

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Radiation protection instrumentation – Installed ambient dose equivalent rate meters, warning and monitoring assemblies for neutrons with energies from thermal to 20 MeV

Instrumentation pour la radioprotection – Débitmètres d'équivalent de dose ambiant, ensembles d'alarmes et moniteurs à poste fixe pour des énergies de neutrons comprises entre l'énergie thermique et 20 MeV



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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 13.280; 17.240

ISBN 978-2-8322-7635-8

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**RADIATION PROTECTION INSTRUMENTATION –
INSTALLED AMBIENT DOSE EQUIVALENT RATE METERS,
WARNING AND MONITORING ASSEMBLIES FOR NEUTRONS
WITH ENERGIES FROM THERMAL TO 20 MeV****FOREWORD**

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International Standard IEC 61322 has been prepared by subcommittee 45B: Radiation protection instrumentation, of IEC technical committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition published in 1994. This edition constitutes a technical revision.

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

- this document has been updated to take account of the requirements of the relevant IEC standards, IEC 60532:2010 and IEC 61005:2014.

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

FDIS	Report on voting
45B/944/FDIS	45B/952/RVD

Full information on the voting for the approval of this document 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- withdrawn,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 – INSTALLED AMBIENT DOSE EQUIVALENT RATE METERS, WARNING AND MONITORING ASSEMBLIES FOR NEUTRONS WITH ENERGIES FROM THERMAL TO 20 MeV

1 Scope

This document applies to installed dose equivalent rate meters, warning assemblies and monitors, as defined below. It covers equipment intended to measure neutron radiation in dose equivalent rates in the energy region between thermal and 20 MeV for the purposes of radiation protection.

Assemblies of this type are commonly defined as area radiation monitors. They are normally employed to determine continuously the radiological situation in working areas in which the radiation field may change with time, for example, nuclear power plants, particle accelerators, high-activity laboratories, fuel reprocessing plants, etc., and provide alarms when the radiation field goes outside predetermined limits.

The assemblies considered in this document comprise at least:

- a detector assembly, which may, for example, consist of a detector probe (for thermal neutrons such as BF₃ proportional counter, ³He proportional counter, ⁶LiI(Tl) scintillation detector, etc.) and a moderating and absorbing medium surrounding the detector;
- a processing assembly, which may be fitted into a centralized panel, which, in the case of warning assemblies and monitors, provides signal outputs and contacts capable of activating alarm or other trip circuits;
- alternatively, the case when all the processing electronics are placed within the detection unit (so called "smart blocks") may be considered. In this case the functions of the processing assembly will be composed of only the indication, the providing signal outputs and contacts.

This document specifies general characteristics, general test procedures, radiation characteristics, as well as electrical, mechanical, safety, and environmental characteristics, as well as the identification certificate for the assemblies defined in the scope.

Assemblies designed to perform combined functions comply with the requirements pertaining to each of these functions.

This document is not applicable to criticality monitors covered by IEC 60860, or to assemblies intended to give information about operational parameters of nuclear plants for control purposes. This document is not applicable to the operating characteristics of indicating or recording instruments as such (for instance, indicating meters, recorders, etc.). The characteristics of such instruments are in conformity with the general requirements appropriate to them.

This document does not cover hand-held neutron dose (rate) meters and instruments that are covered in IEC 61005.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-395:2014, *International Electrotechnical Vocabulary (IEV) – Part 395: Nuclear instrumentation: Physical phenomena, basic concepts, instruments, systems, equipment and detectors*

IEC 60529:1989, *Degrees of protection provided by enclosures – IP Code*

IEC 61000-4-2:2008, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measuring techniques – Electrostatic discharge immunity test*

IEC 61000-4-3:2006, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measuring techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-5:2014, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measuring techniques – Surge immunity test*

IEC 61000-4-6:2013, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measuring techniques – Immunity to conducted disturbances induced by radio-frequency fields*

IEC 61000-4-8, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measuring techniques – Power frequency magnetic field immunity test*

IEC 61000-4-12, *Electromagnetic compatibility (EMC) – Part 4-12: Testing and measuring techniques – Ring wave immunity test*

IEC 61187:1993, *Electrical and electronic measuring equipment – Documentation*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

ISO 4037-1:2019, *Radiological protection – X and gamma reference radiation for calibrating dosimeters and dose rate meters and for determining their response as a function of photon energy – Part 1: Radiation characteristics and production methods*

ISO 4037-2:2019, *Radiological protection – X and gamma reference radiation for calibrating dosimeters and dose rate meters and for determining their response as a function of photon energy – Part 2: Dosimetry for radiation protection over the energy ranges from 8 keV to 1,3 MeV and 4 MeV to 9 MeV*

ISO 4037-3:2019, *Radiological protection – X and gamma reference radiation for calibrating dosimeters and dose rate meters and for determining their response as a function of photon energy – Part 3: Calibration of area and personal dosimeters and the measurement of their response as a function of energy and angle of incidence*

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 – Part 3: Calibration of area and personal dosimeters and determination of response as a function of energy and angle of incidence*

ISO 11929 (all parts): *Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage 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 the basic quantities*

3 Terms and definitions, abbreviated terms 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.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

NOTE For clarity and text conciseness in this document 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 document it is understood that “neutron ambient dose equivalent rate meter” is meant.

3.1.1

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} .

3.1.2

neutron fluence rate

flux density

$\Phi, \dot{\Phi}$

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

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

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

3.1.3**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 [1], [2], [3], [4]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.

3.1.4**ambient dose equivalent rate** $\dot{H}^*(10)$

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

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

3.1.5**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.

3.1.6**calibration distance**

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

3.1.7**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

Note 1 to entry: Effective reference point of an assembly is located at a distance, stated by a manufacturer for specified energy, from a reference point of the assembly to be used in order to position the assembly at a point where the conventional true value of a quantity to be measured is known.

3.1.8**conventional true value** $H_{t, \text{true}}$

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

Note 1 to entry: In this document the quantity is the dose equivalent rate.

Note 2 to entry: Sometimes a conventional true value is an estimate of a true quantity value.

Note 3 to entry: A conventional true value is generally accepted as being associated with a suitably small measurement uncertainty, which might be zero.

¹ Numbers in square brackets refer to the Bibliography.

3.1.9 indicated value

$H, \dot{}$ _i

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

3.1.10 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 3.1.11), and

h_ϕ is the neutron fluence-to-dose conversion coefficient (see definition 3.1.5).

3.1.11 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 (dose rate meter) for the neutron fluence, and

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

Note 1 to entry: The unit of neutron fluence response is m².

3.1.12 reference response

R_r

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

$$R_r = \frac{H, \dot{}}{H, \dot{}}_{\text{r}} / \frac{H, \dot{}}{H, \dot{}}_{\text{t}}$$

where

$H, \dot{}}_{\text{r}}$ is the corresponding indicated value of the quantity to be measured under reference conditions, and

$H, \dot{}}_{\text{t}}$ is the conventional true value (3.1.8) 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.

3.1.13 relative response

r

quotient of the response R (3.1.11) and the reference response R_r (3.1.12)

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

3.1.14**response of a radiation measuring assembly***R*

ratio, under specified conditions, given by the relation

$$R = \frac{H, \dot{i}}{H, \dot{t}}$$

where

$H, \dot{i}$ is the indicated value of the quantity (3.1.9) measured by the instrument under test, and

$H, \dot{t}$ is the conventional true value of this quantity (3.1.8).

3.1.15**relative error of an indication***I*

relative error, *I*, in the indication of an assembly is given as a percentage, by the relationship:

$$I(\%) = \frac{H, \dot{i} - H, \dot{t}}{H, \dot{t}} \times 100$$

3.1.16**coefficient of variation***v*

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

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

3.1.17**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 document

3.1.18**manufacturer**

designer and seller of the equipment

3.1.19**purchaser**

user (operator) of the equipment

3.1.20**order of magnitude**

range of measurement or levels to be measured which differ by about a factor of ten for one order of magnitude, one hundred for two, a thousand for three and so on

3.1.21**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

3.1.22

background level

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

3.1.23

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.

3.1.24

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.

3.1.25

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.

3.1.26

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.

3.1.27

lower limit of effective range of measurement

H_0

lowest dose rate value included in the effective range of measurement

3.1.28 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 JCGM 100:2008[5], 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 ($p = 1 \dots l$) for the influence quantities of type S, and the m relative response values r_q ($q = 1 \dots m$) for the influence quantities of type F:

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

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 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 document, all these data are available.

3.1.29 linearity

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

3.1.30 rated range of use of an ambient 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

3.1.31 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]

3.1.32 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, 395-03-113]

3.1.33 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

3.1.34 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.

3.1.35 time to establish thermal equilibrium <with power off>

time to be considered that the instrument reaches thermal equilibrium without supplying electrical power

3.1.36 detector assembly DA

component of the installed radiation monitor system that contains the detectors and associated electronic devices; it also includes programmable electronic circuits

3.1.37 processing assembly PA

assembly (which can be associated with one or more detector assemblies) which converts the output signal from the detector assemblies into a form, generally digital, suitable for transmission down a data link to the central computer, centralizer, and/or which generates alarm outputs to the alarm units at preset signal levels

3.1.38 alarm assembly AA

assembly that will initiate an audible or visible alarm normally local to the DA in the event of an alarm threshold being breached or in case of fault of the equipment

3.1.39 monitoring assembly MA

combination of processing, alarm, and detector assemblies

3.1.40 test nomenclature

3.1.40.1 qualification tests

tests performed on a representative sample of equipment to verify the adequacy of the design and that the equipment meets the specifications agreed upon between manufacturer and user under normal, operational conditions and anticipated operation occurrences

Note 1 to entry: Qualification tests are performed in order to verify that the requirements of a specification are fulfilled.

Note 2 to entry: Qualification tests are subdivided into type tests and routine tests.

3.1.40.2 type test

conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-151:2001, 151-16-16]

3.1.40.3**routine test**

conformity test made on each individual item during or after manufacture

[SOURCE: IEC 60050-151:2001, 151-16-17]

3.1.40.4**acceptance test**

contractual test to prove to the customer that the device fulfils certain specifications

3.1.40.5**supplementary tests**

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

3.2 Abbreviated terms and symbols

AC	alternating current
D	deviation
Φ	neutron fluence rate
g	free-fall acceleration
$H_{\text{a}}^*(10)$	ambient dose equivalent rate
H_{0}	lower limit of effective range of measurement for ambient dose equivalent rate
$H_{\text{i}}^{*,\text{i}}(10)$	initial indicated value of ambient dose equivalent rate
$H_{\text{i}}^{*,\text{f}}(10)$	final indicated value of ambient dose equivalent rate
H_{a}	dose rate alarm setting
h_{Φ}	neutron fluence-to ambient dose equivalent conversion coefficient
H_{i}	indicated value of the quantity
H_{t}	conventional true value
S_0	input electrical signal to be injected to produce indicated value $H_{\text{0}}(10)$
S_1	input electrical signal to be injected to produce indicated value $H_{\text{1}}(10)$
IP classification	ingress protection rating according to IEC 60529
R_0	reference response
R_H	neutron dose equivalent response
R_{Φ}	neutron fluence response
RF	radio frequency
U	uncertainty
U_{rel}	relative uncertainty of measurement
U_{N}	nominal voltage of AC power line or of supply voltage
v	coefficient of variation

3.3 Quantities and units

In this document, 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 are used, when practicable, according to the SI system.

4 Design requirements

4.1 Construction and performance

4.1.1 General

Equipment may be designed as a single assembly (monitoring assembly) with the detector assembly adjacent to or contained within the monitoring assembly or the detector remote from the remaining equipment.

It is desirable that all these options are provided by a single common design of equipment, and for the design to allow for the use of alternative types of detectors with the same indication and alarm assemblies.

4.1.2 Equipment configuration

The type of equipment defined in this document generally comprises up to four types of assemblies, which may be interconnected in a number of configurations.

These assemblies are:

- detector assembly (DA),
- processing assembly (PA),
- alarm assembly (AA),
- monitoring assembly (MA).

The design of the equipment shall take into account of the practical use of assemblies, noting that it may be required to measure radiation fields incident from various angles relative to their location.

Where detector assemblies are to be used in high neutron radiation fields, the detector assembly should be constructed of materials which will minimize the effects of neutron activation.

The detector assembly should be constructed from smooth, nonporous materials to reduce the possibility of contamination and designed to facilitate decontamination.

4.1.3 Equipment reliability

The required reliability of the functions shall be specified either quantitatively (mean time between failures) or qualitatively (compliance with the single failure criterion).

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

For any part of the equipment (including sampling assembly if any), subject to appropriate planned maintenance, the following requirements should be reached:

- MTBF (mean time between failure): > 20 000 h (with preventive maintenance).

In some circumstances, equipment may be required to operate in locations subject to seismic disturbances. Any requirements for the equipment to operate in such conditions shall be agreed between manufacturer and purchaser, together with any additional test requirements.

Where radioactive sources are incorporated in the equipment, these sources, and the labelling of the instrument, shall conform to the appropriate international and national regulations with regard to radioactive materials.

The time for which any radioactive source will be effective for its function shall be specified by the manufacturer, and shall not be less than 5 years, unless adjustment of the source position is provided to take account of the half-life of the source. In that case, adjustment shall not be required more than once a year.

4.2 Indication facilities

Processing assemblies shall be capable of giving a local indication. The equipment should have the facility to transmit indication to remote locations. The equipment performance shall be independent of any operational mode and be unaffected by failure of the remote location's equipment. Additionally, a facility to allow the connection of a local chart recorder may be provided.

In the case of an analog logarithmic scale meter, the processing assembly display should have a scale length at least 20 mm per decade with appropriate divisional marks. A digital display may be used as long as a clear indication of the scales is provided. In the case of a processing unit with linear scales, the indication ratio between adjacent scales shall not exceed a factor of 10.

4.3 Alarm facilities

4.3.1 General

Alarm assemblies shall be capable of giving local audible and visual alarms. The visual and audible alarm requirements shall be as agreed between the manufacturer and purchaser. The equipment should have the facility to transmit alarms to remote locations.

Measuring assemblies which contain trip circuits shall, if possible, be designed to be "fail safe", that is, be so arranged that interruption or failure of the power supply or component failure causing loss of signal shall result in actuation of a trip circuit to produce an alarm. Failure of the power supply should not disable the alarm. Indication of power supply failure shall be provided.

Alarm circuits shall be operable either to hold an alarm condition until specifically reset by a reset control, or to auto-reset when the alarm state disappears. The two modes of operation shall be available by simple modification on all equipment.

All alarm functions shall be provided with test facilities to allow checking of alarm operation. In the case of adjustable alarms, checking shall be possible over the range of adjustment, with indication of the actual alarm operation point.

The following facilities normally should be provided.

4.3.2 High level alarms

As a minimum one high level alarm should be provided. The alarm set points may be fixed or adjustable. Each alarm activates when the displayed value reached the set point. Other (alert level) alarms may be provided to operate on increasing dose rates but at a level below the alarm level.

Adjustable alarms should cover at least 10 % to 100 % of scale reading (linear scales), from 50 % of the lowest order of magnitude scale to 100 % highest order of magnitude scale (logarithmic scales) and over all but the least significant decade for digital displays.

4.3.3 Low level alarms

A low level alarm facility should be provided. These shall be adjustable as defined in 4.3.2. These are to operate on decreasing dose rate and generally act as an additional fault alarm but could be used for process control.

4.3.4 Instrument fault alarms

Diagnostic facilities should be provided as far as reasonably practicable to detect electronic component, inter-unit communication and processing firmware (software) failures which may cause loss of the safety function of the equipment. These facilities shall result in fault indication or alarm. Separate indication of the source of the fault is desirable.

Where equipment is being used to perform a safety function, the failure of the detector should be identified in timescales comparable to the time to alarm.

4.4 External facilities

If an assembly can be operated with a remote read-out (for example, a counting or integrating device) the output from the assembly shall be appropriately marked.

The provision of the following input and output connections, as appropriate for the assembly, is recommended:

- an input connection to the pre-amplifier input for electrical test purposes;
- an output connection from the amplifier;
- an output connection from the discriminator unit.

4.5 Effective range of measurement

4.5.1 General

The effective range of measurement should cover at least 4 decades. A typical effective range would be from $10 \mu\text{Sv}\cdot\text{h}^{-1}$ to $100 \text{mSv}\cdot\text{h}^{-1}$. Measurement of higher dose equivalent rates, up to $1 \text{Sv}\cdot\text{h}^{-1}$ or higher, may be required and shall be incorporated by agreement between purchaser and manufacturer.

The effective range of measurement of the equipment shall be as follows:

- For processing units with linear scales, the effective range shall be from 10 % to 100 % of each range.
- For processing units with logarithmic scale, the effective range shall be between 1,5 times the lowest significant dose rate marked and full scale.
- For processing units with digital indication, the effective range shall be from an indication in the second least significant digit (i.e, two digits indicated) to the full range of indications available.

4.5.2 Requirements

The effective range of measurement 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 ± ab) the mantissa shall have three digits at least (for instance 1,00 to 9,99). The manufacturer shall define the effective range of measurement (for instance $1,00 \cdot 10^{-7}$ to $9,99 \cdot 10^{-2}$ with the unit $\text{Sv} \cdot \text{h}^{-1}$),
- d) 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.

4.5.3 Interrelationship 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 in 6.8 and 6.9

For high dose rates, it is recommended that whenever possible, while conforming to the limits in this document, the response time be reduced. Response times of less than 1 s offer little advantage and thus it is better practice to reduce the statistical fluctuations.

For very low dose rates, the manufacturer shall indicate the appropriate values of the coefficient of variation and response time which may, with agreement from the purchaser, exceed the limits given in 6.8 and 6.9.

4.5.4 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 4.5.7.

4.5.5 Minimum rated range of influence quantity

The minimum rated range of the specified influence quantity is given in the second column of Tables 2, 3 and 4.

4.6 Ingress protection (IP) classification

The IP classification shall be stated by the manufacturer according to IEC 60529.

4.7 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 (or in the manual),
- e) reference point and reference direction (or in the manual),
- f) serial number of the instrument.

4.8 Functional safety

The basic safety standards that comprise IEC 61508 may apply as well as they have been interpreted for the nuclear industry, and may be selected in some specific cases by agreement between the manufacturer and the purchaser. When the IEC 61508 series is selected, the requirements of that series shall apply as appropriate to the required safety integrity level (SIL) specified for the system.

5 General test procedure

5.1 Test requirements

All the tests enumerated in the following clauses are to be considered type tests (see 3.1.40.2). 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 document 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.

Table 1 – Reference and standard test conditions

Influence quantities	Reference conditions (unless otherwise indicated by the manufacturer)	Standard test conditions (unless otherwise indicated by the manufacturer)
Reference neutron radiation	$^{241}\text{Am}/\text{Be}$, ^{252}Cf , $^{252}\text{Cf}(\text{D}_2\text{O})$, ^{244}Cm or $\text{D}(\text{d},\text{n})$, ^3He , $\text{T}(\text{d},\text{n})$, ^4He , $\text{T}(\text{p},\text{n})$, and $^7\text{Li}(\text{p},\text{n})$ accelerator neutron sources	$^{241}\text{Am}/\text{Be}$, ^{252}Cf , $^{252}\text{Cf}(\text{D}_2\text{O})$, ^{244}Cm or $\text{D}(\text{d},\text{n})$, ^3He , $\text{T}(\text{d},\text{n})$, ^4He , $\text{T}(\text{p},\text{n})$, and $^7\text{Li}(\text{p},\text{n})$ accelerator neutron sources
Dose rate for: $H_{\text{p}}^*(10)$	$10 \mu\text{Sv}\cdot\text{h}^{-1}$	$3 \mu\text{Sv}\cdot\text{h}^{-1}$ to $100 \mu\text{Sv}\cdot\text{h}^{-1}$
Time to establish thermal equilibrium (with power off)	60 min	≥ 60 min
Warm-up time	15 min	≥ 15 min
Ambient temperature	20 °C	18 °C to 22 °C
Relative humidity	65 %	55 % to 75 %
Atmospheric pressure	101,3 kPa	86,0 kPa to 106,0 kPa
Power supply voltage	Nominal power supply voltage, U_N	Nominal power supply voltage, $U_N \pm 1 \%$
Power supply frequency	Nominal frequency f_N	Nominal frequency $f_N \pm 2 \%$
AC power supply waveform	Sinusoidal	Sinusoidal with total distortion lower than 5 %
Angle of incidence of radiation	Calibration direction given by the manufacturer	Direction given $\pm 10^\circ$
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the induction due to the earth's magnetic field
Orientation of assembly	To be stated by the manufacturer	Stated orientation $\pm 10^\circ$
Assembly controls	Set-up for normal operation	Set-up for normal operation
Contamination of radioactive elements	Negligible	Negligible

5.2 Tests performed with variation of influence quantities

5.2.1 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.

In order to simplify these tests for each individual principal influence quantity, only the routine test concerning the intrinsic error need be performed, using one dose rate at approximately two-thirds full scale on any range or decade.

Other aspects of the performance of the assembly should be tested with variation of influence quantities only if it is considered that the routine test specified above will not give a representative indication.

Table 2 – Radiation characteristics of ambient neutron dose equivalent rate meters

Characteristic under test or influence quantity	Minimum rated range of influence quantity	Limit of variation of instrument parameter or relative response for whole rated range	Sub-clause
Linearity of dose rate response	10 $\mu\text{Sv}\cdot\text{h}^{-1}$ to 100 $\text{mSv}\cdot\text{h}^{-1}$ ^{a)}	± 30 %	4.5.1 6.3
Variation of the response due to neutron energy	Thermal to 100 keV 100 keV to 10 MeV 10 MeV to 20 MeV More than 20 MeV	Stated by the manufacturer. Recommended relative response is within (0,2 to 8,0) Relative response shall be within (0,5 to 2,0) Stated by the manufacturer. Recommended relative response is within (0,2 to 2,0) By the agreement between the manufacturer and the purchaser.	6.4
Variation of response with angle of incidence	Configuration a 1) 2 planes including the calibration direction: 0°, $\pm 30^\circ$, $\pm 60^\circ$, $\pm 90^\circ$, $\pm 120^\circ$ 2) A plane perpendicular to the calibration direction: 0°, $\pm 45^\circ$, $\pm 90^\circ$, $\pm 135^\circ$, 180° Configuration b 1) A plane including the calibration direction and its vertical direction: 0°, $\pm 45^\circ$, $\pm 90^\circ$, $\pm 135^\circ$, 180° 2) A plane including the calibration direction and its horizontal direction and a plane perpendicular to the calibration direction: 0°, $\pm 30^\circ$, $\pm 60^\circ$, $\pm 90^\circ$, $\pm 120^\circ$	Relative error of indication to be less than ± 25 % from the forward calibration direction (or stated by manufacturer)	6.5
Overload characteristics	Dose equivalent rate of 10 times scale maximum or 250 $\text{mSv}\cdot\text{h}^{-1}$, whichever is less	Remain off scale at high end	6.7
Response time	Final indications of the dose equivalent rate less than 0.1 $\text{mSv}\cdot\text{h}^{-1}$ Final indications of the dose equivalent rate between 0.1 $\text{mSv}\cdot\text{h}^{-1}$ and 1 $\text{mSv}\cdot\text{h}^{-1}$ Final indications of the dose equivalent rate larger than 1 $\text{mSv}\cdot\text{h}^{-1}$	<100 s <30 s <10 s	6.9
Alarm threshold drift	In accordance with 6.4.2	± 10 %	6.14
Alarm response time and stability	In accordance with 4.3.2	In accordance with 4.3.2	6.14
Response to photon radiation	Ambient dose equivalent rate equal to 10 $\text{mSv}\cdot\text{h}^{-1}$ from a ^{137}Cs source	Indication < 0,1 $\text{mSv}\cdot\text{h}^{-1}$	6.6
^{a)} Minimum dose rate value as low as reasonably achievable. If the maximum dose rate specified by the manufacturer for dose measurements is less than 1 $\text{Sv}\cdot\text{h}^{-1}$, this should be indicated on the neutron dose rate meter.			

5.2.2 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 $10 H_0$. From the result of each test, the respective variation of the relative response r can be determined.

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 document. If during testing larger effects of type S are observed then the respective test shall be performed at a dose value of $10 H_0$ and these findings shall be reported in the type test report.

5.2.3 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 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 document. 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 $10 H_0$, 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.

5.3 Point of test

The assembly shall be placed in such a way that the reference point of the detector is at the point of test, unless otherwise stated by the manufacturer.

The point of test is a point where the conventionally true value of the dose equivalent rate is known. At this point, the uncertainty due to field inhomogeneities throughout the volume of the detector of the assembly should be achieved, that is the irradiation non-uniformity should be less than 5 %.

The dose equivalent rate value of the scattered radiation at the point of tests shall be determined.

5.4 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 (see 6.8) 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.

5.5 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. ^{244}Cm source can also be used as an additional option for the test source.

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 10.2).

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.

5.6 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).

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.

5.7 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

5.8 Functionality test

5.8.1 General

The functionality test consists of comparing the installed neutron monitor functionality before (pre-test) and during or after (post-test) an environmental, mechanical or electromagnetic disturbance described in Clauses 7, 8 and 9.

5.8.2 Pre-test (preparation)

The pre-test or preparation includes the stabilisation of the installed neutron monitor in standard test conditions, checking its correct functioning. For this, place first the neutron source at a position where the monitor does not alarm and calculate the mean value from sufficient readings in accordance with 5.4, and bring closer progressively the neutron source until you find a position where the monitor alarms.

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.

5.8.3 Post-test

The test has two parts:

a) alarm check

In the appropriate part of Clauses 7, 8 or 9, it is stated whether the functionality test is performed during or after the environmental, mechanical or electromagnetic disturbance. Thus, during or after a disturbance (e.g., the low and high temperature extremes), the monitor shall be exposed to a neutron source at the same position determined accordingly to 5.8.2 and check that the neutron alarm activates.

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.

There shall be no alarm during the test when radioactive sources are not present unless otherwise specified.

b) indication check

Place the neutron source at the same position as in the pre-test and take the same number of readings as in the pre-test. The mean value of the post-test readings shall be calculated and compared to the mean value of the pre-test readings. The mean value shall not change by more than the value specified in Clauses 7, 8 or 9.

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.

There shall be no visible external damage after the environmental, mechanical or electromagnetic disturbance and the instrument shall function correctly as prior to these tests.

6 Radiation detection requirements

6.1 General

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

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 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.

6.2 Consideration of the uncertainty of the conventional true value

The expanded ($k = 2$) relative uncertainty, U_{rel} , of the conventional true value of the 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 Linearity of dose rate response

6.3.1 Requirements

This refers to the linearity of the instrument's measurement range. The instrument error is to be established in respect of the radiation quantity which the equipment is designed to measure.

Under standard test conditions, the response linearity of the detector assembly, when exposed to either of the reference radiations shall not exceed $\pm 30\%$, over the effective measurement range.

NOTE This uncertainty is additional to the uncertainty in the value of the conventional true dose rate.

6.3.2 Tests to be performed

A type test shall be performed on monitoring units comprised of at least one of each type of processing, alarm, and detector assemblies.

Routine tests shall be carried out on each combination of processing units, alarm units and detector assemblies.

All tests shall be carried out using a radiation field unless otherwise agreed between manufacturer and purchaser.

6.3.3 Type tests

For assemblies provided with linear scales, the type test shall be carried out on all ranges and on at least 3 points on each range, i.e. at about 20 %, 40 % and 80 % of the scale range.

For assemblies provided with single range and logarithmic scale, or for digital displays, the type test shall be carried out on all order of magnitude scales of dose rate and on at least 2 points on each order of magnitude scale. (The higher value in each decade shall be at least three times the lower and at least 70 % of the maximum of that order of magnitude.) If a detector contains a priming source this shall be taken into account.

6.3.4 Routine tests

For assemblies provided with linear scale, the routine test shall be carried out at one point on one value (between 50 % and 75 %) in the range in which the highest alarm is set.

For assemblies provided with single range and logarithmic scale, or for digital displays, the test shall be carried out on one value (between 10 % and 90 %) in the range in which the highest alarm is set. If a detector contains a priming source this shall be taken into account.

For routine tests, current or pulse injection to the processing assembly is acceptable. When current or pulse injection is used it shall be based on the radiation type test results.

6.3.5 Test method using sources

a) Source to be used

For the purpose of this test, the conventional true 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.

6.3.6 Interpretation of the results of the test using sources

When all response values of the detector assembly are within ± 30 % of conventional true value over the effective measurement range, then the requirements of 6.3.1 are considered met.

6.3.7 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 distance, 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.

6.3.8 Interpretation of the results of the test with variation of the calibration distance

When the relative errors determined by the procedure specified in 6.3.7 are within ± 30 % of conventional true value in the respective scale range, then the requirements of 6.3.1 are considered met.

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

$$U = \left(\frac{H_{\text{eq}}^{*,i2}(10) \times S_1}{H_{\text{eq}}^{*,i1}(10) \times S_2} - 1 \right)$$

and the observation shall be within the limits given in 6.3.8. If the electrical test method is used, this should be stated in the accompanying documents.

6.3.10 Interpretation of the equivalent electrical test result

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 [6]. 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. They shall be verified with reference measurements.

6.4.2 Requirements

The relative response of ambient dose equivalent rate due to variation of the neutron energy shall be for (see Table 2):

- thermal – 100 keV energy range, the manufacturer shall specify the variation of the ambient dose equivalent rate relative response with the neutron energy. The relative response should be at least within the range from 0,2 to 8,0.

- b) 100 keV – 10 MeV energy range, within the range from 0,5 to 2,0.
- c) 10 MeV – 20 MeV energy range, the manufacturer shall specify the variation of the ambient dose equivalent rate relative response with the neutron energy. The variation of the relative response should be at least within the range from 0,2 to 2,0.
- d) More than 20 MeV, by the agreement between the manufacturer and the purchaser.

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 100 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 Method of test

For this test, the dose 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 100 keV, one of them being thermal neutron energy,
- b) at least three neutron energies in the energy range between 100 keV and 10 MeV,
- c) at least one broad spectrum neutron source (e.g. ^{252}Cf , $^{241}\text{Am-Be}$ or D_2O moderated ^{252}Cf),
- 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.

In the realistic neutron producing field, any kind of monoenergetic neutron fields do not exist, only continuous neutron energy fields exist. Therefore, the relative ambient dose equivalent rate response to realistic workplace neutron fields^[6] would be much more appropriate than the response to monoenergetic neutron fields.

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.

The response of 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. Using the provided computational response function by a manufacturer, a test laboratory, a purchaser or a research institute, 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 Variation of response with angle of incidence

6.5.1 General

This document relates to detector assemblies with a wide angle of acceptance and having essentially circular symmetry in one plane, normally horizontal, in use. The document recognizes the practical limitations of achieving a uniform sensitivity over 4π . The following requirements are formulated for two possible detector configurations. Configuration a) where the orientation for calibration can be regarded as approximate to an axis of symmetry, and configuration b) where the orientation for calibration is normal to a direction that can be regarded as approximate to an axis of symmetry.

The manufacturer shall state the configuration used.

6.5.2 Requirements

The requirements are specified below for both configurations of detector calibration (see Table 2).

Figure 1 illustrates the intended procedure.