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Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 3: Measurements at aviation altitudes

Dosimétrie pour les expositions au rayonnement cosmique à bord d'un avion civil —

Partie 3: Mesurages à bord d'avions

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Foreword

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The committee responsible for this document is 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*
- *Part 3: Measurements at aviation altitudes*

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 to be incorporated into laws and regulations of EU Member States and has to be 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 effective dose rate, 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, the ICRP in Publication 75[4] and the ICRU in Report 84.[5]

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, $H^*(10)$. Indeed, as indicated in particular in ICRU Report 84, the ambient dose equivalent is considered to be a conservative estimator of effective dose if isotropic or superior isotropic irradiation can be assumed. 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 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 have to 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 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 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 3: **Measurements at aviation altitudes**

1 Scope

This part of ISO 20785 gives the basis for the measurement of ambient dose equivalent at flight altitudes for the evaluation of the exposures to cosmic radiation in civilian aircraft.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 20785-1, *Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 1: Conceptual basis for measurements*

ISO 20785-2, *Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 2: Characterization of instrument response*

3 Terms and definitions

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

3.1 Quantities and units

3.1.1
particle fluence
fluence
Φ
at a given point of space, 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 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,Ω), 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 may be omitted.

3.1.2
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 increment of the particle fluence during an infinitesimal time interval with duration dt:

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

3.1.3
unrestricted linear energy transfer
linear energy transfer
LET
L_∞
for an ionizing charged particle, mean energy dE_∞ imparted locally to matter along a small path through the matter, minus the sum of the kinetic energies of all the electrons released, divided by the length dl

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

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

3.1.4
dose equivalent
H
at the point of interest in tissue

$$H = DQ$$

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

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:

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

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 of Q and L is given in Reference [2].

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

3.1.5
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}, called sievert (Sv).

3.1.6
particle fluence-to-ambient dose equivalent conversion coefficient
$h(10)^*_{\Phi}$
quotient of the particle ambient dose equivalent, $H^*(10)$, and the particle fluence, Φ

$$h\left(10\right)^*_{\Phi} = \frac{H^*(10)}{\Phi}$$

Note 1 to entry: The 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.

3.1.7
correction factor
K
factor applied to the indication to correct for deviation of the measurement conditions from reference conditions

3.1.8
atmosphere depth
X_v
mass of a unit-area column of air above a point in the atmosphere

Note 1 to entry: The unit of atmosphere depth is kg m^{-2}; a frequently used unit is g cm^{-2}.

3.1.9
standard barometric altitude
pressure altitude
altitude determined by a barometric altimeter calibrated with reference to the International Standard Atmosphere (ISA) (ISO, 1975) when the altimeter's datum is set to 1 013,25 hPa

Note 1 to entry: The flight level is sometimes given as FL 350, where the number represents multiples of 100 feet of pressure altitude, based on the ISA and a datum setting of 1 013,25 hPa. However, in some countries flight levels are expressed in meters, in which case appropriate conversions should be made before applying the data given in this part of ISO 20785.

3.1.10
magnetic rigidity
P
momentum per charge (of a particle in a magnetic field), given by:

$$P = \frac{p}{Ze}$$

where p is the particle momentum, Z the number of charges on the particle and e the charge on the proton

Note 1 to entry: The base unit of magnetic rigidity is the tesla metre (T m) (= V m^{-1} s). A frequently used unit is V (or GV) in a system of units where the values of the speed of light, c, and the charge on the proton, e, are both 1, and the magnetic rigidity is given by pc/Ze.

Note 2 to entry: Magnetic rigidity characterizes 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 charge.

3.1.11
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 1 to entry: Geomagnetic cut-off rigidity depends on angle of incidence. Often, vertical incidence to the Earth's surface is assumed, in which case, the vertical geomagnetic cut-off rigidity is the minimum magnetic rigidity a vertically incident particle can have and still reach a given location above the Earth.

3.1.12
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

3.1.13
deceleration potential
ϕ
cosmic ray modulation parameter deduced from space observations of the abundance variation of the different species in function of the solar cycle epoch

Note 1 to entry: The deceleration potential could be deduced either from the sunspot index or from Climax neutron monitor output, using simple linear formula depending upon the phase of the solar cycle.

3.2 Atmospheric radiation field

3.2.1
cosmic radiation
cosmic rays
cosmic particles
ionizing radiation consisting of high-energy particles, primarily completely ionized atoms, 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 at the Earth's orbit

3.2.3
secondary cosmic radiation
secondary cosmic rays
cosmogenic particles
particles which are created directly or in a cascade of reactions by primary cosmic rays interacting with the atmosphere or other matter

Note 1 to entry: 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

Note 1 to entry: Solar particle events are directional.

3.2.7
ground level enhancement
GLE
sudden increase of cosmic radiation observed on the ground by at least two neutron monitor stations recording simultaneously a greater than 3 % increase in the five-minute-averaged count rate associated with solar energetic particles

Note 1 to entry: A GLE is associated with a solar-particle event having a high fluence rate of particles with high energy (greater than 500 MeV).

Note 2 to entry: GLEs are relatively 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

Note 1 to entry: 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, the Hale cycle.

Note 2 to entry: The sunspot cycle as measured by the relative sunspot number, known as the Wolf number, has an approximate length of 11 years, but this varies between about 7 and 17 years. An approximate 11-year cycle has been found or suggested in geomagnetism, frequency of aurora, and other ionospheric characteristics.

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

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

3.2.12
solar minimum
time period of minimum solar activity during a solar cycle, usually defined in terms of relative sunspot number