SLOVENSKI STANDARD
oSIST prEN ISO 8529-1:2023

01-maj-2023

Referenčna polja nevtronskih sevanj - 1. del: Značilnosti in metode izdelave (ISO 8529-1:2021)

Neutron reference radiations fields - Part 1: Characteristics and methods of production (ISO 8529-1:2021)

Champs de rayonnement neutronique de référence - Partie 1: Caractéristiques et méthodes de production (ISO 8529-1:2021)

Ta slovenski standard je istoveten z: **prEN ISO 8529-1**

ICS:

17.240	Merjenje sevanja	Radiation measurements

oSIST prEN ISO 8529-1:2023 **en,fr,de**

INTERNATIONAL STANDARD

ISO 8529-1

Second edition
2021-11

Neutron reference radiations fields —

Part 1: Characteristics and methods of production

Champs de rayonnement neutronique de référence —

Partie 1: Caractéristiques et méthodes de production

Reference number
ISO 8529-1:2021(E)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiation protection*.

A list of all the parts in the ISO 8529 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This is the first of a set of three International Standards concerning the calibration of dosemeters and dose rate meters for neutron radiation for protection purposes. It describes the characteristics and methods of production of the neutron reference radiation fields to be used for calibrations. ISO 8529-2 describes fundamentals related to the physical quantities characterizing the radiation field and calibration procedures in general terms, with emphasis on active dose rate meters and the use of radionuclide sources. ISO 8529-3 deals with dosemeters for area and individual monitoring, describing the respective procedures for calibrating and determining the response in terms of the International Commission on Radiation Units and Measurements (ICRU) operational quantities. Conversion coefficients for converting neutron fluence into these operational quantities are provided in ISO 8529-3.

Neutron reference radiations fields —

Part 1:
Characteristics and methods of production

1 Scope

This document specifies the neutron reference radiation fields, in the energy range from thermal up to 20 MeV, for calibrating neutron-measuring devices used for radiation protection purposes and for determining their response as a function of neutron energy.

This document is concerned only with the methods of producing and characterizing the neutron reference radiation fields. The procedures for applying these radiation fields for calibrations are described in References [1] and [2].

The neutron reference radiation fields specified are the following:

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

In view of the methods of production and use of them, these neutron reference radiation fields are divided, for the purposes of this document, into the following three separate clauses:

- In Clause 4, radionuclide neutron sources with wide spectra are specified for the calibration of neutron-measuring devices. These sources should 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 and reactor-produced neutrons with wide or quasi monoenergetic spectra are specified for determining the response of neutron-measuring devices as a function of neutron energy. Since these neutron reference radiation fields are produced at specialized and well-equipped laboratories, only the minimum of experimental detail is given.
- In Clause 6, thermal neutron fields are specified. These fields can be produced by moderated radionuclide sources, accelerators, or reactors.

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.

ISO 29661, *Reference radiation fields for radiation protection — Definitions and fundamental concepts*

3 Terms and definitions

For the purposes of this document, the terms and definitions of ISO 29661 and the following apply:

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

- ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
neutron emission rate of a neutron source

B

differential quotient of N with respect to time, where N is the number of neutrons being emitted from the source, in all directions

$$B = \frac{\mathrm{d}N}{\mathrm{d}t}$$

Note 1 to entry: The unit of the neutron emission rate is s^{-1}.

3.2
direction distribution of the neutron emission rate
angular distribution of the neutron emission rate

B_Ω

differential quotient of B with respect to solid angle, where Ω is a specific spatial direction

$$B_\Omega = \frac{\mathrm{d}B}{\mathrm{d}\Omega}$$

Note 1 to entry: The unit of the direction distribution of the neutron emission rate is $\mathrm{s}^{-1}\ \mathrm{sr}^{-1}$.

3.3
energy distribution of the neutron emission rate
spectral neutron emission rate

B_E

differential quotient of B with respect to energy, where E is the neutron energy

$$B_E = \frac{\mathrm{d}B}{\mathrm{d}E}$$

Note 1 to entry: The unit of the spectrum of neutron emission rate is $\mathrm{s}^{-1}\ \mathrm{J}^{-1}$; a frequently used unit is $\mathrm{s}^{-1}\ \mathrm{MeV}^{-1}$.

Note 2 to entry: The terms “spectrum” and “energy distribution” are considered to be equivalent.

Note 3 to entry: The neutron source emission rate B is derived from B_E as follows:

$$B = \int_0^\infty B_E \,\mathrm{d}E$$

Note 4 to entry: At a distance l from a point source, the energy distribution of the fluence rate φ_E, due to neutrons emitted isotropically from the point source with a spectral neutron emission rate B_E (neglecting the influence of the air and the surrounding material), is given by:

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

3.4
fluence-averaged neutron energy

$\bar{E}$

neutron energy averaged over the energy distribution of the fluence

$$\bar{E} = \frac{1}{\Phi}\int_0^\infty E \cdot \Phi_E\left(E\right)\mathrm{d}E$$

where $\Phi_E(E)$ is the energy distribution of the neutron fluence and Φ is the total fluence.

4 Broad spectrum neutron reference radiation fields produced with radionuclide sources

4.1 Overview

In this clause, neutron reference fields produced with radionuclide sources are specified, which are particularly suited for the calibration of neutron-measuring devices (see Reference [2]).

Thermal neutron reference radiation fields are achievable by moderating radionuclide sources, but are covered by Clause 6.

4.2 Types of calibration sources

The radionuclide sources given in Table 1 shall be used to produce neutron reference radiation fields. The numerical values given in Table 1 are to be taken only as a guide to the prominent features of the sources, since the properties of a specific source vary with the construction of the source, because of scattering and absorption of neutron and gamma radiation, and with the isotopic impurities of the radioactive material used. Hence details of the source encapsulation are specified (see 4.3), and the method for determining the anisotropy of the neutron emission is specified (see Annex E).

^{252}Cf has a high specific neutron emission rate and ^{252}Cf sources are therefore comparatively small. Because of their short half-life of 2,647 years, they need regular replacement.

The D_2O-moderated ^{252}Cf source is ideally composed of a point ^{252}Cf source located in the centre of a 300 mm diameter heavy-water sphere, surrounded by

a) a 0,8 mm thick iron shell, and

b) a1 mm thick cadmium shell.

In practice, a number of designs have been developed in reference laboratories, being slightly different in terms of construction details, such as the guide used to locate the source in the sphere centre, the material used to contain the heavy water, and the structure used to suspend or hold the moderating sphere. In addition, every moderating assembly has specific D_2O purity and ^{252}Cf source capsule. The experience of reference laboratories suggests that variability in the construction of D_2O-moderated ^{252}Cf sources results in non-negligible differences in the energy distribution of the neutron fluence[3]. Laboratories should characterize their D_2O-moderated ^{252}Cf sources by simulations and spectral measurements. The energy distribution of the neutron emission rate and spectrum-averaged quantities of these fields should be checked through comparisons. A representative spectrum of the D_2O-moderated ^{252}Cf source was derived, for the purposes of this document, by Monte Carlo simulations. In this model, 11,4 % of the source neutrons are absorbed in the moderating assembly. See Annex C for details.

^{241}Am-Be (α,n) neutron sources include appropriate alloys, mixtures or compounds of americium, such as a compressed mixture of americium oxide and beryllium as appropriate. See Annex D for details.

In addition to the sources listed in Table 1, sources such as ^{241}Am-B(α,n)[4][5][6], Pu-Li(α,n)[7][8], Pu-Be(α,n)[8], ^{241}Am-F(α,n)[6], ^{241}Am-Li(α,n)[9] and ^{244}Cm[10] are also used but are not addressed specifically in this document[1].

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[1] Plutonium-based (α,n) sources may actually include more than one plutonium isotope, such as ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{242}Pu.

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

Source	Half-life	Fluence-averaged energy[a]	Specific source emission rate[b]	Ratio of photon to neutron ambient-dose-equivalent rates[c]
	a[d]	MeV	s^{-1} kg^{-1}	
^{252}Cf (D_2O moderated)	2,647	0,57	2,1 × 10^{15}	<0,18[e]
^{252}Cf	2,647	2,13	2,4 × 10^{15}	0,05[f]
			s^{-1} Bq^{-1}	
^{241}Am-Be(α,n) small source[g] large source	432,6	4,17 4,05	6 × 10^{-5}	<0,035[h]

[a] The reported values are calculated applying the definition of the fluence-averaged neutron energy given in 3.4 to the spectra tabulated in Annexes B, C and D.

[b] For ^{252}Cf sources, the specific emission rate is related to the mass of californium. For the ^{241}Am-Be sources, this is related to the ^{241}Am activity and is subject to variations according to manufacturing process and degree of mixing. For both ^{252}Cf and ^{241}Am-Be, these are indicative values only. For any source used to produce reference fields, a determination of the neutron emission rate is needed. Information on the sources is given in References [3][11][12] for moderated ^{252}Cf, Reference [13] for ^{252}Cf, and References [4][5][14][16] for ^{241}Am-Be.

[c] Calculated on the basis of the neutron spectra given in Annexes B, C and D and the conversion coefficients given in Reference [17].

[d] a = 1 mean solar year = 31 556 926 s or 365,242 20 days. Uncertainties on ^{252}Cf and ^{241}Am half-life can be assumed as 0,1 % (k=1) and 0,14 % (k=1) respectively. Half-life and related uncertainty are taken from Reference [18].

[e] Data from References [12][19].

[f] For approximately 2,5 mm thick steel encapsulation. The low energy gamma spectrum of ^{252}Cf is easily shielded by the small amount of steel in the encapsulation. Other construction details are likely to affect the ratio. Data for the photon component of the ^{252}Cf field are available in References [20][22].

[g] For definition of "small" and "large" ^{241}Am-Be source, see Annex D.

[h] For sources enclosed within an additional 1 mm to 2 mm thick lead shield, see 4.4 for more information.

4.3 Source shape and encapsulation

The shape of the source would ideally be spherical, but most practical sources are cylindrical. 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}Am-Be(α,n) source, the spectral distribution, mainly in the energy range below approximately 2 MeV, depends, to some extent, on the size and the composition of the source[5][15][16]. See Annex D for more details.

Sources should comply with ISO 2919 encapsulation requirements[23].

4.4 Photon component of the neutron field

For ^{252}Cf, the ratio of photon to neutron ambient dose equivalent rate is dependent upon the age of the source because of the build-up of gamma-emitting fission products, as well as upon source encapsulation. The 5 % value reported in Table 1 refers to new sources. During the first 30 years, this is likely to remain below 10 %[21][22].

The ^{241}Am-Be(α,n) source may be wrapped in a lead shield to reduce the gamma component. A thickness of 1 mm to 2 mm reduces the photon to neutron dose-equivalent rate to less than 3,5 %[20][21][23]. This ratio does not depend on the americium activity and source encapsulation. 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 to neutron dose equivalent rate (mainly from 59,5 keV gamma radiation) depends upon the source construction. Based on bibliography data[20], it decreases as the physical size of the source increases. Typical values for bare sources are 50 % for small sources (in the order of 37 GBq), 30 % and 20 % for larger sources (370 GBq and 555 GBq respectively).