



BSI Standards Publication

Dosimetry for exposures to cosmic radiation in civilian aircraft

Part 4: Validation of codes

National foreword

This British Standard is the UK implementation of [ISO 20785-4:2019](#).

The UK participation in its preparation was entrusted to Technical Committee NCE/2, Radiation protection and measurement.

A list of organizations represented on this committee can be obtained on request to its secretary.

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© The British Standards Institution 2019
Published by BSI Standards Limited 2019

ISBN 978 0 580 93530 5

ICS 13.280; 49.020

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 May 2019.

Amendments/corrigenda issued since publication

Date	Text affected
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INTERNATIONAL
STANDARD

ISO
20785-4

First edition
2019-05-23

**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



Reference number
ISO 20785-4:2019(E)

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Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
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Foreword

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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 dosimeters 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

$$\Phi = \frac{dN}{da}$$

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 $\text{m}^{-2} \text{s}^{-1}$, a frequently used unit is $\text{cm}^{-2} \text{s}^{-1}$.

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) ($= \text{V m}^{-1} \text{ s}$). 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.

Note 2 to entry: In its strict definition, the effective geomagnetic cut-off rigidity is not a lower threshold for particles to penetrate the magnetosphere; it lies within a rigidity interval in which charged particles can or cannot penetrate depending on the exact rigidity value. In the context of radiation exposure from GCR, the effective geomagnetic cut-off rigidity has proven to be a good measure for a lower threshold for the primary particle spectrum.

3.1.12

cut-off

vertical cut-off

effective vertical geomagnetic cut-off rigidity

vertical geomagnetic cut-off rigidity

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

Note 1 to entry: Note 2 to entry of [3.1.11](#) applies.

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 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

galactic cosmic radiation

galactic cosmic rays

GCR

cosmic radiation originating outside the solar system

3.2.4

solar particles

solar cosmic radiation

solar cosmic rays

cosmic radiation originating from the sun

3.2.5

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.

3.2.6

GLE

ground level enhancement

sudden increase of cosmic radiation observed on 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.

3.2.7

solar cycle

period during which the solar activity varies with successive maxima separated by an average interval of about 11 years, usually defined in terms of relative sunspot number

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.

3.2.8

relative sunspot number

Wolf number

measure of sunspot activity, computed from the expression

$$k(10g + f)$$

where f is 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)

Note 1 to entry: The solar cycle in terms of the Wolf 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.

Note 2 to entry: The solar maximum corresponds to a minimum intensity in the GCR field.

3.3 Software terms

3.3.1

code

computer code, software, program assessing the radiation exposure of aircraft crew due to cosmic radiation

Note 1 to entry: Examples of such codes are listed in EURADOS report[9].

3.3.2

verification

quality assurance process of determining whether or not the code fulfils the requirements and ensures that the code correctly models the desired data

3.3.3

validation

comparison of the results of the code to experimental or reference data, in order to determine the accuracy or uncertainty

4 General considerations

ICRP **recommends** to use a validated code for the determination of the effective dose on board aircraft[5].

The code should provide dosimetric results consistent with any existing or recommended radiation protection requirements. In [Clause 5](#), criteria are defined for its functionality.

Prior to release of the software for dose record, the software should be thoroughly tested. Procedures defined in the [ISO/IEC/IEEE 29119\[10\]](#) series, Software Testing, should be used. If an alternate method is used, it should be documented and justified.

5 Functionality

5.1 General

Since the radiation protection quantity effective dose, E , cannot be measured, the operational quantity, ambient dose equivalent, $H^*(10)$, or its rate, shall be used for the validation of a software code. Then the validation of the code can be assumed in the procedure for the assessment of effective dose, E .

5.2 Measured data

The ambient dose equivalent calculated by the codes shall be validated by a comparison with measured or reference data. The general approach is to perform a comparison with a selection of data from a representative selection of routes with a range of altitude, latitude, longitude and solar activity. The dose measurements shall be performed according to the other parts of the [ISO 20785](#) series, i.e. [ISO 20785-1](#), [ISO 20785-2](#) and [ISO 20785-3](#).

5.3 ICRU reference data

ICRU has published reference values of the dose rate^[8]. The purpose of the ICRU report is to provide reference data derived from measurements against which the results of routine methods of assessing annual doses using calculations can be compared (benchmarked) for validation purposes.

The cut-off rigidity is not a standard input parameter for flight codes as are position and altitude. There are many points with identical vertical cut-off but different non-vertical cut-offs and hence different dose rates. Comparison of the results for locations with a certain vertical cut-off can be used as a test of the code, but it does not consider the local dose rates which shall be integrated for a flight dose. Therefore, using ICRU 84 cannot be the only test of a code.

5.4 Code validation using measurements or reference data

The agreement between dose values calculated using a code and the comparison data should be as good as possible taking into account the uncertainties of the measurements. The dependence of r_c is to be determined on the basis of different routes over a large range of the magnetic latitude B_m (from the equator to the polar regions), which allows the code validation to be formulated based on either of the following criteria.

- 1) A code for the determination of the dose at flight altitudes can be accepted if the calculated ambient dose equivalent rates $dH^*(10)/dt$ lie, as a function of the cut-off rigidity r_c , for all possible values of r_c in a range of $\pm 30\%$ around the mean values determined from measurements or reference data.
- 2) The route dose can be determined as a cumulative dose from the take-off to the landing. For this purpose, dose values shall be calculated on the basis of flight data from routes representative of the range of cut-off rigidities. A code for the determination of the dose at flight altitudes can be accepted if the route doses in terms of ambient dose equivalent calculated for different flights do not differ by more than $\pm 30\%$ from the measured route doses. The same flight parameters should be used for both the measurements and calculations, especially for flights at high latitude.

Specific attention should be made to neutron spectra measurements as they contribute about 50 % to total ambient dose equivalent at normal flight altitudes (ISO 20785-2, ISO 20785-3).

5.5 Considerations for the routine dose assessment

In order to check the correctness and reliability of the validated code in routine use, regular comparison flights on representative routes should be used to allow dose values obtained by measurements to be directly compared with the values determined by the code. The measurement procedure shall be in accordance with [ISO 20785-3](#).

In routine use, additional requirements shall be fulfilled as good practices in terms of code integrity, data security, plausibility check and traceability of measured data.

The flight data required for calculating the dose are at least: date and time in UTC, departure and arrival airports (given according to IATA or ICAO coding), flight levels, and, if available, way points. The use of departure and arrival airports provides the possibility for the retrospective calculation of the route dose if the input flight data are not valid. However, their use alone may not satisfy the accuracy requirements of this document, particularly at high latitudes.

The user documentation (operating manual) shall be detailed and readily comprehensible. It should include:

- All available functions and how to provide the input data, and view the parameters and calculation results;
- Detailed and comprehensible documentation of the physical background, the physical models used and the calculation methods applied. If the method relates to experimental results or is mainly based on physical simulation, the method used shall be available; and
- A list of the valid ranges of values of the input data (altitude, geographical coordinates, date, etc.).

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