

INTERNATIONAL STANDARD

**ISO
8529**

First edition
1989-10-01

Neutron reference radiations for calibrating neutron-measuring devices used for radiation protection purposes and for determining their response as a function of neutron energy

*Rayonnements neutroniques de référence destinés à l'étalonnage des instruments
de mesure des neutrons utilisés en radioprotection et à la détermination de leur
réponse en fonction de l'énergie des neutrons*



Reference number
ISO 8529:1989 (E)



Documents

Document Sharing Hub

Contents

	Page
Foreword	iii
1 Scope and field of application	1
2 Normative references	2
3 Definitions of quantities and units	2
4 Reference radiations for the calibration of neutron-measuring devices	4
4.1 General properties	4
4.2 Characteristics of sources for routine calibrations	5
4.3 Neutron fluence rate produced by a source	5
4.4 Calibration of the neutron source strength	6
4.5 Irradiation facility	7
5 Reference radiations for the determination of the response of neutron-measuring devices as a function of neutron energy	7
5.1 General properties	7
5.2 Reactor reference neutrons	8
5.3 Photoneutron sources	8
5.4 Accelerator-produced neutrons	9
Annexes	
A Graphical and tabular representation of the neutron spectra for radionuclide sources	10
B "Fluence" to "dose" conversion factors for radionuclide sources	17
C "Fluence" to "dose" conversion factors for monoenergetic neutrons	18
D Conventional thermal neutron fluence rate	19
E Bibliography	20

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 8529 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*.

Annexes A, B, C and D form an integral part of this International Standard. Annex E is for information only.

This page intentionally left blank

Neutron reference radiations for calibrating neutron-measuring devices used for radiation protection purposes and for determining their response as a function of neutron energy

1 Scope

This International Standard specifies the neutron reference radiations, in the energy range from thermal up to 20 MeV, for calibrating neutron-measuring devices used for radiation protection purposes and for determining their variation in response as a function of neutron energy. Reference radiations are given for neutron fluence rates of up to $10^5 \text{ cm}^{-2} \cdot \text{s}^{-1}$, corresponding, at a neutron energy of 1 MeV, to dose equivalent rates of up to $100 \text{ mSv} \cdot \text{h}^{-1}$ ($10 \text{ rem} \cdot \text{h}^{-1}$). This International Standard applies to radiation protection calibrations in units of the quantity "dose equivalent", but values are also given in units of the quantities "absorbed dose" and "kerma" in "standard man tissue".

It should be noted that at the present time, the definitions of "dose equivalent" quantities to be used for radiation protection purposes are under review by both the ICRU and the ICRP¹⁾. The definitions of "dose equivalent" and the conversion factors from neutron fluence to dose equivalent given in this International Standard are therefore subject to possible revision.

This International Standard is concerned only with the methods of producing the neutron reference radiations. The procedures for applying these radiations will be described in a future International Standard.

The reference radiations specified are the following:

- neutrons from radionuclide sources, including neutrons from sources in a moderator;
- neutrons produced by nuclear reactions with charged particles from accelerators;
- neutrons from reactors.

In view of the methods of production and use of them, these reference radiations are divided, for the purposes of this International Standard, into two separate clauses:

— In clause 4, radionuclide neutron sources with wide spectra are specified for the calibration of neutron-measuring devices. These sources shall be used by laboratories engaged in the routine calibration of neutron-measuring devices, the particular design of which has already been type tested.

— In clause 5, accelerator-produced monoenergetic neutrons, reactor-produced neutrons with wide and quasi-monoenergetic spectra, and special radionuclide sources are specified for determining the response of neutron-measuring devices as a function of neutron energy. Since these reference radiations are produced at specialized and well equipped laboratories, only the minimum of experimental detail is given.

For the conversion of "neutron fluence" into the quantities recommended for radiation protection and related purposes, the following conversion factors are specified:

- "neutron fluence" to "dose equivalent";
- "neutron fluence" to "charged particle absorbed dose";
- "neutron fluence" to "photon absorbed dose";
- "neutron fluence" to "kerma".

The conversion factors given in annexes B and C are based on the spectra presented in annex A, and on the "fluence" to "dose" conversion factors referred to in 3.6, 3.8 and 3.11. This International Standard does not preclude the use of the reference radiations specified in this International Standard with other "fluence" to "dose" conversion factors, if applicable, in particular those obtained for a different phantom and/or dose equivalents defined at different positions in the phantom. At the present time, the "fluence" to "dose" conversion factors presented in this International Standard are the only internationally accepted values.

1) ICRU: International Commission on Radiation Units and Measurements
ICRP: International Commission on Radiological Protection

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 1677 : 1977, *Sealed radioactive sources — General*.

ISO 2919 : 1980, *Sealed radioactive sources — Classification*.

ICRP Publication 21, *Protection against Ionizing Radiation from External Sources*, 1973 edition. (Supplement to ICRP Publication 15.)

ICRU Report 26, *Neutron Dosimetry for Biology and Medicine*, 1977 edition.

ICRU Report 33, *Radiation Quantities and Units*, 1980 edition.

3 Definitions of quantities and units

NOTES

- 1 The definitions follow the recommendations of ICRU Report 33.
- 2 Multiples and submultiples of SI units are also used throughout this International Standard.

3.1 neutron fluence, Φ : Quotient of dN by da , expressed in reciprocal square metres (m^{-2}), where dN is the number of neutrons incident on a sphere of cross-sectional area da :

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

3.2 neutron fluence rate; neutron flux density, ϕ : Quotient of $d\Phi$ by dt , expressed in reciprocal seconds reciprocal square metres ($s^{-1} \cdot m^{-2}$), where $d\Phi$ is the increment of neutron fluence (see 3.1) in the time interval dt :

$$\phi = \frac{d\Phi}{dt} = \frac{d^2N}{dadt}$$

3.3 spectral distribution of the neutron fluence, Φ_E : Quotient of $d\Phi$ by dE , expressed in reciprocal joules reciprocal square metres ($J^{-1} \cdot m^{-2}$), where $d\Phi$ is the increment of neutron fluence in the energy interval between E and $E + dE$:

$$\Phi_E = \frac{d\Phi}{dE}$$

NOTE — Another unit frequently used is reciprocal electronvolt reciprocal square centimetre ($eV^{-1} \cdot cm^{-2}$).

3.4 spectral neutron fluence rate; spectral neutron flux density, ϕ_E : Quotient of $d\phi_E$ by dt , expressed in reciprocal joules reciprocal square metres reciprocal seconds ($J^{-1} \cdot m^{-2} \cdot s^{-1}$), where $d\phi_E$ is the increment of spectral distributions of the neutron fluence in the time interval dt :

$$\phi_E = \frac{d\phi_E}{dt} = \frac{d^2\phi}{dEdt}$$

NOTE — Another unit frequently used is reciprocal electronvolt reciprocal square centimetre reciprocal second ($eV^{-1} \cdot cm^{-2} \cdot s^{-1}$).

3.5 absorbed dose, D : Quotient of $d\bar{\epsilon}$ by dm , expressed in grays (Gy)¹⁾, where $d\bar{\epsilon}$ is the mean energy imparted by ionizing radiation to matter of mass dm :

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

NOTE — The special unit of absorbed dose, rad, may be used temporarily; 1 rad = 10^{-2} Gy.

3.6 “neutron fluence” to “absorbed dose” conversion factor, d_ϕ : Quotient of absorbed dose, D , and neutron fluence, Φ , expressed in grays square metres ($Gy \cdot m^2$), at the point of reference undisturbed by the irradiated object:

$$d_\phi = \frac{D}{\Phi}$$

Conversion factors are given in annexes B and C for the following two components:

- the heavy charged particle component of absorbed dose: d_ϕ^c
- the neutron capture photon component of absorbed dose for $^1H(n,\gamma)$ ^2D : d_ϕ^γ

It should be noted that, for neutron sources emitting gamma radiations, the total absorbed dose from photons will be given by the sum of the doses from incident gamma radiations and from neutron capture photons.

The values for the “fluence” to “absorbed dose” conversion factors given in this International Standard were derived using the analytical functions for d_ϕ^c and d_ϕ^γ [1].

These functions, based on the original calculations computed in [26], give the mean values for the components of absorbed dose in tissue for the volume element 57 of a cylindrical phantom (diameter 300 mm, height 600 mm) irradiated by a unidirectional broad beam of neutrons incident normally to the axis of the phantom. The phantom was considered to be composed of

1) 1 Gy = 1 J.kg⁻¹

hydrogen, carbon, nitrogen and oxygen in proportions of standard man. Volume element 57, of thickness 30 mm, is situated in the centre of the front surface of the phantom facing the neutron beam.

3.7 kerma, K : Quotient of dE_{tr} by dm , expressed in grays, where dE_{tr} is the sum of the initial kinetic energies of all the charged ionizing particles liberated by uncharged indirectly ionizing particles in a material of mass dm :

$$K = \frac{dE_{tr}}{dm}$$

NOTE — The special unit of kerma, rad, may be used temporarily; 1 rad = 10^{-2} Gy.

3.8 "neutron fluence" to "kerma" conversion factor, k_ϕ : Quotient of kerma, K , and neutron fluence, ϕ , expressed in grays square metres ($Gy \cdot m^2$), at the point of reference, undisturbed by the irradiated object:

$$k_\phi = \frac{K}{\phi}$$

NOTE — Conversion factors are given in annexes B and C. The values are for standard man tissue, in accordance with appendix A of ICRU Report 26.

3.9 dose equivalent, H : Product, expressed in sieverts (Sv)¹⁾, at the point of interest in tissue, of the absorbed dose, D , the quality factor, Q , and the product of any other modifying factors, N :

$$H = DQN$$

NOTE — The special unit of dose equivalent, rem, may be used temporarily; 1 rem = 10^{-2} Sv.

3.10 dose equivalent rate, $\dot{H}$: Quotient of dH by dt , expressed in sieverts reciprocal seconds ($Sv \cdot s^{-1}$), where dH is the increment of dose equivalent in the time interval dt :

$$\dot{H} = \frac{dH}{dt}$$

NOTE — The special unit of dose equivalent rate, rem reciprocal second, may be used temporarily; 1 rem $\cdot s^{-1}$ = 10^{-2} $Sv \cdot s^{-1}$.

3.11 "neutron fluence" to "dose equivalent" conversion factor, h_ϕ : Quotient of the neutron dose equivalent, H , and the neutron fluence, ϕ , expressed in sieverts square metres ($Sv \cdot m^2$), at the point of reference, undisturbed by the irradiated object:

$$h_\phi = \frac{H}{\phi}$$

Values of the "neutron fluence" to "dose equivalent" conversion factor in this International Standard (see also annexes B and C) are taken from ICRP Publication 21. These values refer to irradiation by a unidirectional broad beam of monoenergetic neutrons and are evaluated at the maxima of the depth-dose equivalent curves. The calculations have been mainly made in a 300 mm diameter, 600 mm high cylinder, equivalent to soft tissue, with the broad beam incident perpendicular to the cylinder axis.

3.12 exposure, X : Quotient of dQ by dm , expressed in coulombs reciprocal kilograms ($C \cdot kg^{-1}$), where the value of dQ is the absolute value of the total charge of the ions of one sign produced in air when all the electrons (negatrons and positrons) liberated by photons in air of mass dm are completely stopped in air:

$$X = \frac{dQ}{dm}$$

NOTE — The special unit of exposure, röntgen (R), may be used temporarily; 1 R = $2,58 \times 10^{-4}$ $C \cdot kg^{-1}$.

3.13 exposure rate, $\dot{X}$: Quotient of dX by dt , expressed in coulombs reciprocal kilograms reciprocal seconds ($C \cdot kg^{-1} \cdot s^{-1}$), where dX is the increment of exposure in the time interval dt :

$$\dot{X} = \frac{dX}{dt} = \frac{d^2Q}{dm dt}$$

NOTE — The special unit of exposure rate, röntgen reciprocal second, may be used temporarily; 1 R $\cdot s^{-1}$ = $2,58 \times 10^{-4}$ $C \cdot kg^{-1} \cdot s^{-1}$.

3.14 activity (of an amount of radioactive nuclide in a particular energy state at a given time), A : Quotient of dN^+ by dt , expressed in becquerels (Bq)²⁾, where dN^+ is the expectation value of the number of spontaneous nuclear transitions from that energy state in the time interval dt :

$$A = \frac{dN^+}{dt}$$

NOTE — The special unit of activity, curie (Ci), may be used temporarily; 1 Ci = $3,7 \times 10^{10}$ Bq.

3.15 neutron source strength (of a neutron source at a given time), B : Quotient of dN^* by dt , expressed in reciprocal

1) 1 Sv = 1 J $\cdot kg^{-1}$

2) 1 Bq = 1 s⁻¹

seconds, where dN^* is the expectation value of the number of neutrons emitted by the source in the time interval dt :

$$B = \frac{dN^*}{dt}$$

3.16 angular source strength, B_Ω : In the case of a neutron source, the quotient of dB by $d\Omega$, expressed in reciprocal seconds reciprocal steradians ($s^{-1} \cdot sr^{-1}$), where dB is the number of neutrons propagating in a specified direction within the solid angle $d\Omega$:

$$B_\Omega = \frac{dB}{d\Omega}$$

3.17 spectral distribution of neutron source strength, B_E : Quotient of dB by dE , expressed in reciprocal joules reciprocal seconds ($J^{-1} \cdot s^{-1}$) [reciprocal electronvolts reciprocal seconds ($eV^{-1} \cdot s^{-1}$)], where dB is the increment of neutron source strength in the energy interval between E and $E + dE$:

$$B_E = \frac{dB}{dE}$$

The source strength B is derived from B_E as follows:

$$B = \int_0^\infty B_E dE$$

The spectral neutron fluence rate ϕ_E , due to neutrons emitted isotropically from a point source with a spectral neutron source strength B_E at a distance l (neglecting the influence of surrounding material), is given by (see also 3.4)

$$\phi_E = \frac{B_E}{4\pi l^2}$$

3.18 mean "neutron fluence" to "dose equivalent" conversion factor, $\bar{h}_\phi$: In the case of a neutron source, the "neutron fluence" to "dose equivalent" conversion factor, h_ϕ (see 3.11), averaged over the neutron source spectrum at the point of reference, undisturbed by the irradiated object:

$$\bar{h}_\phi = \frac{1}{B} \int_0^\infty B_E h_\phi(E) dE$$

For the purposes of this International Standard, the symbol $\bar{h}_\phi$ is used for the mean conversion factor derived from the h_ϕ values given in ICRP Publication 21.

3.19 dose equivalent average neutron energy, $\tilde{E}$: In the case of neutrons emitted from a neutron source, the neutron energy averaged over the dose equivalent spectrum at the point of reference. The "dose equivalent spectrum" is given by the product of Φ_E and $h_\phi(E)$, where Φ_E (see 3.3) is the spectral neutron fluence at neutron energy E , at the point of reference and undisturbed by the irradiated object, and $h_\phi(E)$ (see 3.11) is the "neutron fluence" to "dose equivalent" conversion factor at this energy:

$$\tilde{E} = \frac{1}{H} \int_0^\infty E h_\phi(E) \Phi_E dE$$

where

$$H = \int_0^\infty h_\phi(E) \Phi_E dE$$

The dose equivalent average neutron energy can be regarded as the neutron energy value of the centre of gravity of the dose equivalent spectrum.

3.20 response, R : In the case of a neutron-detecting instrument, the quotient

$$R = \frac{M}{G}$$

where

M is the value of the quantity indicated by the instrument or evaluated from its indication;

G is the quantity causing the instrument response. Generally, G is the quantity to be measured.

For the sake of clarity, the response may be specified as the response to this quantity, for example dose equivalent response R_H .

4 Reference radiations for the calibration of neutron-measuring devices

In this clause, reference radiations produced by radionuclide neutron sources are specified which are particularly suited for the calibration of neutron-measuring devices. It is generally not necessary to calibrate an instrument with all the listed reference radiations.

4.1 General properties

4.1.1 Type

The neutron sources given in table 1 shall be used to produce reference radiations. The numerical values given in table 1 are to be taken only as a guide to the prominent features of the sources. The neutron source strengths and the specific dose equivalent rates vary with the construction of the source, because of scattering and absorption of neutrons and gamma radiations and with the isotopic impurities of the radioactive material used. Hence details of the source encapsulation are specified (see 4.1.2), and the method for determining the anisotropy of the neutron fluence rate is specified (see 4.3). For ^{252}Cf , the specific photon dose equivalent rate is dependent upon the age of the source because of the build-up of γ -emitting fission products. However, the increase is not more than 5 % during the first 20 years.

4.1.2 Source shape and encapsulation

The shape of the source should be spherical or cylindrical, and, in the latter case, it is preferable that the diameter and length are approximately the same. The thickness of the encapsulation should be uniform and small compared to the external diameter. For a $^{241}\text{Am-Be}(\alpha, n)$ source, the spectral distribution,

Table 1 — Reference radionuclide neutron sources for calibrating neutron-measuring devices

Source ¹⁾	Half-life	Dose equivalent average energy ²⁾	Specific source strength ³⁾	Specific neutron dose equivalent rate at 1 m distance ⁴⁾	Specific photon dose equivalent rate ⁵⁾ at 1 m distance ⁴⁾
²⁵² Cf(D ₂ O moderated) ⁷⁾ (sphere 300 mm in diameter)	a ⁶⁾	MeV	s ⁻¹ .kg ⁻¹	Sv.s ⁻¹ .kg ⁻¹	Sv.s ⁻¹ .kg ⁻¹
	2,65	2,2	$2,1 \times 10^{15}$	1,5	0,25
	2,65	2,4	$2,4 \times 10^{15}$	6,5	0,31 ⁸⁾
²⁵² Cf	2,65	2,4	$2,4 \times 10^{15}$	6,5	0,31 ⁸⁾
²⁴¹ Am-B(α ,n)	a	MeV	s ⁻¹ .Bq ⁻¹	Sv.s ⁻¹ .Bq ⁻¹	Sv.s ⁻¹ .Bq ⁻¹
	432	2,8	$1,6 \times 10^{-5}$	5×10^{-20}	$1,9 \times 10^{-19}$
	432	4,4	$6,6 \times 10^{-5}$	2×10^{-19}	$1,9 \times 10^{-19}$
²⁴¹ Am-Be(α ,n)	432	4,4	$6,6 \times 10^{-5}$	2×10^{-19}	$1,9 \times 10^{-19}$

1) In addition to the sources listed, sources such as Pu-Be(α ,n) and Am-Li(α ,n) are also used. However, it is recommended that laboratories should not start using plutonium-beryllium sources if they are not already doing so.

2) Neutron spectra of sources are given in figures A.1 to A.4. Definition of the dose equivalent average energy is given in 3.19.

3) The specific source strength, the specific neutron dose equivalent rate and the specific photon dose equivalent rate are the respective quantities related to the mass of 1 kg or the source activity of 1 Bq. Information on the sources is given for moderated ²⁵²Cf in references [1, 2 and 3], for ²⁵²Cf in [4], for ²⁴¹Am-B in [5], and for ²⁴¹Am-Be in [6].

4) For ²⁵²Cf sources, this is related to the mass of californium contained in the source; for the other sources, this is related to the activity of the ²⁴¹Am contained in the source.

5) Conversion of exposure to dose equivalent was performed using the factor 0,01 Sv.R⁻¹.

6) 1 a = 1 mean solar year = 31 556 926 s or 365,242 20 days.

7) Heavy-water sphere with a diameter of 300 mm covered with a cadmium shell of thickness approximately 1 mm.

8) For approximately 2,5 mm thick steel encapsulation.

mainly in the energy range below approximately 2 MeV, depends, to some extent, on the size and the composition of the source [4]. Sources should comply with the encapsulation requirements laid down in ISO 1677 and ISO 2919.

The ²⁴¹Am-Be(α ,n) source may be wrapped in a 1 mm thick lead shield. This reduces the photon dose equivalent rate to less than 5 % of the neutron dose equivalent rate. The lead shield produces a negligible change (less than 1 %) in the neutron dose equivalent rate. In the absence of the lead shield, the photon dose equivalent rate (mainly from gamma radiations having an energy of 59,5 keV) will depend upon the source construction, but may be comparable with the neutron dose equivalent rate.

4.2 Characteristics of sources for routine calibrations

4.2.1 Types

Preferably ²⁵²Cf spontaneous fission and/or ²⁴¹Am-Be(α ,n) sources should be used for routine calibrations. ²⁵²Cf sources generally have a high specific source strength and are therefore comparatively small. The americium-based neutron sources shall consist of a homogeneous, compressed mixture of americium oxide and beryllium or boron as appropriate. Americium alloys may also be used.

4.2.2 Spectral distribution of neutron source strength

The spectral distributions of neutron source strength for ²⁵²Cf, ²⁴¹Am-Be(α ,n), ²⁵²Cf(D₂O moderated) and ²⁴¹Am-B(α ,n) sources are given in annex A (tables A.1 to A.4 and figures A.1 to A.4). The spectral distribution of the neutron source strength, B_E , of ²⁵²Cf can be described in the energy range from 100 keV to 10 MeV by the following formula:

$$B_E = \frac{2}{\sqrt{\pi} T^{3/2}} \times \sqrt{E} \times e^{-E/T} \times B$$

where T is a spectrum parameter given by $T = 1,42$ MeV [4]. (See figure A.1.)

4.2.3 "Neutron fluence" to "dose equivalent" conversion factors

The dose equivalent for the ²⁵²Cf, ²⁴¹Am-Be(α ,n), ²⁵²Cf(D₂O moderated) and ²⁴¹Am-B(α ,n) sources shall be calculated from the fluence using the values of the mean "neutron fluence" to "dose equivalent" conversion factor, $\bar{h}_\phi$, given in annex B.

4.3 Neutron fluence rate produced by a source

Neutron sources generally show anisotropic neutron emission in a coordinate system fixed in the geometrical centre of the source. For cylindrical sources, the angular source strength, B_Ω , in a direction Ω , which is characterized by the angles θ and