INTERNATIONAL STANDARD

ISO 20785-2

First edition
2011-06-01

Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 2: Characterization of instrument response

Dosimétrie de l'exposition au rayonnement cosmique dans l'aviation civile —

Partie 2: Caractérisation de la réponse des instruments

Reference number
ISO 20785-2:2011(E)

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Published in Switzerland

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Foreword

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The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 20785-2 was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

ISO 20785 consists of the following parts, under the general title *Dosimetry for exposures to cosmic radiation in civilian aircraft*:

- *Part 1: Conceptual basis for measurements*
- *Part 2: Characterization of instrument response*

A Part 3 dealing with measurements at aviation altitudes is in preparation.

Introduction

Aircraft crews are exposed to elevated levels of cosmic radiation of galactic and solar origin and secondary radiation produced in the atmosphere, the aircraft structure and its contents. Following recommendations of the International Commission on Radiological Protection in Publication 60[1], confirmed by Publication 103[2], the European Union (EU) introduced a revised Basic Safety Standards Directive[3] which included exposure to natural sources of ionizing radiation, including cosmic radiation, as occupational exposure. The Directive requires account to be taken of the exposure of aircraft crew liable to receive more than 1 mSv per year. It then identifies the following four protection measures: (i) to assess the exposure of the crew concerned; (ii) to take into account the assessed exposure when organizing working schedules with a view to reducing the doses of highly exposed crew; (iii) to inform the workers concerned of the health risks their work involves; and (iv) to apply the same special protection during pregnancy to female crew in respect of the “child to be born” as to other female workers. The EU Council Directive has already been incorporated into laws and regulations of EU member states and is being included in the aviation safety standards and procedures of the Joint Aviation Authorities and the European Air Safety Agency. Other countries, such as Canada and Japan, have issued advisories to their airline industries to manage aircraft crew exposure.

For regulatory and legislative purposes, the radiation protection quantities of interest are equivalent dose (to the foetus) and effective dose. The cosmic radiation exposure of the body is essentially uniform, and the maternal abdomen provides no effective shielding to the foetus. As a result, the magnitude of equivalent dose to the foetus can be put equal to that of the effective dose received by the mother. Doses on board aircraft are generally predictable, and events comparable to unplanned exposure in other radiological workplaces cannot normally occur (with the rare exceptions of extremely intense and energetic solar particle events). Personal dosemeters for routine use are not considered necessary. The preferred approach for the assessment of doses of aircraft crew, where necessary, is to calculate directly the effective dose per unit time, as a function of geographic location, altitude and solar cycle phase, and to combine these values with flight and staff roster information to obtain estimates of effective doses for individuals. This approach is supported by guidance from the European Commission and the ICRP in Publication 75[4].

The role of calculations in this procedure is unique in routine radiation protection, and it is widely accepted that the calculated doses should be validated by measurement[5]. Effective dose is not directly measurable. The operational quantity of interest is the ambient dose equivalent, $H^*(10)$. In order to validate the assessed doses obtained in terms of effective dose, calculations can be made of ambient dose equivalent rates or route doses in terms of ambient dose equivalent, and values of this quantity determined by measurements traceable to national standards. The validation of calculations of ambient dose equivalent for a particular calculation method may be taken as a validation of the calculation of effective dose by the same computer code, but this step in the process might need to be confirmed. The alternative is to establish, *a priori*, that the operational quantity ambient dose equivalent is a good estimator of effective dose and equivalent dose to the foetus for the radiation fields being considered, in the same way that the use of the operational quantity personal dose equivalent is justified for the estimation of effective dose for radiation workers.

The radiation field in aircraft at altitude is complex, with many types of ionizing radiation present, with energies ranging up to many GeV. The determination of ambient dose equivalent for such a complex radiation field is difficult. In many cases, the methods used for the determination of ambient dose equivalent in aircraft are similar to those used at high-energy accelerators in research laboratories. Therefore, it is possible to recommend dosimetric methods and methods for the calibration of dosimetric devices, as well as the techniques for maintaining the traceability of dosimetric measurements to national standards. Dosimetric measurements made to evaluate ambient dose equivalent need to be performed using accurate and reliable methods that ensure the quality of readings provided to workers and regulatory authorities. The purpose of this part of ISO 20785 is to specify procedures for the determination of the responses of instruments in different reference radiation fields, as a basis for proper characterization of instruments used for the determination of ambient dose equivalent in aircraft at altitude.

Requirements for the determination and recording of the cosmic radiation exposure of aircraft crew have been introduced into the national legislation of EU member states and other countries. Harmonization of methods used for determining ambient dose equivalent and for calibrating instruments is desirable to ensure the compatibility of measurements performed with such instruments.

This part of ISO 20785 is intended for the use of primary and secondary calibration laboratories for ionizing radiation, by radiation protection personnel employed by governmental agencies, and by industrial corporations concerned with the determination of ambient dose equivalent for aircraft crew.

Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 2:
Characterization of instrument response

1 Scope

This part of ISO 20785 specifies methods and procedures for characterizing the responses of devices used for the determination of ambient dose equivalent for the evaluation of exposure to cosmic radiation in civilian aircraft. The methods and procedures are intended to be understood as minimum requirements.

2 Normative references

The following referenced documents are indispensable for the application 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/IEC Guide 98-1, *Uncertainty of measurement — Part 1: Introduction to the expression of uncertainty in measurement*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO 4037-1, *X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 1: Radiation characteristics and production methods*

ISO 6980-1, *Nuclear energy — Reference beta-particle radiation — Part 1: Methods of production*

ISO 8529-1:2001, *Reference neutron radiations — Part 1: Characteristics and methods of production*

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

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

ISO 20785-1, *Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 1: Conceptual basis for measurements*

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

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 General terms

3.1.1
angle of radiation incidence
α
angle between the direction of radiation incidence and the reference direction of the instrument

3.1.2
calibration
operation that, under specified conditions, establishes a relation between the conventional quantity, H_0, and the indication, G

NOTE 1 A calibration can be expressed by a statement, calibration function, calibration diagram, calibration curve or calibration table. In some cases, it can consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

NOTE 2 It is important not to confuse calibration with adjustment of a measuring system, often mistakenly called “self-calibration”, or with verification of calibration.

3.1.3
calibration coefficient
N_{coeff}
quotient of the conventional quantity value to be measured and the corrected indication of the instrument

NOTE 1 The calibration coefficient is equivalent to the calibration factor multiplied by the instrument constant.

NOTE 2 The reciprocal of the calibration coefficient, N_{coeff}, is the response.

NOTE 3 For the calibration of some instruments, e.g. ionization chambers, the instrument constant and the calibration factor are not identified separately but are applied together as the calibration coefficient.

NOTE 4 It is necessary, in order to avoid confusion, to state the quantity to be measured, for example: the calibration coefficient with respect to fluence, N_{Φ}, the calibration coefficient with respect to kerma, N_K, the calibration coefficient with respect to absorbed dose, N_D.

3.1.4
calibration conditions
conditions, within the range of standard test conditions, actually prevailing during the calibration

3.1.5
calibration factor
N_{fact}
factor by which the product of the corrected indication and the associated instrument constant of the instrument is multiplied to obtain the conventional quantity value to be measured under reference conditions

NOTE 1 The calibration factor is dimensionless.

NOTE 2 The corrected indication is the indication of the instrument corrected for the effect of influence quantities, where applicable.

NOTE 3 The value of the calibration factor can vary with the magnitude of the quantity to be measured. In such cases, a detector assembly is said to have a non-constant response.

3.1.6

measured quantity value

measured value of a quantity

measured value

M

quantity value representing a measurement result

NOTE 1 For a measurement involving replicate indications, each indication can be used to provide a corresponding measured quantity value. This set of measured quantity values can be used to calculate a resulting measured quantity value, such as an average or a median value, usually with a decreased associated measurement uncertainty.

NOTE 2 When the range of the true quantity values believed to represent the measurand is small compared with the measurement uncertainty, a measured quantity value can be considered to be an estimate of an essentially unique true quantity value and is often an average or a median of individual measured quantity values obtained through replicate measurements.

NOTE 3 In the case where the range of the true quantity values believed to represent the measurand is not small compared with the measurement uncertainty, a measured value is often an estimate of an average or a median of the set of true quantity values.

NOTE 4 In ISO/IEC Guide 98-3:2008, the terms “result of measurement” and “estimate of the value of the measurand” or just “estimate of the measurand” are used for “measured quantity value”.

3.1.7

conventional quantity value

conventional value of a quantity

conventional value

H_0

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

NOTE 1 The term “conventional true quantity value” is sometimes used for this concept, but its use is discouraged.

NOTE 2 Sometimes, a conventional quantity value is an estimate of a true quantity value.

NOTE 3 A conventional quantity value is generally accepted as being associated with a suitably small measurement uncertainty, which might be zero.

NOTE 4 In ISO 20785, the conventional quantity value is the best estimate of the value of the quantity to be measured, determined by a primary or a secondary standard which is traceable to a primary standard.

3.1.8

correction factor

k

factor applied to the indication to correct for deviation of measurement conditions from reference conditions

NOTE If the correction of the effect of the deviation of an influence quantity requires a factor, the influence quantity is of type F.

3.1.9

correction summand

G_S

summand applied to the indication to correct for the zero indication or the deviation of the measurement conditions from the reference conditions

NOTE If the correction of the effect of the deviation of an influence quantity requires a summand, the influence quantity is of type S.

3.1.10
indication
G

quantity value provided by a measuring instrument or a measuring system

NOTE 1 An indication can be presented in visual or acoustic form or can be transferred to another device. An indication is often given by the position of a pointer on the display for analogue outputs, a displayed or printed number for digital outputs, a code pattern for code outputs, or an assigned quantity value for material measures.

NOTE 2 An indication and a corresponding value of the quantity being measured are not necessarily values of quantities of the same kind.

3.1.11
influence quantity
quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the indication and the measurement result

NOTE 1 An indirect measurement involves a combination of direct measurements, each of which may be affected by influence quantities.

NOTE 2 In ISO/IEC Guide 98-3:2008, the concept “influence quantity” is defined as in ISO/IEC Guide 99:2007, covering not only the quantities affecting the measuring system, as in the definition above, but also those quantities that affect the quantities actually measured. Also, in ISO/IEC Guide 98-3, this concept is not restricted to direct measurements.

NOTE 3 The correction of the effect of the influence quantity can require a correction factor (for an influence quantity of type F) and/or a correction summand (for an influence quantity of type S) to be applied to the indication of the detector assembly, e.g. in the case of microphonic or electromagnetic disturbance.

EXAMPLE The indication given by an unsealed ionization chamber is influenced by the temperature and pressure of the surrounding atmosphere. Although needed for determining the value of the dose, the measurement of these two quantities is not the primary objective.

3.1.12
instrument constant
c_i

quantity value by which the indication of the instrument, G (or, if corrections or normalization were carried out, G_corr), is multiplied to give the value of the measurand or of a quantity to be used to calculate the value of the measurand

NOTE If the instrument's indication is already expressed in the same units as the measurand, as is the case with area dosemeters, for instance, the instrument constant, c_i, is dimensionless. In such cases, the calibration factor and the calibration coefficient can be the same. Otherwise, if the indication of the instrument has to be converted to the same units as the measurand, the instrument constant has a dimension.

3.1.13
measurand
quantity intended to be measured

3.1.14
point of test
point in the radiation field at which the conventional quantity value is known

NOTE The reference point of a detector assembly is placed at the point of test for calibration purposes or for the determination of the response.

3.1.15
primary measurement standard
primary standard
measurement standard established using a primary reference measurement procedure or created as an artifact, chosen by convention

NOTE A primary standard has the highest metrological quality in a given field.

3.1.16

quantity value

number and reference together expressing the magnitude of a quantity

NOTE A quantity value is either a product of a number and a measurement unit (the unit “one” is generally not indicated for quantities of dimension “one”) or a number and a reference to a measurement procedure.

3.1.17

reference conditions

conditions of use prescribed for testing the performance of a detector assembly or for comparing the results of measurements

NOTE 1 The reference conditions represent the values of the set of influence quantities for which the calibration result is valid without any correction.

NOTE 2 The value of the measurand can be chosen freely in agreement with the properties of the detector assembly to be calibrated. The quantity to be measured is not an influence quantity but can influence the calibration result and the response (see also Note 1).

3.1.18

reference direction

direction, in the coordinate system of the detector assembly, with respect to which the angle of the direction of radiation incidence is measured in reference fields

NOTE At the angle of incidence of 0°, the reference direction of the detector assembly is parallel to the direction of radiation incidence. At the angle of 180°, the reference direction of the detector assembly is anti-parallel to the direction of radiation incidence.

3.1.19

reference orientation

orientation of the detector assembly for which the direction of the incident radiation coincides with the reference direction of the detector assembly.

3.1.20

reference point

point in the instrument that is placed at the point of test for calibration and test purposes

NOTE The distance of measurement is given by the distance between the radiation source and the reference point of the detector assembly.

3.1.21

response

R

quotient of the indication, G, or the corrected indication, G_{corr}, and the conventional quantity value to be measured

NOTE 1 To avoid confusion, it is necessary to specify which of the quotients given in the definition of the response (that for the indication, G, or that for the corrected indication, G_{corr}) has been used. Furthermore, it is necessary, in order to avoid confusion, to state the quantity to be measured, for example the response with respect to fluence, R_{Φ}, the response with respect to kerma, R_K or the response with respect to absorbed dose, R_D.

NOTE 2 The reciprocal of the response under the specified conditions is equal to the calibration coefficient, N_{coeff}.

NOTE 3 The value of the response can vary with the magnitude of the quantity to be measured. In such cases, the detector assembly's response is said to be non-constant.

NOTE 4 The response usually varies with the energy and direction distribution of the incident radiation. It is therefore useful to consider the response as a function, $R(E,\Omega)$, of the radiation energy, E, and the direction, $\vec{\Omega}$, of the incident monodirectional radiation. $R(E)$ describes the “energy dependence” and $R(\Omega)$ the “angle dependence” of the response; for the latter, $\vec{\Omega}$ may be expressed by the angle, α, between the reference direction of the detector assembly and the direction of an external monodirectional field.

3.1.22

secondary measurement standard

secondary standard

measurement standard established through calibration with respect to a primary measurement standard for a quantity of the same kind

NOTE 1 Calibration can be carried out directly between a primary measurement standard and a secondary measurement standard or it can involve an intermediate measuring system calibrated by the primary measurement standard followed by assignment of a measurement result to the secondary measurement standard.

NOTE 2 A secondary standard can be variously represented, e.g. as a measuring device or a radionuclide source unit.

NOTE 3 The secondary standard can be used for calibrating a detector assembly and/or for determining its response. The calibration of the secondary standard needs to be valid for the irradiation conditions used, e.g. energy, dose and/or dose rate, and environmental conditions. The stability and reproducibility of the secondary standard has to be verified periodically.

NOTE 4 The quantity value of the secondary standard is equated to the best estimate of the quantity, i.e. the conventional quantity value.

3.1.23

standard test conditions

conditions represented by the range of values for the influence quantities under which a calibration or determination of the response is carried out

NOTE Ideally, calibrations are carried out under reference conditions. As this is not always possible (e.g. for ambient air pressure) or convenient (e.g. for ambient temperature), a (small) interval around the reference values can be acceptable. If a calibration factor or response determined under standard conditions deviates significantly from the value that would be obtained under reference conditions, a correction will normally be applied.

3.1.24

true quantity value

true value of a quantity

true value

quantity value consistent with the definition of a quantity

NOTE 1 In the error approach to describing a measurement, a true quantity value is considered unique and, in practice, unknowable. The uncertainty approach is to recognize that, owing to the inherently incomplete amount of detail in the definition of a quantity, there is not a single true quantity value but rather a set of true quantity values consistent with the definition. However, this set of values is, in principle and in practice, unknowable. Other approaches dispense altogether with the concept of a true quantity value and rely on the concept of metrological compatibility of measurement results for assessing their validity.

NOTE 2 In the special case of a fundamental constant, the quantity is considered to have a single true quantity value.

NOTE 3 When the definitional uncertainty associated with the measurand is considered to be negligible compared to the other components of the measurement uncertainty, the measurand can be considered to have an “essentially unique” true quantity value. This is the approach taken by ISO/IEC Guide 98-3 and associated documents, in which the word “true” is considered to be redundant.

3.2 Terms related to quantities and units

Most of the definitions in this subclause have been adapted from ISO 80000-10:2009[71] and ICRU Reports 36[6] and 51[7].

3.2.1

particle fluence

fluence

Φ

at a given point in space, the mean number, dN, of particles incident on a small spherical domain, divided by the cross-sectional area, da, of that domain:

$$\Phi = \frac{\mathrm{d}N}{\mathrm{d}a}$$

NOTE 1 The base unit of particle fluence is m^{-2}; a frequently used unit is cm^{-2}.

NOTE 2 The energy distribution of the particle fluence, Φ_E, is the quotient dΦ by dE, where dΦ is the fluence of particles of energy between E and $E + \mathrm{d}E$. There is an analogous definition for the directional distribution, Φ_Ω, of the particle fluence.

3.2.2

particle fluence rate

fluence rate

$\dot{\Phi}$

$$\dot{\Phi} = \frac{\mathrm{d}\Phi}{\mathrm{d}t} = \frac{\mathrm{d}^2 N}{\mathrm{d}a \cdot \mathrm{d}t}$$

where dΦ is the mean increment in the particle fluence, dN/da, during an infinitesimal time interval of duration dt

NOTE The base unit of the particle fluence rate is $\mathrm{m}^{-2} \cdot \mathrm{s}^{-1}$; a frequently used unit is $\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$.

3.2.3

energy imparted

ε

for ionizing radiation in the matter in a given three-dimensional domain,

$$\varepsilon = \sum \varepsilon_i$$

where the energy deposit, ε_i, is the energy deposited in a single interaction, i, and is given by $\varepsilon_i = \varepsilon_{\mathrm{in}} - \varepsilon_{\mathrm{out}} + Q$, where $\varepsilon_{\mathrm{in}}$ is the energy of the incident ionizing particle, excluding rest energy, $\varepsilon_{\mathrm{out}}$ is the sum of the energies of all ionizing particles leaving the interaction, excluding rest energy, and Q is the change in the rest energies of the nucleus and of all particles involved in the interaction

NOTE 1 Energy imparted is a stochastic quantity.

NOTE 2 The unit of energy imparted is J.

3.2.4

mean energy imparted

$\bar{\varepsilon}$

for the matter in a given domain,

$$\bar{\varepsilon} = R_{\mathrm{in}} - R_{\mathrm{out}} + \Sigma Q$$

where R_{in} is the radiant energy of all those charged and uncharged ionizing particles that enter the domain, R_{out} is the radiant energy of all those charged and uncharged ionizing particles that leave the domain and ΣQ is the sum of all changes in the rest energies of nuclei and elementary particles that occur in that domain