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Dosemetry for exposures to cosmic radiation in civilian aircraft —

Part 1: Conceptual basis for measurements

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

Partie 1: Fondement théorique des mesurages

Reference number
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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 20785-1 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

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

- *Part 1: Conceptual basis for measurements*

A Part 2 dealing with the characterization of instrument response is in preparation.

Introduction

Aircraft crew 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], the European Union (EU) introduced a revised Basic Safety Standards Directive[2], 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.

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 [2], [3]. The preferred approach for the assessment of doses of aircraft crew, where necessary, is to calculate directly 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[3].

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. 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 effective dose by the same computer code, but it can be necessary to confirm this step in the process. 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 integrated with flight and staff roster information. The calculations of ambient dose equivalent rates or route doses can then be validated by measurements traceable to national standards.

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, and the purpose of this International Standard is to give the conceptual basis for performing such measurements and for the calibration of instruments used for this purpose. 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 dosemetric methods and methods for the calibration of dosemetric devices, as well as the techniques for maintaining the traceability of dosemetric measurements to national standards. Dosemetric measurements taken 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. The future Part 2 of ISO 20785 will give procedures 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 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 International Standard 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.

Dosemetry 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 this purpose.

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.

NOTE The documents published by the ICRP (International Commission on Radiological Protection) and the ICRU (International Commission on Radiation and Measurements) are recognised by the ISO committee as having a wide acceptance and authority status.

ICRU Report 60:1998, *Fundamental Quantities and Units for Ionizing Radiation*

3 Terms, definitions and symbols

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

3.1 Quantities and units

3.1.1
particle fluence
fluence
Φ
quotient of dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da

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

NOTE 1 The unit of the 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 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 the energy, $E = E_0$, is written as $\Phi_E(E_0)$. If no special values are indicated, the brackets can be omitted.

3.1.2
particle fluence rate
fluence rate

$\dot{\Phi}$

quotient of dΦ by dt, where dΦ is the increment of particle fluence in the time interval dt:

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

NOTE The unit of the particle fluence rate is m^{-2}/s, a frequently used unit is cm^{-2}/s.

3.1.3
energy imparted

ε

energy imparted by ionizing radiation to the matter in a given volume

NOTE The unit of the energy imparted is J.

3.1.4
mean energy imparted

$\bar{\varepsilon}$

expectation value of the energy imparted by ionizing radiation to the matter in a given volume

NOTE The unit of the mean energy imparted is J.

3.1.5
specific energy imparted

z

quotient of ε by dm, where ε is the energy imparted by ionizing radiation to matter of mass dm:

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

NOTE The unit of specific energy is J/kg, with the special name gray (Gy).

3.1.6
absorbed dose

D

quotient of d$\bar{\varepsilon}$ by dm, where d$\bar{\varepsilon}$ is the mean energy imparted to matter of mass dm:

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

NOTE The unit of absorbed dose is J/kg, with the special name gray (Gy).

3.1.7
kerma

K

quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all the charged particles liberated by uncharged particles in the mass, dm, of material:

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

NOTE The unit of kerma is J/kg, with the special name gray (Gy).

3.1.8
linear energy transfer
LET

L

quotient of dE by dl, where dE is the energy lost in a material by a charged particle due to electronic collisions in traversing a distance dl:

$$L = \frac{\mathrm{d}E}{\mathrm{d}l}$$

NOTE The unit of the linear energy transfer is J/m, a frequently used unit is keV/µm.

3.1.9
dose equivalent
H

product of Q and D at the point of interest in tissue, where D is the absorbed dose, Q is the quality factor at that point, D_L is the distribution of the dose D in linear energy transfer L, and $Q(L)$ is the quality factor as a function of L in water:

$$H = Q \cdot D = \int Q(L)\, D_L \, \mathrm{d}L$$

NOTE 1 The unit of dose equivalent is J/kg, with the special name sievert (Sv).

NOTE 2 Values for the relationship $Q(L)$ are given in ICRP Publication 60:1998.

3.1.10
dose-mean specific energy per event
single-event dose-mean specific energy

$\bar{z}_D$

expectation value $\bar{z}_D = \int_0^\infty z d_1(z)\mathrm{d}z$, where $d_1(z)$ is the dose probability density of z

NOTE The dose probability density of z is given by $d_1(z) = \mathrm{d}D_1(z)/\mathrm{d}z$, where $D_1(z)$ is the fraction of absorbed dose per event delivered with specific energy less than or equal to z.

3.1.11
lineal energy
y

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

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

NOTE The unit of the lineal energy is J/m, a frequently used unit is keV/µm.

3.1.12
dose-mean lineal energy
$\bar{y}_D$

expectation value $\bar{y}_D = \int_0^\infty y\, d(y)\, \mathrm{d}y$, where $d(y)$ is the dose probability density of y.

NOTE 1 The dose probability density of y is given by $d(y) = \mathrm{d}D(y)/\mathrm{d}y$, where $D(y)$ is the fraction of absorbed dose delivered with lineal energy less than or equal to y.

NOTE 2 Both $\bar{y}_D$ and the distribution $d(y)$ are independent of the absorbed dose or dose rate.

3.1.13

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 The unit of the ambient dose equivalent is J/kg, with the special name sievert (Sv).

3.1.14

particle fluence-to-ambient dose equivalent conversion coefficient

h_Φ^*

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

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

NOTE The unit of the particle fluence-to-ambient dose equivalent conversion coefficient is J·m^2/kg with the special name Sv·m^2, a frequently used unit is Sv·cm^2.

3.1.15

indication

reading

M

⟨of a measuring instrument⟩ value of a quantity provided by a measuring instrument

NOTE 1 The value read from the displaying device can be called the direct indication; it is multiplied by the instrument constant to give the indication.

NOTE 2 The quantity can be the measurand, a measurement signal, or another quantity to be used in calculating the value of the measurand.

NOTE 3 It is necessary to document whether the indication (reading) is normalized to the reference conditions to account for influence quantities and is corrected for intrinsic background and other factors.

3.1.16

response characteristic

response

R

quotient of the indication (reading), M, of the instrument, by the value of the quantity, X, to be measured by the instrument, for a specified type, energy and direction distribution of radiation:

$$R = \frac{M}{X}$$

NOTE 1 VIM says, as a note in the definition of “measurement signal”, that “the input signal to a measuring system may be called the stimulus, the output signal may be called the response.” The term “response characteristic” is defined as the “relationship between a stimulus and the corresponding response, for defined conditions”. In radiation metrology generally, the term “response” is an abbreviated form of “response characteristic”.

NOTE 2 It is necessary, in order to avoid confusion, to state the type of response, e.g. fluence response (response with respect to Φ):

$$R_\Phi = \frac{M}{\Phi}$$

or, dose equivalent response (response with respect to dose equivalent H)

$$R_H = \frac{M}{H}$$

3.1.17
atmospheric depth

X_v

mass of a unit-area column of air above a point in the atmosphere

NOTE The unit of atmospheric depth is kg/m^2; a frequently used unit is g/cm^2.

3.1.18
magnetic rigidity

rigidity

momentum per unit charge (of a particle in a magnetic field)

NOTE 1 The unit of rigidity is T·m. A frequently used unit is V (or GV) in a system of units where momentum, p, is given in eV/c (or GeV/c), and where rigidity is c times momentum per unit charge, $p \cdot c/Q$.

NOTE 2 Rigidity is especially useful in characterizing charged particle trajectories in magnetic fields. All particles having the same magnetic rigidity have identical trajectories in a magnetic field, independent of particle mass or atomic charge.

3.1.19
geomagnetic cut-off rigidity

cut-off rigidity

r_c

minimum magnetic rigidity an incident particle can have and still penetrate the geomagnetic field to reach a given location above the Earth

NOTE Cut-off rigidity depends on angle of incidence. Often vertical incidence is assumed.

3.1.20
vertical geomagnetic cut-off rigidity

vertical cut-off

cut-off

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

3.2 Atmospheric radiation field

3.2.1
cosmic radiation

cosmic rays

cosmic particles

ionizing radiation consisting of high-energy particles, primarily ionized nuclei, of extra-terrestrial origin and the particles they generate by interaction with the atmosphere and other matter

3.2.2
primary cosmic radiation

primary cosmic rays

cosmic radiation incident from space

3.2.3
secondary cosmic radiation

secondary cosmic rays

cosmogenic particles

particles that are created, directly or in a cascade of reactions, by primary cosmic radiation interacting with the atmosphere or other matter

NOTE Important particles with respect to radiation protection and radiation measurements in aircraft are neutrons, protons, photons, electrons, positrons, muons, and to a lesser extent, pions and nuclear ions heavier than protons.

3.2.4
galactic cosmic radiation
galactic cosmic rays
GCR
cosmic radiation originating outside the solar system

3.2.5
solar cosmic radiation
solar cosmic rays
solar particles
cosmic radiation originating from the sun

3.2.6
solar particle event
SPE
large fluence rate of energetic solar particles ejected into space by a solar eruption, or the sudden increase of cosmic radiation observed when such particles arrive at Earth

3.2.7
ground level event
GLE
sudden increase of cosmic radiation, observed on the ground and at flight altitudes associated with a solar particle event, having a high flux of particles with high energy (greater than 500 MeV)

NOTE GLEs are rare, occurring on average about once per year.

3.2.8
solar modulation
change of the GCR field (outside the earth's magnetosphere), caused by change of solar activity and consequent change of the magnetic field of the heliosphere

3.2.9
solar cycle
period during which the solar activity varies with successive maxima separated by an average interval of about 11 years, the so-called solar cycle

NOTE 1 If the reversal of the Sun’s magnetic field polarity in successive 11 year periods is taken into account, the complete solar cycle may be considered to average some 22 years.

NOTE 2 The sunspot cycle, as measured by the relative sunspot number, has an approximate length of 11 years, but this varies between about 7 years and 17 years. An approximate 11-year cycle has been found or suggested in geomagnetism, frequency of aurora, and other ionospheric characteristics. The u index of geomagnetic intensity variation shows one of the strongest known correlations to solar activity.

3.2.10
relative sunspot number
measure of sunspot activity computed from the expression $k(10\,g + f)$, where f is the number of individual spots, g is the number of groups of spots, and k is a factor that varies with the observer's personal experience of recognition and with observatory (location and instrumentation)

NOTE The relative sunspot number is also known as the “Wolf number”.

3.2.11
solar maximum
time period of maximum solar activity during a solar cycle, usually defined in terms of the relative sunspot number