

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Radiation protection instrumentation – Neutron ambient dose equivalent
(rate) meters**

**Instrumentation pour la radioprotection – Appareils de mesure de l'équivalent
de dose ambiant neutron (ou de son débit d'équivalent de dose)**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

RADIATION PROTECTION INSTRUMENTATION – NEUTRON AMBIENT DOSE EQUIVALENT (RATE) METERS

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International Standard 61005 has been prepared by subcommittee 45B: Radiation protection instrumentation, of IEC technical committee 45: Nuclear instrumentation.

This third edition cancels and replaces the second edition of IEC 61005 issued in 2003 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) upper neutron energy of the instruments covered by the standard is increased to 20 MeV;
- b) requirement for the variation of the relative response due to neutron energy is modified;
- c) a clause for additivity of the indicated value (neutron dose/dose rate) is introduced;
- d) a clause and requirement for Monte Carlo calculation of the instrument response are introduced;
- e) a clause and requirement for the software for generation of the measured values are introduced;
- f) environmental testing methods and requirements are referred to IEC 62700;

g) influence quantities of type S and F are introduced.

The text of this standard is based on the following documents:

FDIS	Report on voting
45B/792/FDIS	45B/797/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

RADIATION PROTECTION INSTRUMENTATION – NEUTRON AMBIENT DOSE EQUIVALENT (RATE) METERS

1 Scope

This International Standard is applicable to assemblies designed to measure the ambient dose equivalent (rate) due to neutron radiation in fields that contain neutrons with energies below 20 MeV, and which comprise at least:

- a) a detection assembly, which may, for example, consist of a detector probe for thermal neutrons and an arrangement of neutron moderating and absorbing media surrounding the detector;
- b) a measuring assembly with a display for the measured quantity, which may be incorporated into a single assembly with the detector or connected to it by means of a flexible cable.

Instruments with energy range up to 20 MeV are covered by this standard. If the instrument also provides indication of the neutron dose, it should meet the neutron dose requirements stated in this standard.

No tests are specified in this standard for performance requirements of assemblies in pulsed radiation fields. It is understood that an assembly designed to meet this standard may not be suitable for use in such fields.

The object of this standard is to specify requirements for the performance characteristics of neutron ambient dose equivalent (rate) meters, and to prescribe the methods of testing in order to determine compliance with this standard. This standard specifies general characteristics, general test procedures, radiation characteristics, electrical, mechanical, safety and environmental characteristics, and also the identification certificate (see 13.2). Requirements and test procedures are also specified for the alarm performance of the neutron ambient dose equivalent (rate) meters, equipped with alarm provisions.

NOTE The response of ambient dose equivalent (rate) meters for neutrons is energy dependent and may deviate considerably from unity. The response in realistic neutron fields, however, is such that the response deviations in different energy ranges tend to offset each other. Consequently, the response in realistic fields is generally much closer to unity.

ISO 12789 specifies a list of appropriate broad-spectrum neutron sources that are suitable for the testing of such (rate) meters. For example, simulated workplace neutron fields from ISO 12789 may be specified by agreement between manufacturer and purchaser to be appropriate for testing when the spectral environment is well defined.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts): *International Electrotechnical Vocabulary* (available at <http://www.electropedia.org>)

IEC 60086-1:2011, *Primary batteries – Part 1: General*

IEC 60086-2:2011, *Primary batteries – Part 2: Physical and electrical specifications*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61187, *Electrical and electronic measuring equipment – Documentation*

IEC 62706, *Radiation protection instrumentation – Environmental, electromagnetic and mechanical requirements*

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 characterising the radiation field*

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

ISO 11929:2010, *Determination of the characteristic limits (decision threshold, detection limit and limits of the confidence interval) for measurements of ionizing radiation – Fundamentals and application*

ISO 12789-1:2008, *Reference radiation fields – Simulated workplace neutron fields – Part 1: Characteristics and methods of production*

ISO 12789-2:2008, *Reference radiation fields – Simulated workplace neutron fields – Part 2: Calibration fundamentals related to basic quantities*

3 Terms and definitions, abbreviations and symbols, quantities and units

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60050-395 apply.

NOTE For sentence clarity and text conciseness in this standard the term “neutron ambient dose equivalent (rate) meter” is abbreviated as “neutron dose (rate) meter”. Whenever the term “neutron dose (rate) meter” appears in this standard it is understood that “neutron ambient dose equivalent (rate) meter” is meant.

3.1.1

alarm

audible, visual, or other signal activated when the instrument reading exceeds a preset value, falls outside of a preset range, when the instrument is unable to function properly (component failure), or when the instrument detects the presence of the source of radiation according to a preset condition

3.1.2

ambient dose equivalent

$H^*(10)$

dose equivalent at a point in a radiation field that would be produced by the corresponding aligned and expanded field, in the ICRU sphere at a depth of 10 mm on the radius opposing the direction of the aligned field ([2], [5]¹)

Note 1 to entry: An instrument that has an isotropic response and is calibrated in terms of $H^*(10)$ will measure $H^*(10)$ in a radiation field that is uniform over the dimensions of the instrument.

¹ Numbers in square brackets refer to the Bibliography.

3.1.3

ambient dose equivalent rate

$H^*(10)$

ratio of $dH^*(10)$ by dt , where $dH^*(10)$ is the increment of ambient dose equivalent in the time interval dt

$$\dot{H}^*(10) = \frac{dH^*(10)}{dt}$$

3.1.4

background level

radiation field in which the instrument is intended to operate, including that produced by naturally occurring radioactive material and cosmic radiation

3.1.5

calibration distance

distance between the reference point of the assembly and the centre of the calibration source

3.1.6

coefficient of variation

v

ratio of the experimental standard deviation s to the arithmetic mean $\bar{H}$ of a set of n indications H_j . It is given by the following formula:

$$v = \frac{s}{\bar{H}} = \frac{1}{\bar{H}} \cdot \sqrt{\frac{1}{n-1} \cdot \sum_{j=1}^n (H_j - \bar{H})^2}$$

3.1.7

conventional quantity value

H_t

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

Note 1 to entry: In this standard the quantity is the dose equivalent (rate).

Note 2 to entry: The term "conventional true quantity value" is sometimes used for this concept.

Note 3 to entry: Sometimes a conventional quantity value is an estimate of a true quantity value.

Note 4 to entry: A conventional quantity value is generally accepted as being associated with a suitably small measurement uncertainty, which might be zero.

[SOURCE: VIM:2008, 2.12]

3.1.8

deviation

D

difference between the indicated values for the same value of the measurand of a dose equivalent (rate) meter, when made under reference conditions and when subject to an influence quantity

$$D = H_i - H_r$$

Where

H_i is the indicated value under the effect of an influence quantity, and

H_r is the indicated value under reference conditions.

Note 1 to entry: The deviation can be positive or negative resulting in an increase or a decrease of the indicated value, respectively.

Note 2 to entry: The deviation is of special importance for influence quantities of Type S.

3.1.9**effective range of measurement**

range of values of ambient dose equivalent (rate) over which the performance of the ambient dose equivalent (rate) meter meets the requirements of this standard

3.1.10**indicated value** H_i

value given by the (digital) indication of the dose (rate) meter in units of dose equivalent or dose equivalent rate

3.1.11**influence quantity**

quantity that is not the measurand but that affects the result of the measurement

Note 1 to entry: For example, temperature of a micrometer used to measure length.

Note 2 to entry: If the effect on the result of a measurement of an influence quantity depends on another influence quantity, these influence quantities are treated as a single one.

[SOURCE: IEC 60050-394:2007, 394-40-27]

3.1.12**influence quantity of type F**

influence quantity whose effect on the indicated value is a change in response

Note 1 to entry: An example is radiation energy and angle of radiation incidence.

Note 2 to entry: “F” stands for factor: The indication due to radiation is multiplied by a factor due to the influence quantity.

3.1.13**influence quantity of type S**

influence quantity whose effect on the indicated value is a deviation independent of the indicated value

Note 1 to entry: An example is the electromagnetic disturbance.

Note 2 to entry: All requirements for influence quantities of type S are given with respect to the value of the deviation D .

Note 3 to entry: “S” stands for sum. The indication is the sum of the indication due to radiation and due to the influence quantity, e.g., electromagnetic disturbance.

3.1.14**lower limit of effective range of measurement** H_0 or $(\dot{H}_0)$

the lowest dose (rate) value included in the effective range of measurement

3.1.15**maximum dose equivalent rate for dose (rate) meters** $\dot{H}_{\max}$

dose rate, specified by the manufacturer, below which the effect of the dose rate on the dose rate reading is within specified limits

3.1.16**measured value** M

value that can be obtained from the indicated value H_i by applying the model function for the measurement

Note 1 to entry: The model function is necessary to evaluate the uncertainty of the measured value according to the GUM (see [3]:2008, 3.1.6, 3.4.1 and 4.1).

Note 2 to entry: An example of a model function is given herein. It combines the indicated value H_i

with the reference calibration factor N_0 , the correction for non-linear response r_n , the l deviations D_p ($p = 1..l$) for the influence quantities of type S, and the m relative response values r_q ($q = 1..m$) for the influence quantities of type F:

$$M = \frac{N_0}{r_n \prod_{q=1}^m r_q} \left[H_i - \sum_{p=1}^l D_p \right].$$

Note 3 to entry: The calculations according to such model function are usually not performed, only in the case that specific influence quantities are well known and an appropriate correction is applied.

Note 4 to entry: If necessary another model function closer to the design of a certain dose (rate) meter may be used.

Note 5 to entry: With the calibration controls adjusted according to the manufacturer's instructions, the reference calibration factor, the correction for non-linear response and all relative response values are set to one and the deviations are set to zero, these settings cause an uncertainty of measurement which can be determined from the measured variation of the response values and the measured deviations. For a dose (rate) meter tested according to this standard, all these data are available.

3.1.17

minimal rated range of use

the smallest range being specified for an influence quantity or instrument parameter over which the dose equivalent (rate) meter shall operate within the specified limits of variation in order to comply with this standard

Note 1 to entry: The minimal rated ranges of the influence quantities dealt with in this standard are given in the second column of Tables 2, 4, 5 and 6.

3.1.18

neutron ambient dose equivalent (rate) meter

assembly intended to measure the ambient dose equivalent dose and/or rate from neutron radiation

3.1.19

neutron dose equivalent response

R_H

ratio, under specified conditions, given by the relation

$$R_H = \frac{R_\Phi}{h_\Phi}$$

Where

R_Φ is the neutron fluence response (see definition 3.1.22) and

h_Φ is the neutron fluence-to-dose conversion coefficient (see definition 3.1.23).

3.1.20

neutron fluence

Φ

quotient of dN by da , where dN is the number of neutrons incident on a sphere of cross-sectional area da :

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

Note 1 to entry: The unit of neutron fluence is m^{-2} .

3.1.21

neutron fluence rate (flux density)

$\dot{\Phi}$

quotient of $d\Phi$ by dt , where $d\Phi$ is the increment of neutron fluence in the time interval dt .

$$\dot{\Phi} = \frac{d\Phi}{dt}$$

Note 1 to entry: The unit of neutron fluence rate is $\text{m}^{-2}\cdot\text{s}^{-1}$.

3.1.22

neutron fluence response

R_{Φ}

ratio, under specified conditions, given by the relation

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

Where

M is the reading by the instrument under test (dosemeter) for the neutron fluence and

Φ is the conventional quantity value of the neutron fluence to which the instrument has been exposed.

Note 1 to entry: The unit of neutron fluence response is m^2 .

3.1.23

neutron fluence-to-ambient dose equivalent conversion coefficient

h_{Φ}

quotient of the neutron ambient dose equivalent, $H^*(10)$, and the neutron fluence, Φ , at a point in the radiation field, undisturbed by the irradiated object

$$h_{\Phi} = \frac{H^*(10)}{\Phi}$$

Note 1 to entry: The conversion coefficients are given in Annex A.

3.1.24

non-linearity

variation of the value of the (relative) response with the dose (rate) being measured

3.1.25

point of test of a dose (rate) equivalent meter

point at which the conventional quantity value is determined and at which the reference point of the dose equivalent (rate) meter is placed for calibration and test purposes

Note 1 to entry: For all tests involving the use of radiation, the reference point of the assembly is placed at the point of test in the orientation indicated by the manufacturer. An exception is the test of variation in response with angle of incidence.

3.1.26

quantity value of ambient dose equivalent (rate)

best estimate of the true ambient dose equivalent (rate), $H_t^*(10)$, used for calibration of the assembly. This value and its uncertainty are determined from a primary or a secondary standard, or by a reference instrument which has been calibrated against a secondary or a primary standard.

Note 1 to entry: Primary or secondary standards for neutron radiation are usually standardized in terms of fluence (rate). For converting the fluence (rate) to the conventional true value of the ambient dose equivalent (rate), the appropriate fluence to ambient dose equivalent conversion coefficients given in Annex A shall be used.

3.1.27

rated range of use of a dose equivalent (rate) meter

range of values of an influence quantity or instrument parameter over which the dose equivalent (rate) meter will operate within the specified limits of variation. Its limits are the maximum and minimum rated values

3.1.28

reference direction

direction in the coordinate system of the dose (rate) meter with respect to which the angle of the direction of radiation incidence is measured in unidirectional fields

[SOURCE: ISO 8529-3:1998, 3.2.7]

3.1.29

reference point of an assembly

physical or virtual mark or marks on the assembly to be used in order to position it at the test point. This mark is usually either the geometric centre of the detector or its effective centre.

3.1.30

reference response

R_r

response for a reference value of the quantity to be measured under reference conditions

$$R_r = \frac{H_r}{H_t}$$

Where

H_r is the corresponding indicated value of the quantity to be measured under reference conditions and

H_t is the conventional quantity value (3.1.7) under reference conditions

Note 1 to entry: The reference response is the reciprocal of the reference calibration factor.

Note 2 to entry: The reference values for the dose (rate) are given in Table 1.

3.1.31

reference standard

standard generally having the highest metrological quality available at a given location or in a given organization from which measurements made are derived

[SOURCE: IEC 60050-395:2014, 395-03-118; IEC 61577-1:2006, 3.1.5; IEC 61577-4:2009, 3.1.5]

3.1.32

relative response

r

quotient of the response R (3.1.22) and the reference response R_r (3.1.30)

$$r = \frac{R}{R_r}$$

3.1.33

response of a radiation measuring assembly

R

ratio, under specified conditions, given by the relation

$$R = \frac{H_i}{H_t}$$

where

H_i is the indicated value of the quantity (3.1.10) measured by the instrument under test and

H_t is the conventional quantity value of this quantity (3.1.7).

3.1.34

standard test conditions

conditions representing the range of values of a set of influence quantities under which a calibration or a determination of response is carried out.

[SOURCE: ISO 4037-3:1999, 3.2.3, modified]

3.1.35

standard test values

value, values, or range of values of an influence quantity or instrument parameter, which are permitted when carrying out calibrations or tests on another influence quantity or instrument parameter.

Note 1 to entry: Under standard test conditions, influence quantities and instrument parameters have their standard test values.

3.2 Test nomenclature

3.2.1

qualification tests

tests, which are performed in order to verify that the requirements of a device specification are fulfilled. Qualification tests are subdivided into type tests and routine tests

3.2.2

type tests

conformity testing on the basis of one or more devices representative of the production

3.2.3

routine tests

tests to which each individual device is subjected during or after manufacture to ascertain whether it complies with certain criteria

3.2.4

acceptance tests

contractual tests to prove to the customer that the device meets certain conditions of its specification

3.2.5

supplementary tests

tests intended to provide supplementary information on certain characteristics of the device

3.3 Abbreviations and symbols

Abbreviations and symbols are provided in Table 8.

3.4 Quantities and units

In this standard, units of the International System (SI) are used². The definitions of radiation quantities are given in IEC 60050-395. The corresponding old units (non-SI) are indicated in brackets.

Nevertheless, the following units may also be used:

- for energy: electron-volt (symbol: eV), $1 \text{ eV} = 1,602 \times 10^{-19} \text{ J}$;
- for time: days (symbol: d), hours (symbol: h), minutes (symbol: min).

Multiples and submultiples of SI units will be used, when practicable, according to the SI system.

4 General test procedure

4.1 Test requirements

All the tests enumerated in the following clauses are to be considered type tests (see 3.2.2). During type tests, all values of influence quantities which are not the subject of the test are fixed within the interval of the standard test conditions.

Nevertheless, some of these tests may, by agreement between manufacturer and purchaser, be considered as acceptance tests.

Reference conditions and standard test conditions are defined in Table 1.

The tests described in this standard may be classified according to whether they are performed under standard test conditions or under other conditions. For those tests carried out under standard test conditions, the values of temperature, pressure and relative humidity at the time of test shall be stated and the appropriate corrections made to give the response under reference conditions.

4.2 Tests performed with variation of influence quantities

4.2.1 General

These tests are intended to determine the effects of variation in influence quantities. The range of variation of each influence quantity and acceptable limits of consequent variation in the indication of an assembly are given in Table 2. The range of variation of influence quantities indicated in Table 2 defines a nominal operating range within which the limits of the variation in indication stated by the manufacturer shall remain. These limits shall in no case exceed those laid down in Table 2.

In order to test the effect of variation in any one of the influence quantities listed in Table 2, all other influence quantities are normally maintained within the limits for standard test conditions given in Table 1, unless otherwise specified in the test procedure concerned.

4.2.2 Tests for influence quantities of type F

These tests may be performed at any value of the quantity to be measured above or equal to $10 \dot{H}_0$ or $10 H_0$. From the result of each test, the respective variation of the relative response r can be determined.

² International Bureau of Weights and Measures: The International System of Units, 8th edition, 2006

It is acceptable that some effects of the influence quantities classified as type F could be regarded as effects produced by type S influence quantities. If these effects are small they shall be ignored in relation to the use of this standard. If during testing larger effects of type S are observed then the respective test shall be performed at a dose value of $10 \dot{H}_0$ or $10 H_0$ and these findings shall be reported in the type test report.

4.2.3 Tests for influence quantities of type S

These tests shall be performed at a value of the quantity to be measured of less than or equal to 10 times the lower limit $\dot{H}_0$ or H_0 of the effective range of measurement, even zero dose (rate) is possible if no other specification is given in the respective subclause and a negative deviation can be excluded. The result of each test is a deviation D .

It is acceptable that some small part of the effects of the type S influence could be regarded as the effects produced by type F influence quantities. If these effects are small they should be ignored in relation to the use of this standard. If larger effects of Type F or significant negative effects are observed during testing, then the respective test shall be performed at a dose value of $10 \dot{H}_0$ or $10 H_0$, and these findings shall be reported in the type test report. Due to the generally lower indicated value when compared to tests for influence quantities of type F the necessary number of measurements may be increased.

4.3 Consideration of non-linearity

The effect of a non-linear response shall be regarded.

Testing should be undertaken in a dose (rate) region where non-linearity is not significant. A practical method is to first undertake a linearity test in order to identify the region of non-linearity, and then perform the other tests in a dose (rate) region where non-linearity is negligible (1 % to 2 %).

4.4 Consideration of several detectors or signals in a dose (rate) meter

If more than one signal or detector is used to evaluate the indicated value, each signal or detector shall be tested separately. Separate tests are necessary only when the different signals are used to evaluate the indicated value in different dose (rate) regions of the measuring range or in different regions of an influence quantity e.g. energy.

4.5 Statistical fluctuations

For any test involving the use of radiation, if the magnitude of the statistical fluctuations of the indication, arising from the random nature of radiation alone, is a significant fraction of the variation of the indication permitted in the test, then sufficient readings shall be taken to ensure that the mean indicated value may be estimated with sufficient precision to demonstrate compliance with the test in question. The recommendations of ISO 11929 should be employed.

The time interval between such readings shall be sufficient to ensure that the indicated values are statistically independent.

4.6 Radiation sources

The reference neutron radiation source shall be as described in ISO 8529-1 and can be one of the following: ^{241}Am -Be radionuclide source, ^{252}Cf spontaneous fission source, ^{252}Cf source moderated by D_2O sphere of 30 cm in diameter or by well defined moderator/filter or accelerator target sources (ISO 8529). For thermal and epithermal neutron reference fields, accelerator target, reactor beams, ^{241}Am -Be or ^{252}Cf sources with well defined moderator/filter arrangements may be used.

The nature, construction and conditions of use of the source shall be in accordance with recommendations of ISO 8529-1, ISO 8529-2, and ISO 8529-3.

The quantity value of the ambient dose equivalent rate from these sources may be obtained from the spectral fluence rate distribution delivered by the source and the fluence-to-ambient dose equivalent conversion coefficients (see Annex A, Table A.1). Average fluence-to-ambient dose equivalent conversion coefficients for five reference sources are given in Annex A, Table A.2. The neutron fluence-to-ambient dose equivalent conversion coefficients employed shall be specified by the manufacturer (see 13.2 e).).

The ambient dose equivalent rate of the photon emission from the source should be significantly less than that due to neutrons, or suitable shielding be used to ensure that this is true at the detector. The response of the device to gamma rays shall be determined with ^{137}Cs or ^{60}Co source and/or with other photon sources if necessary.

4.7 Work place neutron fields

Work place neutron fields may be:

- a) simulated fields specified in ISO 12789 or
- b) other work place environments whose fields are well defined by spectral calculations and/or measurements traceable to or recognized by a primary standards laboratory.

The nature, production and conditions of use of the fields shall be in accordance with the recommendations of ISO 12789.

The conventional true ambient dose equivalent rate at the point of measurement in these fields may be obtained from the spectral fluence rate distribution and the fluence-to-ambient dose equivalent conversion coefficients (see Annex A, Table A.1).

NOTE Survey fields may differ considerably from the reference radiation fields. In order to increase the accuracy of the measurement in such fields, correction factors may be applied to the reading of the instrument; these are calculated from the fluence response of the device, the fluence-to-ambient dose equivalent conversion coefficients, and the spectral fluence of the calibration and the survey field, respectively.

5 General requirements

5.1 Summary of requirements

In Tables 2, 4, 5, and 6 instrument requirements are summarized.

5.2 General characteristics

5.2.1 Effective range of measurement

The effective range of measurement, starting at $\dot{H}_0$ or H_0 shall not be less than the following:

- a) for dose equivalent (rate) meters with an analogue type of display (e.g. linear or logarithmic), one range per order of magnitude from 10 % to 100 % of the scale maximum angular deflection on each scale range, and for dose equivalent (rate) meters with two ranges per order of magnitude from 30 % to 100 % of the scale maximum angular deflection on each scale range;
- b) for dose equivalent (rate) meters with a digital display, from an indication in the second least significant digit up to the maximum indication on each range. As an example, for a display with a maximum indication of 9 999,9, the effective range can extend from 1,0 to 9 999,9 – i.e. four orders of magnitude – or from 3,0 to 9 999,9 – i.e. three and a half orders of magnitude;
- c) for dose equivalent (rate) meters with a digital and scientific display (e.g. $x,yz E \pm ab$) the mantissa shall have three digits at least (for instance 1,00 to 9,99). The maximum

shall define the effective range of measurement (for instance $1,00 \cdot 10^{-7}$ to $9,99 \cdot 10^{-2}$ with the unit $\text{Sv} \cdot \text{h}^{-1}$).

For dose equivalent (rate) meters with more than one scale, the effective range of measurement shall be from 10 % of the lowest scale range to 100 % of the highest scale and all scales shall be arranged to make the total range covered by the effective range of measurement.

When the test methods do not extend over the entire effective range of measurement and any of the observed variations are near the permitted limit, further tests to demonstrate compliance with the requirement in question over the whole effective range of measurement may be necessary. Agreement on supplementary tests shall be reached between the purchaser and the manufacturer.

5.2.2 Minimum range of measurement

The minimum effective range of measurement of dose equivalent rate shall cover at least four orders of magnitude and shall include $10 \mu\text{Sv} \cdot \text{h}^{-1}$ for the measuring quantity $\dot{H}^*(10)$.

The minimum effective range of dose equivalent shall cover at least four orders of magnitude and shall include 0,1 mSv.

5.2.3 Rated range of an influence quantity

The rated range of any influence quantity has to be stated in the documentation. In addition, some rated ranges have to be stated on the instrument, see 5.3.2.

5.2.4 Minimum rated range of influence quantity

The minimum rated range of the specified influence quantity is given in the second column of Tables 2, 4, 5 and 6.

5.2.5 Indication of the assembly

The indication of the assembly shall be in units of ambient dose equivalent (rate), for example in millisieverts (per hour). The indication may be on an analogue type of display or on a digital display. It is recommended that the indication may be read remotely.

5.3 Mechanical characteristics

5.3.1 IP classification

The IP classification shall be stated by the manufacturer according to IEC 60529. The minimum IP requirement for hand-held instruments is given in IEC 62706.

5.3.2 Assembly labels and markings

An assembly for the measurement of neutron ambient dose equivalent (rate) shall be labelled with a specific indication of its intended use.

The following information shall be clearly visible on the dose (rate) meter:

- a) the quantity that is measured;
- b) the effective range of measurement;
- c) the type of radiation (for example neutron) the dose (rate) meter is suitable for;
- d) the rated range of particle energy;
- e) reference point and reference direction (or in the manual);
- f) serial number of the instrument.

5.3.3 Ease of decontamination

The assembly shall be constructed in such a manner as to facilitate decontamination. In order to achieve this, it should, for example, have a smooth non-porous external surface, which is free from crevices, or be usable when placed inside a thin and flexible envelope, provided with transparent parts to allow the instrument scale to be read.

5.4 Interface requirements

The provision of an output connection for a remote readout, which shall be appropriately marked, is recommended (for example for an external counter or integrator, a recorder or a secondary digital display).

If the assembly is equipped with a data processor and memory, an output to an external data device is recommended, for example by a serial data interface.

5.5 Algorithm to evaluate the indicated value

For the type test of multiple detector assemblies according to this standard, the manufacturer shall deliver the evaluation algorithm of the indicated value starting from the signal(s) of the detector(s) and ending at the indicated value. This shall include all the calculations and/or the decision tree.

NOTE This algorithm may be confidential (proprietary) and only be used by the testing laboratory for the purpose of type testing.

6 Radiation detection requirements

6.1 General

All influence quantities dealt with in this clause are regarded as of type F.

NOTE 1 The requirements for the influence quantity *radiation energy and angle of radiation incidence* are given with respect to the reference response R_r under reference conditions (reference radiation and 0° radiation incidence, reference dose and/or dose rate and all the other reference conditions as given in Table 1). The possible reference radiations can be found for neutron radiation in Table 1 of ISO 8529-1:2001. The most used reference radiations are given in Table 1, but it may be necessary to choose other radiations as reference radiation to comply with the requirements for this influence quantity, even an energy value can be chosen as reference condition for which no physical radiation is available. In that case this (virtual) reference radiation is realized by an available reference radiation and the deviation of the response to the (virtual) reference radiation.

NOTE 2 For details regarding the reasons for the non-symmetric limits for the relative response due to radiation energy and angle of radiation incidence see IEC TR 62461.

6.2 Consideration of the uncertainty of the conventional quantity value

The expanded ($k = 2$) relative uncertainty, U_{rel} , of the conventional quantity value of the dose equivalent or dose equivalent rate shall be taken into account and should be less than $\pm 20\%$. This is accounted for by adding U_{rel} to the allowed variation of the relative response. If several tests are to be performed with the same radiation quality, for example, the test for the constancy of the response, only the uncertainty of the ratio of the actual value and the reference value of the dose equivalent (rate) shall be considered. In case of other requirements, the consideration is mentioned in the respective method of test.

6.3 Constancy of the dose rate response, dose dependence and statistical fluctuations

6.3.1 General

The tests for constancy of dose rate response, dose dependence and statistical fluctuations are performed using the same measurement data.

If the manufacturer can show that the technical design of the dose (rate) meter ensures the fulfilment of the requirements on constancy of the dose rate response for a large range of dose rate values, then the number of tests can be reduced.

6.3.2 Requirements

- a) Under standard test conditions, with the calibration controls adjusted according to the manufacturer's instructions, the variation of the relative response due to the non-constancy of the dose rate response shall not exceed -17% to $+25\%$ over the whole of the effective range of measurement for neutron reference radiations chosen. The dose shall be varied over the whole range of dose specified by the manufacturer for dose rate measurements.
- b) The statistical fluctuations of the indication measured as coefficient of variation shall fulfil the requirements given in Table 3.

6.3.3 Test method using sources

- a) Source to be used

For the purpose of this test, the conventional quantity value of the ambient dose equivalent (rate) at the point of test shall be known. The tests shall be performed with reference sources of appropriate activity irradiating the dose (rate) meter free in air as given in Table 1, e.g. $^{241}\text{Am-Be}$ for neutron radiation.

- b) Tests to be performed

The response shall be measured for at least three dose rate values in each order of magnitude of the effective range of measurement of dose rates. These shall be at approximately 20% , 40% and 80% of each full order of magnitude. At different dose rate values, different dose values in the rated range shall be applied as well. In total, n repeated measurements at each of the w dose rate values shall be performed, depending on the effective range of measurement of dose rate. From these measurements of the w response values, the variation of the relative response due to the non-constancy of the response may be determined.

6.3.4 Interpretation of the results of the test using sources

Determine the mean value and the coefficient of variation of the n values of the indication for each of the w dose rate values.

Using the w mean values, the variation of the relative response due to the non-constancy of the response shall not exceed the range from -17% to $+25\%$. Also, using the w values of the coefficients of variation and the values of c_1 and c_2 given in Table 3, show that

- for $(w - 2)$ dose rate values the coefficients of variation are less than c_1 times the limits given in Table 3 and
- for the remaining two dose rate values – which shall not be adjacent – the coefficients of variation are less than c_2 times the limits given in Table 3.

In that case, the requirements a) and b) of 6.3.2 can be considered met.

NOTE 1 The value of c_1 is always smaller than that of c_2 .

NOTE 2 This method ensures that the probability of passing the test is independent of the number w of dose values at which the test is performed. Without applying the factors c_1 and c_2 the probability of passing the test decreases with increasing number w of dose values at which the tests are performed.

NOTE 3 More information on the test procedure is given in [8].

6.3.5 Test procedure with variation of the calibration distance

Several practical procedures are established in ISO 8529-2 to determine the instrument response by employing the reference neutron radiation sources, taking into account the characteristic contribution of scattered radiation and the position of the reference point of the device. The procedures include the determination of indicated values at a series of calibration

distances, where the indicated values may range over one or more orders of magnitude. Response, scatter contribution and geometry parameters are determined by data analytical fitting methods. In this case, any indicated value may count as a point in the respective scale ranges given in 6.4.2. For the determination of the relative error in the respective scale range, the fitted indicated values may be employed, if the fitted values for the scatter and geometry parameters are in agreement with calculated and/or experimentally determined experience values.

6.3.6 Equivalent electrical test method

In the event that the full range of ambient dose equivalent rates required for the above tests cannot be provided by the sources of neutron radiation available, it is permissible to employ an equivalent electrical test in order to determine the relative error at the ambient dose equivalent rates that cannot be provided by the sources of radiation.

In this case, the radiation sources shall be capable of providing at least one ambient dose equivalent rate in the upper part of the effective range of measurement of the assembly for the type test, and at least one ambient dose equivalent rate in the lower part of the effective range of measurement of the assembly. The electrical signal shall have a form which simulates as closely as necessary the form of signal delivered by the detector and shall be injected at a point that will test the entire assembly apart from the detector itself or the photomultiplier in the case of a scintillator detector.

If $\dot{H}_{i1}^*(10)$ is the indicated ambient dose equivalent rate when the assembly is subjected to a conventionally true ambient dose equivalent rate, $\dot{H}_i^*(10)$, from the neutron reference source available, then an electrical signal, S_1 , shall be injected such as to produce the same indicated value, $\dot{H}_{i1}^*(10)$. Then if another indicated value $\dot{H}_{i2}^*(10)$ is produced by an input signal, S_2 , the relative error is given by:

$$U = \left(\frac{\dot{H}_{i2}^*(10) \times S_1}{\dot{H}_{i1}^*(10) \times S_2} - 1 \right)$$

and the observation shall be within the limits given in 6.3.7. If the electrical test method is used, this should be stated in the accompanying documents.

6.3.7 Interpretation of the equivalent electrical test results

It is necessary to make allowance for the relative uncertainty $U(k = 2)$ in the values of the conventional true ambient dose equivalent rates employed in the test. If no single observed mean value of the relative error, U , exceeds $\pm(20 \% + U)$, then the requirement for constancy of the dose rate response can be considered met.

6.4 Variation of the response due to neutron energy

6.4.1 General

The response of all neutron dose (rate) meters is very dependent on the neutron energy [1]. For radiological protection purposes, it would be desirable for the variation of the response with the neutron energy over the entire energy range from thermal to the maximum energy specified by the manufacturer not to exceed a factor of 1,5. However, at the time of publication, such requirement is not practically achievable.

As all existing devices and those being developed are essentially based on appropriate detector response calculations, the results of these calculations shall be made available for the entire neutron energy range with calculated data at least at two energy points per decade of neutron energy.

6.4.2 Requirements

The relative ambient dose (rate) equivalent response, $r_{H^*(10)}$ and $r_{H^*(10)}$ due to variation of the neutron energy shall be for

thermal – 50 keV energy range	the manufacturer shall specify the variation of the ambient dose (rate) equivalent relative response with the neutron energy. The relative response shall be at least within the range from 0,2 to 8,0.
50 keV – 10 MeV energy range	within the range from 0,5 to 2,0.
10 MeV – 20 MeV	the manufacturer shall specify the variation of the ambient dose (rate) equivalent relative response with the neutron energy. The variation of the relative response shall be at least within the range from 0,2 to 2,0.

The relative response herein is relative to the reference neutron energy and 0° between the incident neutron radiation and the reference direction. The instrument axis, the reference plane and reference direction of incidence shall be defined by the manufacturer.

The requirement for the neutron energy range from 50 keV to 10 MeV is mandatory for every instrument. For the remaining energy range the manufacturer shall state the energy range where the stated requirements are met by their instrument.

All indicated dose values shall be corrected for non-constant response and, if necessary, for the effect of the influence quantity dose rate on dose measurements.

6.4.3 Test method

For this test, the dose (rate) meter shall be placed free in air. The neutron radiation qualities specified in ISO 8529-1, ISO 8529-2, ISO 8529-3 and ISO 12789-1, ISO 12789-2 shall be used.

Since it is impracticable to investigate the performance of an assembly and to validate the calculated data over nine decades of neutron energy from thermal neutrons up to 20 MeV, the following energies may be used:

- a) at least two neutron energies below 50 keV, one of them being thermal neutron energy;
- b) at least three neutron energies in the energy range between 50 keV and 10 MeV;
- c) at least one broad source (e.g. ^{252}Cf or $^{241}\text{Am-Be}$);
- d) at least one neutron energy exceeding 10 MeV.

Only tests at energies that are within the manufacturer's specified energy range are required. In addition, it is recommended to state the response to standardized simulated work place neutron field sources.

The test distance should be at least 3 times the sum of the largest linear dimension of the source and the detector. The scatter contribution to the indicated value of the device shall not exceed 20 % of the indicated value contributed by the unscattered neutrons. The determination of the scatter contribution shall be in compliance with ISO 8529-2.

In principle, this test is best performed at the same ambient dose equivalent rate for each neutron energy. In practice, this may not be possible, in which case the indicated ambient dose equivalent rate of each neutron energy shall be corrected for the relative response (interpolated if necessary) at the same indication as for the reference neutron radiation.

Using the provided computational response function calculate the ambient neutron dose equivalent (rate) at the selected neutron energies in 6.4.3 a) through d) and compare them with the experimentally determined values.

NOTE Details of the reference radiations and the calibration procedure are given in ISO 8529-1, ISO 8529-2 and ISO 8529-3. For simulated realistic work place neutron field sources, see ISO 12789-1 and ISO 12789-2.

6.4.4 Interpretation of the results

When all experimentally measured relative response values due to variation of the neutron energy are within the ranges specified in 6.4.2 and the calculated values of the ambient dose equivalent (rate) are within $\pm 20\%$ of the experimentally measured values, then the requirements of 6.4 are considered met.

6.5 Monte Carlo calculation of the instrument response

6.5.1 General

The response of the existing and those being developed neutron dose (rate) meters in the neutron energy regions where measurements are not available or feasible is essentially based on Monte Carlo calculations. The calculated relative response curve is usually relative to ^{252}Cf response.

6.5.2 Requirements

A Monte Carlo response curve shall be provided by the manufacturer to cover the energy range stated by the manufacturer. Calculated numerical values of the response shall be provided to accompany each measured energy in 6.4.3 a) through d). Additionally calculated numerical values of the response shall be provided at additional energies to fill in the gaps between the available monoenergetic fields and to extend the data to cover the full energy range. Calculated numerical values of the response shall be provided at least in each order of magnitude of the neutron energy (e.g. 10^{-2} eV, 10^{-1} eV, 10^0 eV, 10^1 eV, ..., 10^6 eV, 10^7 eV, $>10^7$ eV). The accuracy of the Monte Carlo results for the detector response shall be such that the calculated ambient neutron dose equivalent (rate) at the selected neutron energies in 6.4.3 a) through d) is within $\pm 20\%$ of the measured ambient neutron dose equivalent (rate). Monte Carlo calculations shall be fully documented so that they can be repeated (or verified) by independent entity or laboratory.

NOTE This information may be confidential and only be used by the testing laboratory for the purpose of type testing.

6.5.3 Test method

Verify that the Monte Carlo calculated response curve cover the entire energy region stated by the manufacturer. Verify that Monte Carlo calculations are fully documented and can be independently repeated. This can be accomplished either by repeating portion of the calculations or by reviewing the documentation. Verify that calculated numerical response values at the selected energies in 6.4.3 a) through d) are provided. Verify that calculated numerical response values at energies between those selected in 6.4.3 a) through d) are provided at least in each order of magnitude of the neutron energy.

6.5.4 Interpretation of the results

The instrument meets the requirements in 6.5.2 if

- Monte Carlo calculated response curve is provided that covers the entire energy region stated by the manufacturer, and
- Monte Carlo calculations are fully documented and can be independently repeated, and
- calculated and experimental data at the selected energy points in 6.4.3 a) through d) are within $\pm 20\%$, and
- calculated numerical response values in each order of magnitude of the neutron energy between those energies selected in 6.4.3 a) through d) are provided.

6.6 Variation of the response due to angle of incidence

6.6.1 General

This standard relates to detector assemblies with a wide angle of acceptance and having essentially circular symmetry in one plane. The standard recognizes the practical limitations of achieving a uniform response over 4π solid angle.

6.6.2 Requirements

The variation of the indication of the assembly to radiation incident at any angle from 0° to 90° to the reference (calibration) direction in the reference plane shall not exceed $\pm 25\%$ in the rated energy range.

The variation of the indication of the assembly to radiation incident at any angle from $+90^\circ$ to $+180^\circ$ and -90° to -180° to the reference direction in the reference plane shall be stated by the manufacturer. The variation of the indication of the assembly to radiation incident at any angle to the reference direction in a plane orthogonal to the reference direction should be stated by the manufacturer. The reference plane and the reference direction of incidence shall be defined by the manufacturer.

6.6.3 Test method

The detection assembly shall be exposed to one of the reference neutron radiation sources specified in 4.6. The assembly shall be placed in its reference plane with the radiation source in the reference direction (i.e. the calibration direction defined by the manufacturer in relation to the radiation source being used). The calibration distance should be at least 3 times the sum of the largest linear dimension of the source and the detector. The scatter contribution to the indicated value of the device shall not exceed 20 % of the indicated value due to the unscattered neutrons. The determination of the scatter contribution shall be in compliance with ISO 8529-2. The detection assembly shall then be turned in the reference plane through angles from 0° to $\pm 180^\circ$ from this position in steps of 30° and the indicated values noted. Similar observations shall then be taken as the assembly is rotated in a plane orthogonal (perpendicular) to the reference direction.

6.6.4 Interpretation of the results

The instrument meets the requirements of 6.6.2 if

- a) the variation of the indication of the assembly to radiation incident at any angle from 0° to 90° to the reference direction in the reference plane does not exceed $\pm 25\%$ and
- b) the variation of the indication of the assembly to radiation incident at any angle from $+90^\circ$ to $+180^\circ$ and -90° to -180° to the reference direction in the reference plane does not exceed the values stated by the manufacturer and if provided
- c) the variation of the indication of the assembly to radiation incident at any angle to the reference direction in a plane orthogonal to the reference direction does not exceed the values stated by the manufacturer.

6.7 Overload characteristics

6.7.1 Dose equivalent meters

6.7.1.1 Requirements

- a) The dose equivalent meter shall read off-scale on the high side or shall indicate overload when exposed to doses greater than the maximum of its measuring range. This requirement shall apply to all ranges.
- b) When subjected to dose rates high enough to cause wrong dose indication, there shall be indication that the equipment is not able to provide correct dose indication.

6.7.1.2 Test method

The test may be carried out either with a suitable neutron source or by injection of a suitable signal into the input of the measuring assembly (see 6.3.6) if high neutron dose rates are not available.

- a) Subject the dose equivalent meter to a dose between 1 Sv and 50 Sv and in excess of 10 times the maximum dose that can be indicated. The dose rate during the exposure shall be less than the maximum dose rate capability as specified by the manufacturer. The equipment shall not be reset or switched off for at least 30 min after the equipment has been subjected to the test dose.
- b) Subject the dose equivalent meter to a dose rate 10 % in excess of that specified as the dose rate limit by the manufacturer for a period of 100 s. In case no error of the dose value (due to dose rate overload) is indicated, subject the dose equivalent meter to further increased dose rates in steps of 10 % for 100 s until the error indication of the dose value (due to dose rate overload) is displayed.

6.7.1.3 Interpretation of the results

- a) The indication shall be off-scale on the high side or overload shall be indicated and shall remain so until the dose indication is reset or the equipment is switched off.
- b) Ensure that either the dose indication has increased appropriately (within the manufacturer's stated tolerance) or indication is given that the reading of dose (due to dose rate overload) is in error. Prior to the error indication the dose indication shall increase as appropriate within its tolerance.

6.7.2 Dose rate equivalent meters

6.7.2.1 Requirements

The dose rate equivalent meter shall read off-scale on the high side or shall indicate overload when exposed to dose rates greater than the maximum of its measuring range. This requirement shall apply to all ranges.

6.7.2.2 Test method

The test may be carried out either with a suitable neutron source or by injection of a suitable signal into the input of the measuring assembly (see 6.3.6) if high neutron dose rates are not available.

The dose rate equivalent meter shall be submitted for a period of 5 min to a dose equivalent rate 10 times the range (scale) maximum.

6.7.2.3 Interpretation of the results

The indication of the dose equivalent rate shall read off-scale on the high side or indicate overload throughout this period. The dose rate equivalent meter shall function within the specification 5 min after completion of this test. If the device is not functioning within the specification, a warning shall be displayed. The warning may extinguish only when the device meets again the specifications without restrictions. This test is applicable to each range.

6.8 Response time

6.8.1 Requirements

The response time shall be such that, if there is a sudden change in the ambient dose equivalent rate, the indication shall reach the following value:

$$\dot{H}_i^*(10) + \frac{90}{100} \left(\dot{H}_f^*(10) - \dot{H}_i^*(10) \right)$$

Where $\dot{H}_i^*(10)$ is the initial indicated value and $\dot{H}_f^*(10)$ the final indicated value, in a time smaller than those specified below:

- a) 30 s for the increases or decreases of the ambient dose equivalent rate less than $0,1 \text{ mSv}\cdot\text{h}^{-1}$;
- b) 10 s for the increases or decreases of the ambient dose equivalent rate between $0,1 \text{ mSv}\cdot\text{h}^{-1}$ and $1 \text{ mSv}\cdot\text{h}^{-1}$;
- c) 4 s for the increases or decreases of the ambient dose equivalent rate greater than $1 \text{ mSv}\cdot\text{h}^{-1}$.

The manufacturer shall state the response time.

6.8.2 Test method

The test may be carried out either with a suitable neutron source or by the injection of a suitable electrical signal into the input of the measuring assembly.

The initial and final ambient dose equivalent rates shall differ by a factor of at least 10 and measurements shall be carried out for both an increase and a decrease in the ambient dose equivalent rate by this factor.

If the electrical test method is employed, the injected signals shall correspond to the above requirements.

For the increasing ambient dose equivalent rate test, the detection assembly shall be subjected first to the higher ambient dose equivalent rate and the indicated value $\dot{H}_f^*(10)$ shall be noted.

The assembly shall then be subjected to the lower ambient dose equivalent rate for a time sufficient for the indication $\dot{H}_i^*(10)$ to reach a steady value and this indicated value shall be noted.

The ambient dose equivalent rate shall then be changed as quickly as possible to that corresponding to the indicated value $\dot{H}_f^*(10)$, and the time taken to reach the value given by the formula in 6.8.1 shall be measured.

The test for decreasing ambient dose equivalent rate shall be performed in the same way with the values of ambient dose equivalent rates corresponding to $\dot{H}_f^*(10)$ and $\dot{H}_i^*(10)$ interchanged.

6.8.3 Interpretation of the results

The instrument meets the requirements if the indication following a sudden change of the ambient equivalent dose rate reaches the value defined by the formula in 6.8.1 in time less than those specified in 6.8.1.

6.9 Relationship between response time and statistical fluctuations

The response time and the coefficient of variation of the statistical fluctuations are interdependent characteristics, for which acceptable limits are given above in 6.8.1 and 6.3.2.

For high ambient dose equivalent rates, it is recommended that, whenever possible, while conforming to the limits laid down for the statistical fluctuations, the response time should be reduced.

There is little advantage in reducing response time much below 1 s; in such cases, it would be more advisable to reduce the statistical fluctuations.

6.10 Dose equivalent rate alarm

6.10.1 Requirements

Under standard test conditions, when the dose equivalent (rate) meter is subjected to a dose equivalent rate of 0,8 of the dose equivalent rate corresponding to the dose equivalent rate alarm set point for 10 min, the alarm shall not be activated for more than 10 % of the period of test. Similarly, at a dose equivalent rate of 1,2 times the alarm level set, the alarm shall be activated for at least 90 % of the test period. When the dose equivalent (rate) meter is subjected to dose equivalent rates of 1,2 times the dose equivalent rate alarm set point, the alarm shall actuate within 5 s or within a time such that the product of this time and the dose equivalent rate of the alarm point is less than 10 μSv .

When a dose equivalent (rate) meter utilises more than one radiation detector to cover the full range of dose equivalent (rates) indicated by the dose equivalent (rate) meter, these requirements apply to the relevant ranges for each detector separately.

6.10.2 Test method

At least two tests shall be carried out, one with the alarm set near the maximum effective indicated value and one near the maximum of the second least significant decade.

6.10.3 Interpretation of the results

The instrument meets the dose equivalent rate alarm requirement if it satisfies 6.11.1 requirement for 2 alarm set points, one near the maximum effective indicated values and one near the maximum of the second least significant decade. Allowance shall be made for the relative uncertainty ($k = 2$) in the conventional true dose equivalent rate to which the neutron dose (rate) meter is subjected. Where this is U , the dose rates used shall be: $0,8(1 - U)$ and $1,2(1 + U)$ of the dose equivalent alarm rate set point.

6.11 Dose equivalent alarm

6.11.1 Requirements

Under standard test conditions, when the dose equivalent meter is subjected to a dose equivalent of 0,8 times the dose equivalent corresponding to the dose equivalent alarm set, no alarm shall be given, and when the dose equivalent meter is subject to a dose equivalent rate of 1,2 times the dose equivalent alarm set point, the alarm shall be actuated.

6.11.2 Test method

At least two tests shall be carried out, one with the alarm set near the maximum effective indicated value and one with the alarm set near the maximum of the second least significant decade. The alarm shall be reset and then the dose equivalent meter shall be subjected to a conventionally true dose equivalent rate such that the alarm will not occur for at least 100 s. The time of exposure of the dose equivalent meter shall be measured.

6.11.3 Interpretation of the results

The instrument meets the dose equivalent alarm requirement if it satisfies 6.12.1 requirement for 2 alarm set points, one near the maximum effective indicated value and one near the maximum of the second least significant decade and if the quotient of the alarm set point by the product of the dose equivalent rate used and the measured time lie within the range $0,8(1 - U)$ to $1,2(1 + U)$, where U is the relative uncertainty ($k = 2$) in the conventionally true dose equivalent rate.

6.12 Response to photon radiation

6.12.1 Requirements

Practically all neutron radiation fields are contaminated by photon radiation, which leads to the necessity to determine the response to photon radiation.

The response to photon radiation shall be quoted in terms of the indication of the assembly per unit of photon ambient dose equivalent rate at the point of test.

Photon radiation incident on a neutron assembly may not only cause the assembly to give an indication, but it may also modify the response of the assembly to neutron radiation. Therefore, there are two separate requirements.

- a) The indication produced by a ^{137}Cs or ^{60}Co photon ambient dose equivalent rate of $10 \text{ mSv}\cdot\text{h}^{-1}$ shall not be greater than the indicated value due to a neutron ambient dose equivalent rate of $0,1 \text{ mSv}\cdot\text{h}^{-1}$.
- b) In a neutron reference field producing an indication of $1 \text{ mSv}\cdot\text{h}^{-1}$, exposure to $10 \text{ mSv}\cdot\text{h}^{-1}$ from ^{137}Cs or ^{60}Co photon radiation shall not change this neutron indication by more than 10 %. The ^{137}Cs or ^{60}Co sources used for the above tests should conform to the requirements of the ISO 4037 series.
- c) Furthermore, since in some situations where neutron ambient dose equivalent rate is to be measured, high-energy photon radiation (for example 6 MeV from ^{16}N) may be present, the response to photon radiation shall, by agreement between the manufacturer and the purchaser, be checked at higher energies as well as with ^{137}Cs or ^{60}Co energy. In this case, the manufacturer shall state the response to high-energy photon radiation.

6.12.2 Test method

For requirement a) of 6.13.1, the assembly shall be exposed to a ^{137}Cs or ^{60}Co source in a field having an ambient dose equivalent rate of $10 \text{ mSv}\cdot\text{h}^{-1}$ at the reference point of the assembly.

For requirement b) of 6.13.1 the assembly shall be exposed to the neutron reference source so that an indicated value of $1 \text{ mSv}\cdot\text{h}^{-1}$ is obtained. The assembly is now additionally exposed to a ^{137}Cs or ^{60}Co source such that the photon dose equivalent rate at the point of test is $10 \text{ mSv}\cdot\text{h}^{-1}$.

For requirement c) of 6.13.1, the radiation sources used for this test shall conform to the ISO 4037 series.

6.12.3 Interpretation of the results

The requirements stated in 6.13.1 a) and c) are satisfied if the indication produced by a ^{137}Cs and higher energy ($> 1,5 \text{ MeV}$) photon ambient dose equivalent rate of $10 \text{ mSv}\cdot\text{h}^{-1}$ is less than the indicated value due to a neutron ambient dose equivalent rate of $0,1 \text{ mSv}\cdot\text{h}^{-1}$. The response to photon radiation shall be quoted in terms of the indication of the assembly per unit of photon ambient dose equivalent rate at the point of test.

The requirement in 6.13.1 b) is met if the indication of the neutron ambient dose equivalent rate does not change by more than 10 % when exposed to photon dose equivalent rate of $10 \text{ mSv}\cdot\text{h}^{-1}$ from a ^{137}Cs source.

6.13 Response to other external ionizing radiations

Due to the design of this type of assembly, it will not respond to alpha or beta radiations. Accordingly, no tests are specified.

7 Additivity of indicated value

7.1 Requirements

The indicated value shall be additive with respect to simultaneous irradiation with different types of radiation (for example, photon and neutron) and with different neutron energies and angles of radiation incidence.

If the dose (rate) meter uses only one signal (measured with one detector) to evaluate the indicated value, then this requirement is fulfilled.

If a dose (rate) meter uses more than one signal (measured either with several detectors or with one detector using for example pulse height analysis) to evaluate the indicated value, then this requirement is not automatically fulfilled. In that case, it shall be ensured that the relative change in indication, Δg_{mix} caused by the mix of radiation shall not exceed $\pm 0,1$.

If the algorithm used to evaluate the indicated value, (see 5.5) is either a linear combination of the signals or a linear optimization of them, then this requirement is fulfilled or no tests are required.

7.2 Test method

Perform subsequently two irradiations under the two different irradiation conditions K and L (different energies, different angles of incidence or even different types of radiations) with the conventional quantity values H_{tK} and H_{tL} . Determine the indicated values H_{iK} and H_{iL} for the two irradiations. Then perform a third simultaneous irradiation under the two irradiation conditions K and L with the conventional quantity value $H_{\text{t(K+L)}} = H_{\text{tK}} + H_{\text{tL}}$ and determine the indicated value $H_{\text{i(K+L)}}$ or this simultaneously mixed irradiation.

The relative change in indication is then given by:

$$\Delta H_{\text{imix}} = \frac{H_{\text{iK}} + H_{\text{iL}} + H_{\text{i(K+L)}}}{H_{\text{i(K+L)}}}$$

ΔH_{imix} shall be determined for any value of H_{tK} and H_{tL} and any simultaneous combination of radiation fields S_{K} and S_{L} . As simultaneous irradiations are very difficult to perform, the use of calculations as a replacement for the simultaneous irradiations is permitted and recommended for this test. A prerequisite of the use of calculations is the knowledge of measured response values of each signal to all the irradiation conditions K and L and of the evaluation procedure to determine the indicated value from these signals. The calculation of the response of the entire dose (rate) meter with the aid of radiation transport simulations to determine the response values of each signal to all the irradiation conditions is not permitted.

The non-linearity of the signals is treated in 4.3 and 6.3. Therefore, when no calculation is performed, the signals shall be corrected for non-linearity for this test. When different dose (rate) meters are used to determine H_{iK} , H_{iL} and $H_{\text{i(K+L)}}$, any difference in the reference calibration factor shall be corrected.

7.3 Interpretation of the results

The relative change in indication, ΔH_{imix} shall not exceed $\pm 0,1$. In this case, the requirements of 7.1 can be considered met.

8 Software

8.1 General

The final version of the software shall be available at the beginning of the type test, as a great part of the software test is indirectly covered by the metrological test. The manufacturer shall be aware of the fact that any change of the “data relevant part” of the software may question the validity of the type test.

NOTE In modern instruments, the software has an increasing importance for the generation of the measured value. Therefore, the type test automatically includes the performance of the software running in the device under test. This is considered by the given requirements.

The requirements given are guided by the WELMEC software guide 7.2, see [7]. The requirements are based on the requirements for instruments with embedded software in a built-for-purpose measuring instruments (Type P) and a risk class B (low level).

8.2 Requirements

8.2.1 General requirements

The requirements set shall safeguard against any unintended modification of the data software. In addition, any attempted modification of the software shall be prohibited unless it is done under the supervision of authorized personnel and in the intended way.

8.2.2 Design and structure of the software

The software shall be designed in such a way that the part relevant to the indicated value is not affected by other software unless the effect is required for the correct use of the dose equivalent (rate) meter.

NOTE One possible technical solution is to separate the software into two parts. One part may contain all the functions necessary to evaluate, store and display the indicated values. This part is the “data relevant part”. The other parts of the software, the “non data relevant part”, may contain, for example, the value, the date and the time of a maximum of an indication. The data relevant part has well defined functions (software interface) that are used to communicate with the non data relevant software parts. This technical concept of software separation has the advantage, that the “non data relevant part” may be modified without influencing the “data relevant part”. The concept of software separation is state of the art in software engineering.

8.2.3 Protection of the software and data

8.2.3.1 Identification

The “data relevant part” of the software (see note to 8.2.2) shall have an identification. It shall be possible to display this identification while the software is running. This identification can be compared with the identification given in the test record or in the user instructions.

NOTE If the identification automatically changes when the software is changed – in that case a simple version number is not sufficient – an additional benefit is given. Any change of a bit in the stored software of the dose equivalent (rate) meter, e.g. due to radiation, is recognized. One possible technical solution is a check sum algorithm (at least CRC-16) built over the software (see [7]). The reference value of the checksum of all bytes of the software is calculated and is stored. During startup of the instrument, the checksum is calculated again and compared with the stored reference value. In case a change occurred, the software stops and supplies an appropriate error message.

8.2.3.2 Alarm under abnormal operating conditions

When abnormal operating conditions occur in components of the dose equivalent (rate) meter, this shall be indicated. These abnormal operating conditions include those that could lead to a faulty indication or loss of dose information, for example high voltage failure in a photomultiplier tube.