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Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 2:
Characterization of instrument response

Dosimétrie pour l'exposition au rayonnement cosmique à bord d'un avion civil —

Partie 2: Caractérisation de la réponse des instruments

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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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*.

This second edition cancels and replaces the first edition (ISO 20785-2:2011), which has been technically revised. The main changes compared to the previous edition are as follows:

- revision of the definitions of the terms;
- updated references.

A list of all the parts in the ISO 20785 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

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] and International Atomic Energy Agency (IAEA)[4] issued a revised Basic Safety Standards. Those standards included exposure to natural sources of ionizing radiation, including cosmic radiation, as occupational exposure. The EU 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:

a) to assess the exposure of the crew concerned;

b) to take into account the assessed exposure when organizing working schedules with a view to reducing the doses of highly exposed crew;

c) to inform the workers concerned of the health risks their work involves; and

d) 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 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 the equivalent dose (to the foetus) and the 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 dosimeters 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 the ICRP in Publications 75[5] and 132[6] and in guidance from the European Commission.

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[7]. 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 and taking instrument responses and related uncertainties properly into account. 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 ground-based 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 instrument response to particles and energies of the atmospheric radiation field that are not covered by reference fields are carefully taken into account in the evaluation of measurement results. While, 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 should be performed using accurate and reliable methods that ensure the quality of readings provided to workers and regulatory authorities. The purpose of this document 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 document 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 document 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 five 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/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)*

3 Terms and definitions

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

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

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

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 to entry: 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 to entry: 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 to entry: The calibration coefficient is equivalent to the calibration factor multiplied by the instrument constant.

Note 2 to entry: The reciprocal of the calibration coefficient, N_{coeff}, is the response.

Note 3 to entry: 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 to entry: 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 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 to entry: The calibration factor is dimensionless.

Note 2 to entry: The corrected indication is the indication of the instrument corrected for the effect of influence quantities, where applicable.

Note 3 to entry: 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.

3.1.5
measured quantity value
measured value of a quantity
measured value

M

quantity value representing a measurement result

Note 1 to entry: 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 to entry: 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 to entry: 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 to entry: 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”.

3.1.6

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

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

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

Note 4 to entry: In ISO 20785 series[8][9][10], 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.

3.1.7

correction factor

k

factor applied to the *indication* (3.1.9) to correct for deviation of measurement conditions from reference conditions

Note 1 to entry: If the correction of the effect of the deviation of an influence quantity requires a factor, the influence quantity is of type F.

3.1.8

correction summand

G_S

summand applied to the *indication* (3.1.9) to correct for the zero indication or the deviation of the measurement conditions from the reference conditions

Note 1 to entry: If the correction of the effect of the deviation of an influence quantity requires a summand, the influence quantity is of type S.

3.1.9

indication

G

quantity value provided by a measuring instrument or a measuring system

Note 1 to entry: 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 to entry: An indication and a corresponding value of the quantity being measured are not necessarily values of quantities of the same kind.

3.1.10

influence quantity

quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the *indication* (3.1.9) and the measurement result

Note 1 to entry: An indirect measurement involves a combination of direct measurements, each of which can be affected by influence quantities.

Note 2 to entry: In ISO/IEC Guide 98-3:2008, the concept “influence quantity” is defined as in ISO/IEC Guide 99:2007[11], 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 to entry: 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.

3.1.11
instrument constant
c_i
quantity value by which the *indication* (3.1.9) 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 1 to entry: 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* (3.1.3) 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.

3.1.12
measurand
quantity intended to be measured

3.1.13
primary measurement standard
primary standard
measurement standard established using a primary reference measurement procedure or created as an artefact, chosen by convention

Note 1 to entry: A primary standard has the highest metrological quality in a given field.

3.1.14
quantity value
number and reference together expressing the magnitude of a quantity

Note 1 to entry: 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.

3.1.15
reference conditions
conditions of use prescribed for testing the performance of a detector assembly or for comparing the results of measurements

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

Note 2 to entry: 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 to entry).

3.1.16
response
response characteristic
R
quotient of the indication, G, or the corrected indication, G_corr, and the conventional quantity value to be measured

Note 1 to entry: 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* G_corr) is applied. 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 to entry: The reciprocal of the response under the specified conditions is equal to the calibration coefficient, N_{coeff}.

Note 3 to entry: 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 to entry: 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.

3.2 Terms related to quantities and units

Most of the definitions in this subclause have been adapted from ISO 80000-10:2019[12] and ICRU Reports 36[13] and 51[14].

3.2.1
particle fluence
fluence
Φ

number, dN, at a given point in space, 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 to entry: The unit of the fluence is m−2; a frequently used unit is cm−2.

Note 2 to entry: 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+dE. There is an analogous definition for the direction distribution, Φ_Ω, of the particle fluence. The complete representation of the double differential particle fluence can be written (with arguments) $\Phi_{E,\Omega}(E,\Omega)$, where the subscripts characterize the variables (quantities) for differentiation and where the symbols in the brackets describe the values of the variables. The values in the brackets are needed for special function values, e.g. the energy distribution of the particle fluence at energy $E = E_0$ is written as $\Phi_E(E_0)$. If no special values are indicated, the brackets may be omitted.

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* (3.2.1), dN /da, during an infinitesimal time interval of duration dt

Note 1 to entry: 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
kerma
K

for indirectly ionizing (uncharged) particles, the sum of the initial kinetic energies, dE_{tr}, of all the charged ionizing particles liberated by uncharged ionizing particles in an element of matter, divided by the mass, dm, of that element:

$$K = \frac{\mathrm{d}E_{\mathrm{tr}}}{\mathrm{d}m}$$

Note 1 to entry: The quantity dE_{tr} includes the kinetic energy of the charged particles emitted in the decay of excited atoms or molecules or nuclei.

Note 2 to entry: The unit of kerma is J·kg^{-1}, with the special name gray (Gy).

3.2.4
dose equivalent

H

at the point of interest in tissue,

$$H = DQ$$

where D is the absorbed dose and Q is the quality factor at that point

Note 1 to entry: Q is determined by the unrestricted linear energy transfer, L_∞ (often denoted by L or LET), of charged particles passing through a small volume element (domain) at this point (the value of L_∞ is given for charged particles in water, not in tissue; the difference, however, is small). The dose equivalent at a point in tissue is then given by:

$$H = \int_{L=0}^{\infty} Q(L) D_{\mathrm{L}} \, \mathrm{d}L$$

where D_{L} (= dD/dL) is the distribution in terms of L of the absorbed dose at the point of interest.

Note 2 to entry: The relationship between Q and L is given in ICRP Publication 103[2].

Note 3 to entry: The unit of dose equivalent is J·kg^{-1}, with the special name sievert (Sv).

3.2.5
ambient dose equivalent

$H^*(10)$

dose equivalent, at a point in a radiation field, that would be produced by the corresponding expanded and aligned field in the ICRU sphere at 10 mm depth on the radius opposing the direction of the aligned field

Note 1 to entry: The unit of ambient dose equivalent is J·kg^{-1}, with the special name sievert (Sv).

3.2.6
particle fluence to ambient dose equivalent conversion coefficient

h_{Φ}^{*}

quotient of the particle *ambient dose equivalent* (3.2.6), $H^*(10)$, and the *particle fluence* (3.2.1), Φ:

$$h_{\Phi}^{*} = \frac{H^*(10)}{\Phi}$$

Note 1 to entry: The base unit of the particle fluence to ambient dose equivalent conversion coefficient is J·m^2·kg^{-1}, with the special name Sv·m^2; a frequently used unit is pSv·cm^2.

3.2.7
vertical cut-off
vertical geomagnetic cut-off rigidity
cut-off

minimum magnetic rigidity a vertically incident particle can have and still reach a given location above the Earth