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Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 4:
Validation of codes

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

Partie 4: Validation des codes

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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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

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

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 (ICRP) in Publication 60,[1] the European Union (EU) introduced a Basic Safety Standards Directive[2] (BSS) which included exposure to natural sources of ionizing radiation, including cosmic radiation, as occupational exposure for aircrew. International guidance was also provided by the IAEA Safety Standards Series[3]. This action was confirmed by ICRP Publications 103[4] and 132[5], and the EU BSS[6] was revised. 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 organising working schedules with a view to reducing the doses of highly exposed crew;

iii) to inform workers concerned with the health risks involved in their work; 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 fetus) and effective dose. The cosmic radiation exposure of the body is essentially uniform and the maternal abdomen provides no effective shielding to the fetus. As a result, the magnitude of equivalent dose to the fetus 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 thus not needed nor practical, The preferred approach for the assessment of doses of aircraft crew, where necessary, is to calculate directly the 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 ICRP in Publication 75[7] and Publication 132[5], and the ICRU in Report 84[8].

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 irradiation can be assumed. The operational quantity ambient dose equivalent is a good estimator of effective dose and equivalent dose to the fetus 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. 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 the results can be compared to 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 code. 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 fetus 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 route dose is the best estimate of ambient dose equivalent for the actual route recorded for the aircrew. However, the actual route flown for that specific flight may vary due to weather, scheduling, etc.

It should be noted that this document addresses galactic cosmic radiation (GCR) only. First discovered by Victor Hess more than 100 years ago, GCR is a well understood and permanent source of ionizing radiation both on Earth and in flight. GCR can be modelled with reasonable precision and accuracy. It should be recognized that there are other sources of radiation that are intermittent. These sources cannot currently be modelled prior to their occurrence, and are not a subject of this document. These sources include solar proton events (often called solar particle events), solar neutron events, solar gamma events, solar magnetic storms that alter the magnetic shielding and terrestrial gamma flashes which are associated with some lightning. Exposures can also occur from shipments of radioactive material and also from any medical procedures required as a condition of employment for aircrew. These intermittent sources can produce radiation exposures that exceed limits for both aircrew and members of the public.

In order to adequately address the total radiation exposure for occupational workers and for members of the public who fly, radiation exposure to intermittent sources needs to be addressed after an event occurs with either radiation monitoring or with modelling.

Dosimetry for exposures to cosmic radiation in civilian aircraft —

Part 4: Validation of codes

1 Scope

This document is intended for the validation of codes used for the calculation of doses received by individuals on board aircraft. It gives guidance to radiation protection authorities and code developers on the basic functional requirements which the code fulfils.

Depending on any formal approval by a radiation protection authority, additional requirements concerning the software testing can apply.

2 Normative references

The following 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 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*

ISO 20785-3, *Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 3: Measurements at aviation altitudes*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20785-1, ISO 20785-2, ISO 20785-3 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Quantities and units

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

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

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 $d\Phi$ by dE, where $d\Phi$ 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 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
$\dot{\Phi}$
quotient of the increment of the particle fluence $d\Phi$ in a time interval dt by that time interval

$$\dot{\Phi} = \frac{d\Phi}{dt} = \frac{d^2N}{da \cdot dt}$$

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
absorbed dose
D
quotient of $d\bar{\varepsilon}$ by dm, where $d\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass dm, thus

$$D = \frac{d\bar{\varepsilon}}{dm}$$

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

3.1.4
quality factor
Q
factor in the calculation and measurement of dose equivalent by which the absorbed dose is to be weighted in order to account for different biological effectiveness of radiations, for radiation protection purposes

Note 1 to entry: The quality factor is a dimensionless quantity. See also 3.1.7.

3.1.5
dose equivalent
H
product of the absorbed dose D to tissue at the point of interest and the quality factor Q at that point

$$H = DQ$$

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

3.1.6
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).

3.1.7
effective dose
E
tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body, given by the expression

$$E = \sum_{T} w_T H_T = \sum_{T} w_T \sum_{R} w_R D_{T,R}$$

where H_T or w_R $D_{T,R}$ is the equivalent dose in a tissue or organ, T, and w_T is the tissue weighting factor.

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

3.1.8
equivalent dose
H_T
dose in a tissue or organ T given by

$$H_T = \sum_{R} w_R D_{T,R}$$

where $D_{T,R}$ is the mean absorbed dose from radiation R in a tissue or organ T, and w_R is the radiation weighting factor. w_R is dimensionless.

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

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 1013,25 hPa

Note 1 to entry: ISO Directives Part 2 requires ISO documents to use SI units and to comply with ISO 80000, so the default should be metres. However, in aviation, the flight level is mostly given as FLxxx, where xxx is a three-digit number representing multiples of 100 feet of pressure altitude, based on the ISA and a datum setting of 1013,25 hPa; for instance FL350 corresponds to 35 000 ft or, using 1 foot = 0,304 8 m, 10 668 m.

3.1.10
magnetic rigidity
r
quotient of momentum of a particle in a magnetic field, *p*, by the product of the number of charges on the particle *Z*, and the elementary charge, *e*, thus

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

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 value of the speed of light, *c*, is 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
effective geomagnetic cut-off rigidity
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 on the Earth

Note 1 to entry: Effective geomagnetic cut-off rigidity depends on the angle of incidence.