INTERNATIONAL STANDARD

ISO 10647

First edition
1996-12-15

Procedures for calibrating and determining the response of neutron-measuring devices used for radiation protection purposes

Méthodes d'étalonnage et de détermination de la réponse des instruments de mesure des neutrons utilisés en radioprotection

Reference number
ISO 10647:1996(E)

Contents

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Annexes

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 voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10647 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

Annexes A to F form an integral part of this International Standard. Annexes G and H are for information only.

Procedures for calibrating and determining the response of neutron-measuring devices used for radiation protection purposes

1 Scope

This International Standard specifies procedures for the calibration of neutron-measuring devices used for radiation protection purposes, and for determining their response as a function of energy, angle of incidence and dose equivalent rate, using the neutron reference radiations specified in ISO 8529.

Since, according to ICRU Report 39 and ICRU Report 43, neutrons of all energies are strongly penetrating, area monitors should be calibrated in terms of ambient dose equivalent [$H^*(10)$], and individual dosemeters should be calibrated to measure individual dose equivalent, penetrating [$H_p(10)$]. The procedures given in this International Standard are, however, quite general, and may be used with any system of dose equivalent quantities. A diagrammatic scheme of the physical characteristics to be tested is given as annex A.

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 indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 8529:1989, *Neutron reference radiations for calibrating neutron-measuring devices used for radiation protection purposes and for determining their response as a function of neutron energy.*

IEC 1005, 1990: *Portable neutron ambient dose equivalent rate-meters for use in radiation protection.*

ICRP Publication 21 (1973): *Data for Protection Against Ionizing Radiation from External Sources.* (Supplement to ICRP Publication 15.)

ICRU Report 13 (1969): *Neutron Fluence, Neutron Spectra and Kerma.* International Commission on Radiation Units and Measurements, Washington, D.C., USA.

ICRU Report 20 (1971): *Radiation Protection Instrumentation and its Application.* International Commission on Radiation Units and Measurements, Washington, D.C., USA.

ICRU Report 26 (1977): *Neutron Dosimetry for Biology and Medicine.* International Commission on Radiation Units and Measurements, Washington, D.C., USA.

ICRU Report 33 (1980): *Radiation Quantities and Units.* International Commission on Radiation Units and Measurements, Washington, D.C., USA.

1) ICRP: International Commission on Radiological Protection.

ICRU Report 39 (1985): *Determination of Dose Equivalents Resulting from External Radiation Sources*. International Commission on Radiation Units and Measurements, Bethesda, MD, USA.

ICRU Report 43 (1988): *Determination of Dose Equivalents Resulting from External Radiation Sources — Part 2*. International Commission on Radiation Units and Measurements, Bethesda, MD, USA.

3 Devices covered in this International Standard

This International Standard applies to individual dosemeters and to portable devices for surveying and area monitoring, some examples of which are given in 3.1 and 3.2. Some of these devices may also be used as reference instruments.

3.1 Individual dosemeters

Individual dosemeters include devices such as

— nuclear emulsions;

— solid-state nuclear track detectors;

— albedo dosemeters;

— pocket ionization chambers;

— bubble, or superheated drop, detectors;

— semiconductor detectors.

These shall be calibrated on a suitable phantom (see annex B). Reviews of the physical characteristics of individual dosemeters are given by Griffith et al. [1]. Reviews of calibration procedures are given by Eisenhauer et al. [2] and by Burger and Schwartz [3].

3.2 Devices for surveying and area monitoring

Dose equivalent meters, dose equivalent ratemeters or monitors for surveying and area monitoring of neutrons are generally portable devices, calibrated free-in-air, rather than on a phantom. These devices include

— moderating devices with thermal-neutron detectors for the measurement of neutrons over a wide range of energies;

— low-pressure tissue-equivalent proportional counters for the measurement of absorbed dose and dose equivalent;

— large ionization chambers for the measurement of tissue kerma;

— BF_3 and ^3He proportional counters for the measurement of thermal neutrons;

— bubble, or superheated drop, detectors;

— recombination dose equivalent ratemeters.

More details concerning the characteristics of portable neutron dose-equivalent ratemeters, and of their calibration requirements and procedures are given in references [3] and [4] in annex H, and in IEC 1005. Complete definitions of radiation quantities and units can be found in ICRP Publication 21, ICRU Report 13, ICRU Report 33, ICRU Report 39, ICRU Report 43, and ISO 8529.

4 Definitions

For the purposes of this International Standard, the following definitions apply.

4.1 Metrological terms

4.1.1 reading, M: Value of the quantity indicated by an instrument.

4.1.2 response, R: Reading divided by the magnitude of the quantity causing it.

The type of response shall be specified, for example:

"fluence response",

$$R_{\Phi} = \frac{M}{\Phi} \quad \ldots (1)$$

"dose equivalent response",

$$R_{H} = \frac{M}{H} \quad \ldots (2)$$

or "photon dose equivalent response",

$$R_{H_\gamma} = \frac{M}{H_\gamma} \quad \ldots (3)$$

If M is a measurement of a rate, the quantities fluence, Φ, and dose equivalent, H, are replaced by fluence rate, ϕ, and dose equivalent rate, H, respectively.

The concept of dose equivalent, H, in this International Standard is intended to be general. For example, it may apply to the dose equivalent calculated at the maximum of the depth-dose equivalent curve, i.e. MADE (ICRP Publication 21) or the ambient dose equivalent (ICRU Report 39).

4.1.3 calibration factor, C: Reciprocal of the response; factor by which the reading, M, is multiplied to obtain the value of the quantity to be measured.

4.1.4 energy dependence of response, $R_{\Phi}(E)$ or $R_H(E)$: Response, R, with respect to fluence, Φ, or dose equivalent, H, to monoenergetic neutrons as a function of neutron energy, E.

4.1.5 angular dependence of response: Response as a function of the direction of incidence of neutrons on the device.

4.1.6 gamma-ray sensitivity: Change in the neutron reading of a device when gamma-rays are added to a neutron field.

(Compare with "photon dose equivalent response" in 4.1.2).

4.1.7 free-field quantities: Quantity which would exist if irradiations were performed in free space with no scatter or background effects.

4.2 Reference and monitoring instruments

4.2.1 primary standard instrument: Instrument that is capable of determining the required radiation quantity from known physical data only.

4.2.2 secondary standard instrument: Instrument whose radiation response characteristics have been determined by comparison with a primary standard instrument.

4.2.3 transfer instrument: Instrument whose radiation response characteristics, response precision and long-term stability make it suitable for comparing the measurement of a radiation quantity in one laboratory with that in another.

4.2.4 monitoring instrument: Instrument with suitable physical properties to monitor the radiation field characteristics in a given laboratory over a long term.

More details concerning primary standards, secondary standards, and transfer instruments can be found in ICRU Report 20 and ICRU Report 26.

4.3 Devices to be tested

4.3.1 neutron dosemeter: Device for the determination of neutron dose equivalent, kerma, or absorbed dose.

4.3.2 neutron dose-ratemeter: Device for the determination of neutron dose equivalent rate, kerma rate, or absorbed dose rate.

4.3.3 neutron detector: Device sensitive to neutrons.

5 Symbols

For the purposes of this International Standard, the following symbols, and certain symbols listed in annex G, apply.

Symbol	Meaning
k	Characteristic constant for source-detector combination
r	Detector radius
A	Total air-scatter component
C	Calibration factor
F_1	Geometry-correction factor
F_A	Air outscatter factor
F_I	Anisotropy correction factor
M_c	Instrument reading under free-field conditions
M_S	Instrument reading due to inscattered neutrons alone, during a shadow-cone calibration procedure
M_T	Total instrument reading during a calibration procedure
S	Room back-scatter component
δ	Effectiveness factor
Δ	Lateral dosemeter distance on phantom surface
$\overline{\Sigma}$	Linear attenuation coefficient (energy averaged)

6 Traceability of the calibration of the reference radiation field

The neutron fluence rate of a radiation field established in a calibration laboratory in accordance with this International Standard shall be traceable to a recognized national or international standard. The method used to provide this calibration link is dependent upon the type of reference radiation field, but measurement traceability is usually achieved through the utilization of a transfer standard. This may be, for example, a radionuclide source (6.1) or an approved transfer instrument (see 6.2). The calibration of the field is valid in exact terms only at the time of the calibration, and thereafter shall be inferred, for example, from a knowledge of the half-life and isotopic composition of the radionuclide source, or knowledge of the properties of the transfer instrument.

The measurement technique used by the laboratory in the calibration of a neutron-measuring device shall also be approved by a body or institution as required by national regulations. An instrument of the same, or similar, type as that routinely calibrated by the laboratory shall be calibrated by both the reference laboratory and the calibration laboratory. These measurements shall be performed within each laboratory using its own approved calibration methods. In order to demonstrate that adequate traceability has been achieved, the calibration laboratory should obtain the same calibration factor, within agreed-upon limits, as that obtained by the reference laboratory.

The frequency of field calibrations shall be such that there is reasonable confidence that its value will not move outside the limits of its specification between successive calibrations. The frequency of calibration of the radionuclide neutron sources is given in ISO 8529. The calibration of the laboratory-approved transfer instrument, and the check on the measurement techniques used by the calibration laboratory, shall be carried out at least every five years, or whenever there are significant changes in the laboratory environment.

6.1 Traceability for radionuclide neutron sources

For calibrations using neutron fields produced by radionuclide neutron sources, traceability shall be provided either by using a radionuclide source whose angular source strength has been determined by a reference laboratory (see 7.2.1 for angular source strength), or by determining the fluence rate at the instrument test position using an agreed-upon transfer instrument, calibrated in a reference laboratory. If the source is encapsulated according to the recommendations in ISO 8529:1989, 4.1.2, it may then be assumed that the spectral neutron fluence from the source is sufficiently similar to the appropriate spectral fluence given in ISO 8529 for the recommended fluence-to-dose equivalent conversion factors to be used. The uncertainties in the conversion factors recommended in 10.1.8 of this International Standard reflect both uncertainties in the spectra given in ISO 8529, as well as variations in the spectra caused by differences in source construction and encapsulation.

6.2 Traceability for neutrons produced by an accelerator

Traceability shall be provided by using a transfer instrument which has been agreed upon by the calibration and reference laboratories. The transfer instrument shall be used in the same manner, for similar neutron fields, as when it was calibrated, and the proper corrections shall be applied (see 7.2).

The laboratory transfer and monitoring instruments shall be checked at intervals as required by national regulations (for example, by using an appropriate radionuclide neutron source), and the results shall be recorded.

6.3 Traceability for reactor neutron beams

The same general principle of traceability to a recognized standard shall be applied to the calibration of these specialized reference radiation fields (thermal or filtered neutron beams). For example, the thermal-neutron fluence rate may be measured by the activation of gold foils, for which the measurement is traceable to a primary standard.

7 Calibration principles for radionuclide neutron sources

7.1 General principles

The response or calibration factor of a device is a unique property of the type of device, and may depend on the dose equivalent rate, the neutron source spectrum or the angle of incidence of the neutrons, but should not be a function of the characteristics of the calibration facility or experimental techniques employed. Hence, in this International Standard, detailed procedures are given for the calibration of neutron-measuring devices which should ensure that their calibration is independent of the technique, and of such factors as the source-to-device distance and room size.

For simplicity, general principles are given for the calibration of devices such as dose equivalent ratemeters, but most of the principles apply to other devices as well. The instrument is placed in a radiation field of known free-field fluence rate and the instrument reading is noted. In accordance with the above paragraph, the reading must be corrected for all extraneous neutron scattering effects, including neutron scattering by the air and by the walls, floor and ceiling of the calibration room (see 7.2). It may also have to be corrected for effects due to source or detector size (see discussion of the geometry-correction factor $F_1(l)$ in 8.3).

The free-field fluence response, R_Φ, of the instrument is then given by

$$R_\Phi = \frac{M_c}{\Phi} \qquad \ldots (4)$$

where M_c is the measured reading corrected for all extraneous effects.

The free-field fluence rate ϕ to which the instrument has been exposed is calculated from

$$\phi = \frac{B_\Omega}{l^2} \qquad \ldots (5)$$

where l is the distance from the centre of the source to the effective point of measurement (see 7.4).

The neutron angular source strength, B_Ω, (defined in ISO 8529) is calculated from

$$B_\Omega = \frac{B \times F_l(\theta)}{4\pi} \qquad \ldots (6)$$

where

B is the neutron source strength (i.e. the total neutron emission rate into 4π sr);

$F_l(\theta)$ is the source anisotropy correction (reference [5] in annex H).

Anisotropy functions for two types of sources are shown in annex C.

It is sometimes convenient to introduce the source-detector characteristic constant, k, which is just the instrument reading at unit distance, fully corrected for all scattering effects (see 7.3). In general

$$k = M_C\, l^2 \qquad \text{. . . (7)}$$

Then, from equations (4) and (5), we obtain

$$k = R_\phi\, B_\Omega \qquad \text{. . . (8)}$$

The constant k is specific to each source-detector combination, since it depends on the quantities B_Ω and R_ϕ.

Finally, the dose equivalent response, R_H, is obtained from

$$R_H = \frac{R_\Phi}{h_\Phi} \qquad \text{. . . (9)}$$

where h_Φ is the fluence-to-dose equivalent conversion factor. Recommended values of h_Φ, in accordance with ICRP Publication 21, are given in annex B of ISO 8529:1989 for ISO standard sources. The value of h_Φ and an appropriate reference should always be given.

7.2 Important features of a neutron calibration facility

7.2.1 Source

The calibration field of the radionuclide source shall be traceable to a reference laboratory (see clause 6). To minimize anisotropic neutron emission, the source shall be spherical or cylindrical. In the latter case, it is preferable that the diameter and length be approximately the same. For cylindrical sources, the detector shall be calibrated at $\theta = 90°$ to the cylindrical axis (see ISO 8529:1989, 4.3). The anisotropy shall be measured for each source used. The encapsulation shall be as light as possible, consistent with relevant national and international standards for the integrity of sealed radioactive sources. For heavily encapsulated sources, there may be spectral changes associated with the anisotropic emission. Eisenhauer and Hunt [5] used a long counter to determine the fluence anisotropy. Examples of the anisotropy function are given in annex C of this International Standard, and 4.3 of ISO 8529:1989 (see Eisenhauer et al. [2] for a more complete discussion.)

The source shall be located at the centre of the room or, in the case of an open facility, as high as practical above the ground. The source shall be supported by a non-hydrogenous structure with as small a mass as possible.

In order to perform a complete linearity check, a variation in dose equivalent rate of more than three decades may be required (e.g. from ~ 10 µSv · h^{-1} to ~ 40 mSv · h^{-1}). It will usually be impractical to cover this range by varying only the distance, l. Rather, two (or more) sources, varying in source strength by factors of 10 to 100, will generally be required. The anisotropy factor, $F_l(\theta)$, will not necessarily be the same for the different sources, even if they are nominally identical in construction.

7.2.2 Irradiation set-up

A support system shall be used to position the instrument under test at a known distance and angle relative to the calibration source. The support shall be rigid, but designed to minimize scattered radiation. It shall be possible to move the detector such that the detector-to-source separation distance can be varied. When a calibrated device is used to determine the fluence rate, its support system should satisfy the same requirements.

7.2.3 Irradiation room

The response of the device to room-scattered neutrons will vary with the size, shape and construction of the room. The room shall be such that scatter contributions are as low as possible, but in any case they shall not cause an increase in the instrument reading of more than 40% at the calibration point (see annex D).

7.3 Sources of scattered neutrons

Calibration factors shall be a unique property of the instrument type and neutron source spectrum, and **not** a function of the characteristics of the calibration facility. All calibrations shall therefore refer to the free-field quantities, and corrections shall be made for the influence of scattered neutrons upon the reading of the device.

In general, the scattering effects described in 7.3.1 to 7.3.5 may occur.