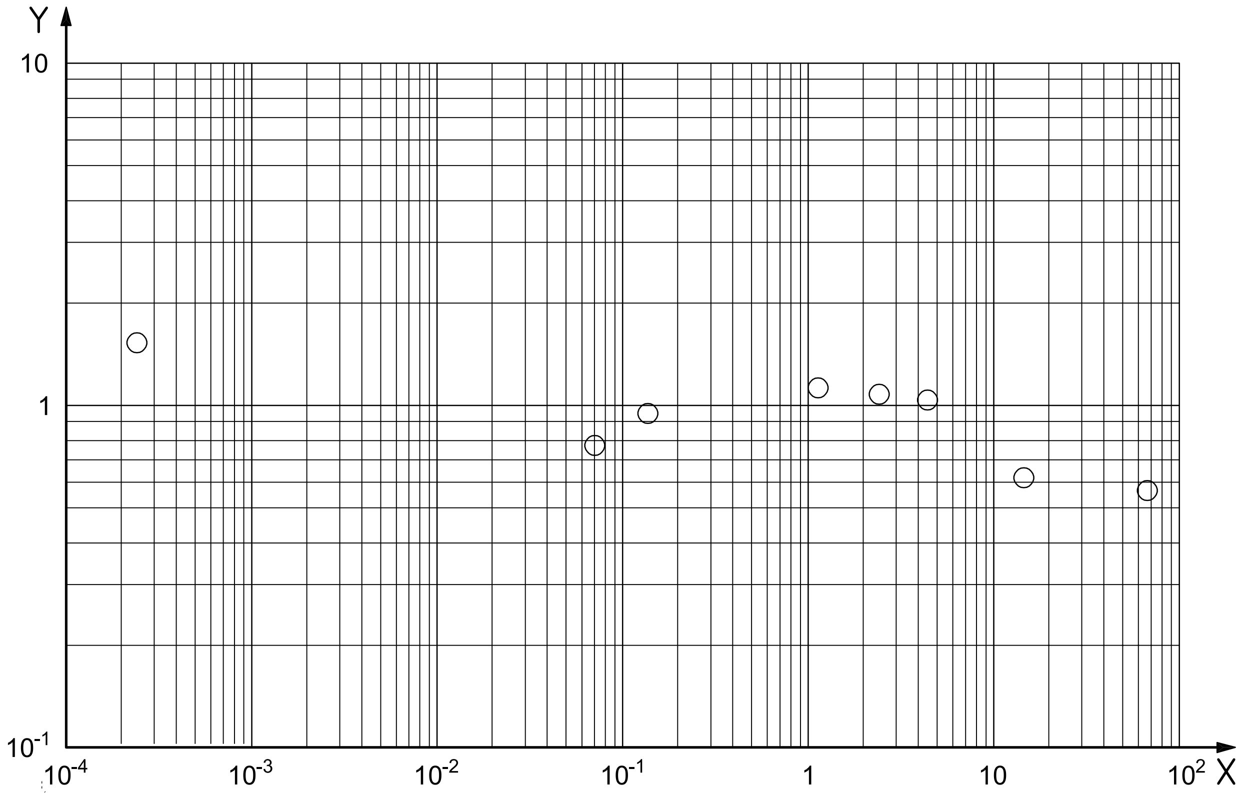
X neutron energy, MeV

Y response, number of bubbles per square centimetre and conversion coefficient μSv·cm²

● experimental data points[29]

Figure E.4 — Comparison of bubble detector response with personal dose — Relative response of bubble detectors compared with the conversion coefficient $h_{p\Phi}(10;E,0°)$ **in** μSv cm² [21], [22]

Figure E.5 shows the personal dose equivalent response of superheated drop detectors.



Key

X neutron energy, MeV

Y personnal dose equivalent response

O data points

Figure E.5 — Personal dose equivalent response of superheated drop detectors based on Freon-12™ **as a function of neutron energy**[30]

E.5 Ion chamber detectors with direct ion storage

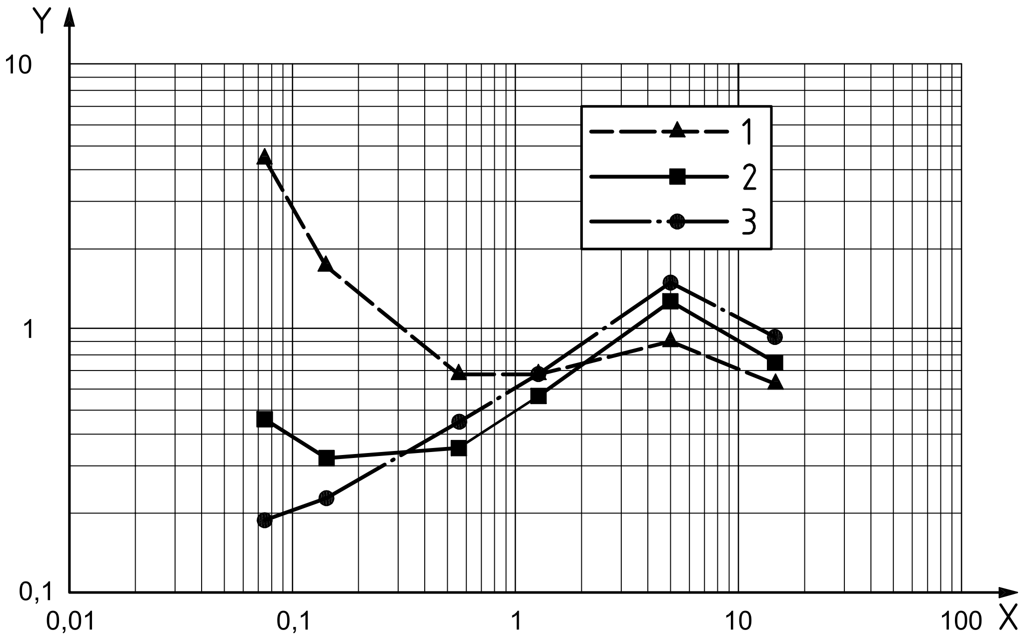
Two ionization chambers, where one detector has a high and the other a low sensitivity to neutrons, are routinely used in neutron therapy for the determination and separation of absorbed dose components in human tissue from photons and neutrons. The principle of direct ion storage (DIS) has increased the sensitivity of the double-chamber method such that it made it possible to operate neutron personal dosemeters.

Ionization chambers are sensitive to both neutrons and photons. Therefore, the application of ion chamber detectors with direct ion storage (DIS) to neutron dosimetry requires a double-chamber system for the separation of the neutron from the photon dose component where one detector has a high and the other a low neutron sensitivity. The difference between the two signals is interpreted as a neutron dose. The energy dependence for photons of the two chamber types must be almost equal to obtain good photon discrimination.

The neutron response, R, of the detector system used for personal dosimetry is calculated according to the following formula interpreting the signal (reading) of each of the chambers as a photon dose, H_a, using their respective calibration with ^{137}Cs as given in Equation (E.1):

$$R = \left(H_{an} - H_{ap}\right) / H_{p,t}(10) \quad \text{(E.1)}$$

H_{an} is the apparent photon dose of the neutron and photon sensitive detector, H_{ap} is the photon dose of the photon sensitive detector and $H_{p,t}(10)$ the conventional true value of the personal neutron dose equivalent. The energy dependence of the response of ion chamber detectors is greatly influenced by the material the ion chamber walls are made of. An example is given in Figure E.6.



Key

X neutron energy, MeV

Y neutron response normalized to Am-Be response

1 10 % BN-Gr (BN: boronitrite, Gr: graphite)

2 4 % $LiNO_3$-Gr

3 0,1 % BN-Te-Gr (TE: Teflon®)

NOTE Angle = 0°

Figure E.6 — $H_p(10)$ energy dependence of the response of ion chamber detectors with different wall materials[8]

Annex F
(normative)

Conversion tables

Table F.1 — Conversion coefficient $h_{p\Phi}(10;E,\alpha)$ from neutron fluence Φ to personal dose equivalent $H_p(10)$ in the ICRU tissue slab phantom for mono-energetic and parallel neutron radiation (expanded field)

(Values are in pSv·cm^2.)

Neutron energy keV	**Angle of incidence**			
	0°	15°	45°	60°
Thermal	11,4	10,6	6,61	4,04
2	8,72	8,22	5,43	3,46
24	20,2	19,9	13,6	7,85
144	134	131	102	69,9
250	215	214	173	125
565	355	349	313	245
1 200	433	427	412	355
2 500	437	434	441	410
2 800	433	431	441	412
5 000	420	418	435	409
14 800	561	563	572	576
19 000	600	596	614	620

NOTE Taken from ISO 8529-3: 1998, Table 3.

Table F.2 — Conversion coefficient $h_{p\Phi}(10;E,\alpha)$ from neutron fluence Φ to personal dose equivalent $H_p(10)$ in the ICRU tissue slab phantom for parallel neutron radiation (expanded field)

(Values are in pSv·cm^2.)

Neutron source	**Angle of incidence**			
	0°	15°	45°	60°
^{252}Cf (D_2O-moderated)	110	109	102	87
^{252}Cf	400	397	389	346
^{241}Am-B (α, n)	426	424	431	399
^{241}Am-Be (α, n)	411	409	415	383

NOTE Taken from ISO 8529-3: 1998, Table 4.

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