INTERNATIONAL STANDARD

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Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 1:
Conceptual basis for measurements

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

Partie 1: Fondement théorique des mesurages

Reference number
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Foreword

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ISO 20785-1 was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

This second edition cancels and replaces the first edition (ISO 20785-1:2006), which has been technically revised.

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*

Measurements at aviation altitudes is to form the subject of a future Part 3.

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 crews 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 crews; (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 crews 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 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 dosemeters for routine use are not considered necessary. The preferred approach for the assessment of doses of aircraft crews, 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 fold 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. The effective dose is not directly measurable. The operational quantity of interest is 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 the effective dose by the same computer code, but this step in the process may 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. Ambient dose equivalent rate as a function of geographic location, altitude and solar cycle phase is then calculated and folded with flight and staff roster information.

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 must be performed using accurate and reliable methods that ensure the quality of readings provided to workers and regulatory authorities. This part of ISO 20785 gives a conceptual basis for the characterization of the response of instruments for the determination of ambient dose equivalent in aircraft.

Requirements for the determination and recording of the cosmic radiation exposure of aircraft crews 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 crews.

Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 1:
Conceptual basis for measurements

1 Scope

This part of ISO 20785 gives the conceptual basis for the determination of ambient dose equivalent for the evaluation of exposure to cosmic radiation in civilian aircraft and for the calibration of instruments used for that purpose.

2 Terms and definitions

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

2.1 General

2.1.1
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 may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called “self-calibration”, or with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

2.1.2
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}.

2.1.3
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.

2.1.4
reference conditions

conditions of use prescribed for testing the performance of a detector assembly or for comparison of 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 may 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 may influence the calibration result and the response.

2.1.5
response

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 (to G or to 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, 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 $N_{\mathrm{coeff.}}$

Note 3 to entry: The value of the response may 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 of the direction, $\vec{\Omega}$, of the incident monodirectional radiation. $R(E)$ describes the "energy dependence" and $R(\Omega)$ the "angle dependence" of 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.

2.2 Quantities and units

2.2.1
particle fluence

fluence

Φ

number, dN, at a given point of 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.

2.2.2
particle fluence rate
fluence rate

$\dot{\Phi}$

rate of the particle fluence expressed as

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

where dΦ is the increment of the particle fluence during an infinitesimal time interval with duration dt

Note 1 to entry: The unit of the fluence rate is $\mathrm{m}^{-2}\ \mathrm{s}^{-1}$, a frequently used unit is $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$.

2.2.3
energy imparted

ε

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

$$\varepsilon = \sum \varepsilon_i$$

where

ε_i is the energy deposited in a single interaction, i, and given by $\varepsilon_i = \varepsilon_{in} - \varepsilon_{out} + Q$, where

ε_{in} is the energy of the incident ionizing particle, excluding rest energy,

ε_{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 to entry: Energy imparted is a stochastic quantity.

Note 2 to entry: The unit of the energy imparted is J.

2.2.4
mean energy imparted

$\bar{\varepsilon}$

mean energy imparted to the matter in a given domain, expressed as

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

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

$\sum Q$ is the sum of all changes of the rest energy of nuclei and elementary particles that occur in that domain

Note 1 to entry: This quantity has the meaning of expected value of the energy imparted.

Note 2 to entry: The unit of the mean energy imparted is J.

2.2.5
specific energy imparted
specific energy

z

for any ionizing radiation,

$$z = \frac{\varepsilon}{m}$$

where

ε is the energy imparted to the irradiated matter,

m is the mass of the irradiated matter

Note 1 to entry: Specific energy imparted is a stochastic quantity.

Note 2 to entry: In the limit of a small domain, the mean specific energy imparted is equal to the absorbed dose.

Note 3 to entry: The specific energy imparted can be the result of one or more (energy-deposition) events.

Note 4 to entry: The unit of specific energy is J·kg^{-1}, with the special name gray (Gy).

2.2.6
absorbed dose

D

for any ionizing radiation,

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$

where

$\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to an element of irradiated matter of mass dm, where

$$\bar{\varepsilon} = \int D \mathrm{d}m$$

Note 1 to entry: In the limit of a small domain, the mean specific energy is equal to the absorbed dose.

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

2.2.7

kerma

K

for indirectly ionizing (uncharged) particles, the mean sum of the initial kinetic energies $\mathrm{d}E_{\mathrm{tr}}$ of all the charged ionizing particles liberated by uncharged ionizing particles in an element of matter, divided by the mass $\mathrm{d}m$ of that element:

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

Note 1 to entry: Quantity $\mathrm{d}E_{\mathrm{tr}}$ 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).

2.2.8

unrestricted linear energy transfer

linear energy transfer

LET

$L_{\varDelta}$

for an ionizing charged particle, the mean energy, $\mathrm{d}E_{\varDelta}$, imparted locally to matter along a small path through the matter minus the sum of the kinetic energies of all the electrons released with kinetic energies in excess of $\varDelta$, divided by the length, $\mathrm{d}l$:

$$L_{\varDelta} = \frac{\mathrm{d}E_{\varDelta}}{\mathrm{d}l}$$

Note 1 to entry: This quantity is not completely defined unless $\varDelta$ is specified, i.e. the maximum kinetic energy of secondary electrons whose energy is considered to be "locally deposited". $\varDelta$ may be expressed in eV.

Note 2 to entry: Linear energy transfer is often abbreviated LET, but to which should be appended the subscript $\varDelta$ or its numerical value.

Note 3 to entry: The unit of the linear energy transfer is J m^{-1}, a frequently used unit is keV µm^{-1}.

Note 4 to entry: If no energy cut-off is imposed, the unrestricted linear energy transfer L_{∞} is equal to the linear electronic stopping power S_{el} and may be denoted simply as L.

2.2.9

dose equivalent

H

at the point of interest in tissue,

$$H = DQ$$

where

D is the absorbed dose,

Q is the quality factor at that point, and

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

Note 1 to entry: Q is determined by the unrestricted linear energy transfer, L_{∞} (often denoted as L or LET), of charged particles passing through a small volume element (domains) 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 the above formula, where $D_{\mathrm{L}} = \mathrm{d}D/\mathrm{d}L$ is the distribution in terms of L of the absorbed dose at the point of interest.

Note 2 to entry: The relationship of Q and L is given in ICRP Publication 103 (ICRP, 2007).[2]

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

2.2.10
single-event dose-mean specific energy

dose-mean specific energy per event

$\bar{z}_\mathrm{D}$

expectation

$$\bar{z}_\mathrm{D} = \int_0^\infty z d_1(z)\,\mathrm{d}z$$

where $d_1(z)$is the dose probability density of z

Note 1 to entry: The dose probability density of z is given by $d_1(z)$, where $d_1(z)$ dz is the fraction of the absorbed dose delivered in single events with specific energies in the interval from z to z+dz.

2.2.11
lineal energy

y

quotient of the energy, ε_s, imparted to the matter in a given volume by a single energy deposition event, by the mean chord length, $\bar{l}$, in that volume:

$$y = \frac{\varepsilon_\mathrm{s}}{\bar{l}}$$

Note 1 to entry: The unit of lineal energy is J m^{-1}, a frequently used unit is keV µm^{-1}.

2.2.12
dose-mean lineal energy

$\bar{y}_\mathrm{D}$

expectation

$$\bar{y}_\mathrm{D} = \int_0^\infty y\, d(y)\,\mathrm{d}y$$

where $d(y)$is the dose probability density of y

Note 1 to entry: The dose probability density of y is given by $d(y)$, where $d(y)$dz is the fraction of absorbed dose delivered in single events with lineal energy in the interval from y to y+dy.

Note 2 to entry: Both the dose-mean lineal energy and distribution $d(y)$ are independent of the absorbed dose or dose rate.

2.2.13
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).