BS ISO 20785-3:2015

BSI Standards Publication

# Dosimetry for exposures to cosmic radiation in civilian aircraft

## Part 3: Measurements at aviation altitudes

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## National foreword

This British Standard is the UK implementation of ISO 20785-3:2015.

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.

Published by BSI Standards Limited 2015

ISBN 978 0 580 81938 4

ICS 13.280; 49.020

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2015.

**Amendments/corrigenda issued since publication**

| Date | Text affected |
|---|---|

INTERNATIONAL STANDARD

ISO 20785-3

First edition
2015-11-15

# 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*

Reference number
ISO 20785-3:2015(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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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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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**
$\Phi$
at a given point of space, number d$N$ of particles incident on a small spherical domain divided by the cross-sectional area d$a$ of that domain:

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

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

Note 2 to entry: The energy distribution of the particle fluence, $\Phi_E$, 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, $\Phi_\Omega$, 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

$\dot{\Phi}$

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

where $d\Phi$ 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

$L_\infty$

for an ionizing charged particle, mean energy $dE_\infty$ 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 $dl$

$$L_\infty = \frac{dE_\infty}{dl}$$

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

### 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, $L_\infty$ (often denoted as L or LET), of charged particles passing through a small volume element (domains) at this point (the value of $L_\infty$ 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:

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

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, $\Phi$

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

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

$X_\mathrm{v}$

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**
$r_\mathrm{c}$
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**
$\phi$
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

### 3.2.13
**cosmic ray neutron monitor**
**ground level neutron monitor**
**GLNM**
large detector used to measure the time-dependent relative fluence rate of high-energy cosmic radiation, in particular the secondary neutrons generated in the atmosphere

Note 1 to entry: Protons, other hadrons, and muons, may also be detected.

Note 2 to entry: Installed worldwide at different locations and altitudes on the ground (and occasionally placed on ships or aircraft), cosmic radiation neutron monitors are used for various cosmic radiation studies and to determine solar modulation.

# 4 General considerations

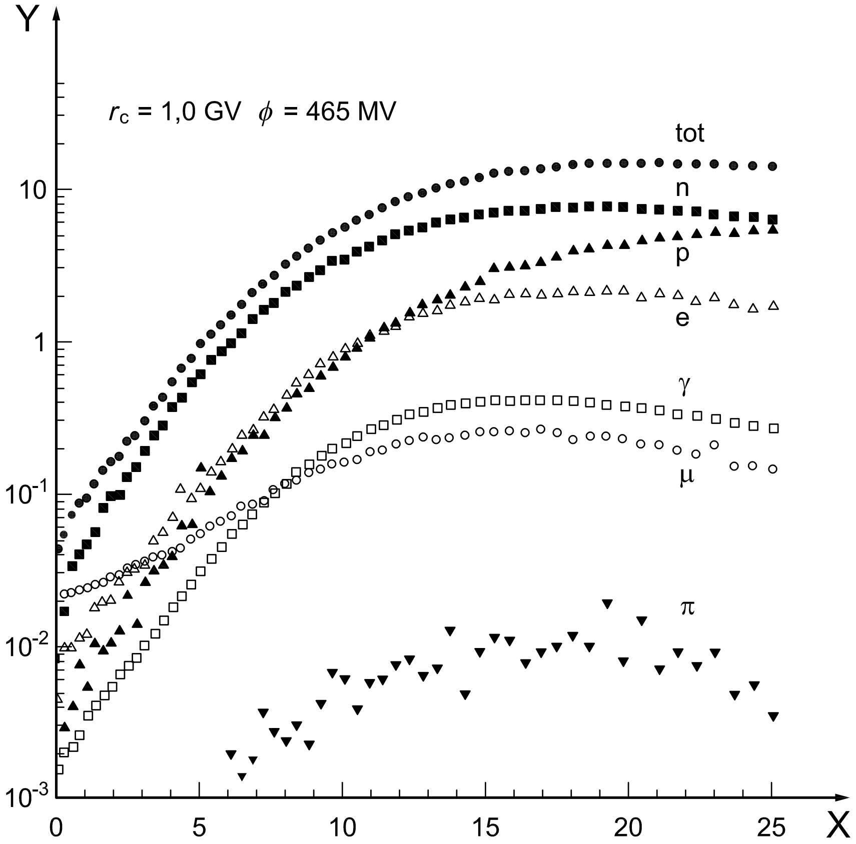
## 4.1 General description of the cosmic radiation field in the atmosphere

The primary galactic cosmic radiation (and energetic solar particles) interact with the atomic nuclei of atmospheric constituents, producing a cascade of interactions and secondary reaction products that contribute to cosmic radiation exposures that decrease in intensity with depth in the atmosphere from aviation altitudes to sea level[6]. Galactic cosmic radiation (GCR) can have energies up to $10^{20}$ eV, but lower-energy particles are the most frequent. After the GCR penetrates the magnetic field of the solar system, the peak of its energy distribution is at a few hundred MeV to 1 GeV per nucleon, depending on solar magnetic activity, and the spectrum follows a power function of the form $E^{-2,7}$ eV up to $10^{15}$ eV; above that energy, the spectrum steepens to $E^{-3}$. The fluence rate of GCR entering the solar system is fairly constant with time, and these energetic ions approach the Earth isotropically.

The magnetic fields of the Earth and Sun alter the relative number of GCR protons and heavier ions reaching the atmosphere. The GCR ion composition for low geomagnetic cut-off and low solar activity is approximately 90 % protons, 9 % He ions and 1 % heavier ions; at a vertical cut-off of 15 GV, the composition is approximately 83 % protons, 15 % He ions and nearly 2 % heavier ions[7].

The changing components of ambient dose equivalent caused by the various secondary cosmic radiation constituents in the atmosphere as a function of altitude are illustrated in Figure 1. At sea level, the muon component is the most important contributor to ambient dose equivalent and effective dose. At aviation altitudes, neutrons, protons, electrons/positrons, photons and muons are the most significant components. At higher altitudes, nuclear ions heavier than protons start to contribute. Figures showing representative normalized energy distributions of fluence rates of all the important particles at low and high cut-offs and altitudes at solar minimum and maximum are shown in Annex A.

The Earth is also exposed to bursts of energetic protons and heavier particles from magnetic disturbances near the surface of the sun and from ejection of large amounts of matter (coronal mass ejections — CMEs) with, in some cases, acceleration by the CMEs and associated solar wind shock waves. The particles of these solar particle events, or solar proton events (both abbreviated to SPE), are much lower in energy than GCR, generally below 100 MeV and only rarely above 10 GeV. SPEs are of short duration, a few hours to a few days, and highly variable in intensity. Only a small fraction of SPEs, on average one per year, produce large numbers of high-energy particles which cause significant dose rates at high altitudes and low geomagnetic cut-offs and can be observed by neutron monitors on the ground. Such events are called ground level enhancements (GLEs). For aircraft crew, the cumulative dose from GCR is far greater than the dose from SPEs. Intense SPEs can affect GCR dose rates by disturbing the Earth's magnetic field in such a way as to change the galactic particle intensity reaching the atmosphere.



**Key**

X altitude (km)

Y ambient dose equivalent rate (μSv/h)

NOTE Conditions: 1 GV cut-off and solar minimum (deceleration potential,$\phi$ of 465 MV)[8].

**Figure 1 — Calculated ambient dose equivalent rates as a function of standard barometric altitude for high latitudes at solar minimum for various atmospheric cosmic radiation component particles**

The field comprises mainly neutrons, protons, electrons/positrons, photons and muons. There is not a significant contribution to dose equivalent from energetic primary heavy charged particles (HZE) or fragments. The electrons/positrons and muons are directly ionizing radiation, and together with indirectly ionizing photons and secondary electrons, interact with matter via the electromagnetic force. Neutrons (and a small contribution from pions), interact via the strong interaction producing directly ionizing secondary particles. Protons are both directly ionizing via the electromagnetic force and indirectly via neutron-like strong interactions.

The directly ionizing component and the secondary electrons from indirectly ionizing photons, comprise the non-neutron component. The neutrons plus the neutron-like interactions of protons comprise the neutron component. Alternatively for dosimetric purposes, the field can be divided into low LET (<10 keV/μm) and high LET (>10 keV/μm) components. This definition is based on the dependence of quality factor on LET. Quality factor is unity below 10 keV/μm. This separation between low and high LET particles can be applied to TEPCs, and to other materials and detectors, but the low LET/high LET threshold may vary between 5 keV/μm and 10 keV/μm. The low LET component comprises the directly ionizing electrons/positrons and muons; secondary electrons from photon interactions, most of the energy deposition by directly ionizing interactions of protons; and part of the energy deposition by secondary particles from strong interactions of protons and neutrons. The high LET component is from relatively short range secondary particles from strong interactions of protons and neutrons. The relative contributions to the total ambient dose equivalent of low LET and non-neutron component, and high LET and neutron and neutron-like component are not necessarily the same, but are generally similar in magnitude.

## 4.2 General considerations concerning the measurements

### 4.2.1 General

The main purpose of measurements on-board aircraft is to determine the ambient dose equivalent or its rate to monitor the exposure of aircraft crew. These measurements are also suitable to validate codes calculating ambient dose equivalent and to investigate the influence of solar activity on the dose rate.

Since the radiation field is complex in terms of radiation types covering a wide range of energies, detailed investigations are required concerning the response of the systems to the different types of radiation. The general approach to determine the ambient dose equivalent at aviation altitudes consists of several steps:

- selection of appropriate instruments (see ISO 20785-1);
- characterization of the responses of the instruments (see ISO 20785-2);
- measurements inside an aircraft (this part of ISO 20785);
- application of appropriate correction factors (this part of ISO 20785).

### 4.2.2 Selection of appropriate instruments

Dosimetry of the radiation field in aircraft requires specialized instruments and techniques. The selection of instruments should be based on their appropriateness to measure the ambient dose equivalent in the complex radiation field in aircraft at altitude.

Refer to ISO 20785-1 for possible instruments and considerations for their use.

### 4.2.3 Characterization of the responses of the instruments

Since it is not possible to characterize the instruments in the actual radiation field at altitude, it is necessary to perform the characterizations using appropriate radiation fields available at ground based facilities. Such fields are ISO reference radiation fields for individual radiation components. However, ISO reference radiation fields do not fully cover the energy range of photons, neutrons and electrons to account for the majority of the contributions to total ambient dose equivalent. Thus, additional calibration fields are required, including, for some devices, proton radiation fields or complex fields simulating the secondary cosmic radiation at altitude. For non-ISO fields a traceable technique to measure the particle fluence and convert it to ambient dose equivalent by applying fluence to dose conversion factors can be used.

Refer to ISO 20785-2 for details of the characterization procedures.

### 4.2.4 Measurements inside an aircraft

Most measurements are made inside the aircraft (cabin or flight deck). For radiation protection purposes, measurements should be performed in a location inside the aircraft representative of the average exposure of aircrew members. In practice, this is difficult to achieve because of the on-board constraints of space limitation and safety regulations.

The alignment of the instruments shall be done according to the calibration/characterization procedures (see ISO 20785-2). The reference orientation of the instrument, i.e. the axis from which the angular dependence of the instrument response was determined, should be parallel to the vertical direction.

### 4.2.5 Application of appropriate correction factors

The aircraft structure may influence the dose rate along the cabin. Depending on location of the instruments inside the aircraft, a correction factor, $K_l$, should be applied. In practice, such a correction factor is very difficult to determine because it depends on the aircraft type, the varying fuel level, the number of passengers, the cabin baggage and the cargo. Also the radiation field along the route may change (relative contributions of the field components and their energy distributions). Calculations indicate that the dose rate varies within ± 10 % along the fuselage.[9][10][11]

For devices having an energy dependence of their response to the different radiation components (see ISO 20785-2), correction factors, $K_{E,R}$, should be applied. The subscripts refer to the energy dependence ($E$) of a device in a radiation field of type $R$. This factor may be estimated using calculated spectra of the secondary cosmic radiation field in the atmosphere (typical spectra are provided in Annex A).

The responses of devices should be as isotropic as possible because of the complexity of the radiation field. For devices having an anisotropic response (see ISO 20785-2), a correction factor, $\mathrm{K}_{\Omega}$, should be evaluated by numerical simulations of the response of the device to the secondary cosmic radiation field.

In practice, if a correction factor cannot be evaluated, it shall be taken into account by an estimate of the associated uncertainty.

## 4.3 Safety and regulatory requirements for in-flight measurements

The methods and procedures shall always be in compliance with other technical and regulatory requirements and regulations concerning the operation of electronic equipment inside aircraft, such as:

— EMI test according to RTCA/DO-160G;

— IATA regulations;

— approval by airline, airport security, flight operations, aircraft commander;

— securing the instruments on-board.

Experimenters should be aware that these preparations are often time-consuming, but are not covered in this part of ISO 20785. The most recent documents shall be used.

# 5 Measurement at aviation altitude

## 5.1 Parameters determining the dose rate

### 5.1.1 Barometric altitude

The altitude required for aviation and for dosimetry is the barometric altitude. It may differ from the geographic altitude considerably. Therefore, the barometric altitude shall be provided (flight plan, on-board flight information system) or determined by making use of an air pressure sensor. For the latter, it is assumed that the air cabin pressure is directly related to barometric altitude, but this relation has to be established for each aircraft individually.

### 5.1.2 Geographic coordinates

Owing to the dependence of the dose rate on the geographic position in the atmosphere, the current coordinates during the measurements shall be logged. These data can be obtained from the aircraft internal system, manually or automatically, from the data streams inside the aircraft, or, which is the most aircraft independent way, by a highly sensitive GPS (Global positioning system) receiver system. Because the GPS signal is difficult to detect inside the cabin, the GPS antenna needs to be mounted on a window which is not covered by a thin metallic layer. The GPS receiver shall be able to work at aviation altitudes and the aircraft speed shall not influence the tracking.

### 5.1.3 Solar activity

The solar activity influences the dose rate at the aviation altitudes only on a long term scale according to the solar cycle (11 years) on a level not exceeding ± 20 %, approximately. In practice, measurements are performed during constant solar conditions and do not need particular consideration. In case of SPE, the radiation field may change considerably and requires specific investigations concerning the influence on the measurements.

## 5.2 Possible influence quantities

### 5.2.1 General

The experimental conditions on-board the aircraft may be beyond the control of the experimenters. Influence quantities (pressure, temperature and humidity) should be considered for the measuring equipment, both in preparing for the measurements as well as during the measurements. The experimenters should ensure that the environmental conditions are within the operating ranges of the instruments.

### 5.2.2 Cabin air pressure

In typical civilian aircraft with pressurized cabin, the air pressure is maintained at a level comparable to conditions ranging from sea level to about 3 000 m. Changes in cabin pressure can affect the measurements. Pressure changes may influence the instrument’s calibration or damage the instrument.

### 5.2.3 Cabin air temperature

The cabin air temperature can be expected to be close to normal room temperature (about 20 °C). However, depending on the location of the instrument in the aircraft, the temperature can affect the measurements.

### 5.2.4 Cabin air humidity

The relative humidity in the cabin is typically within 10 % to 20 % at altitude, depending on the type of aircraft. Changes in humidity can affect the measurements.

## 5.3 Specific considerations for active instruments

### 5.3.1 Power supply

Active instruments require a power supply which is able to provide electrical power throughout the entire flight time (up to about 18 h for ultra-long haul flights), which can be achieved by using the aircraft’s internal power supply or by a carry-on battery pack. For the first option, electronic modules are needed which convert the aircraft power (voltage, frequency, etc.) to the one needed for the devices. In this case, care shall be taken not to introduce external noise on all signal lines inside the active system. For both, aviation safety requirements shall be fulfilled.

If the device uses an internal current fuse for protection against electronic damage, special attention has to be paid if the device is connected to the aircraft power network. When switching on an electronic device, an immediate and short increase of the current consumption can occur. Under laboratory conditions, the laboratory electric power network has an intrinsic current regulation; therefore, the maximum current defined by fuses is not exceeded. The aircraft electric power network is not regulated and, thus, it could provide high peak currents. In this case, measures have to be undertaken to limit the maximum input current.

### 5.3.2 Vibrations and shocks

Devices sensitive to micro-phonic effects and mechanical vibrations require specific packaging to avoid erroneous measurements.

### 5.3.3 Electromagnetic interferences from the aircraft

Measures have to be undertaken in order to avoid electromagnetic interferences, in particular, regarding signal noise and ground loops for active devices connected to the aircraft. The measuring equipment should be as autonomous as possible, for example, by having an internal battery pack.

## 5.4 Specific considerations for passive measurements

### 5.4.1 Security X-ray scanning

The expected doses are a few μSv for hand-luggage scanning systems and can reach a few mSv for luggage or cargo scanning systems. To minimize the additional dose, it is highly recommended to transport the dosemeters as hand-luggage and, if possible, the scanning should be avoided. If not, the additional dose shall be estimated by the data sheet of the scanning system or by measurements.

### 5.4.2 Background subtraction

In order to measure only the in-flight dose, the dose measured before and after the flight shall be determined by measurements with control dosemeters or by local dose records of the background, and be subtracted.

# 6 Uncertainties

For the determination of the uncertainties, ISO/IEC Guide 98-1 and ISO/IEC Guide 98-3 shall be used. The statement of uncertainty shall be consistent with the approaches recommended by ISO/IEC Guide 98-3 and its supplements.

# Annex A
(informative)

## Representative particle fluence energy distributions for the cosmic radiation field at flight altitudes for solar minimum and maximum conditions and for minimum and maximum vertical cut-off rigidity

Figures A.1 to Figures A.6 depict the calculated energy distribution of particle fluence rates free in air for neutrons, protons, pions, electrons, photons and muons. The values of solar activity, geomagnetic cut-off and altitude are assumed to approximate the extreme values which could be expected for civilian aircraft. These values are:

— minimum and maximum solar activity, described by the solar deceleration potential = 465 MV and 1 700 MV, respectively, which covers presumably the entire dynamic range of solar modulation;

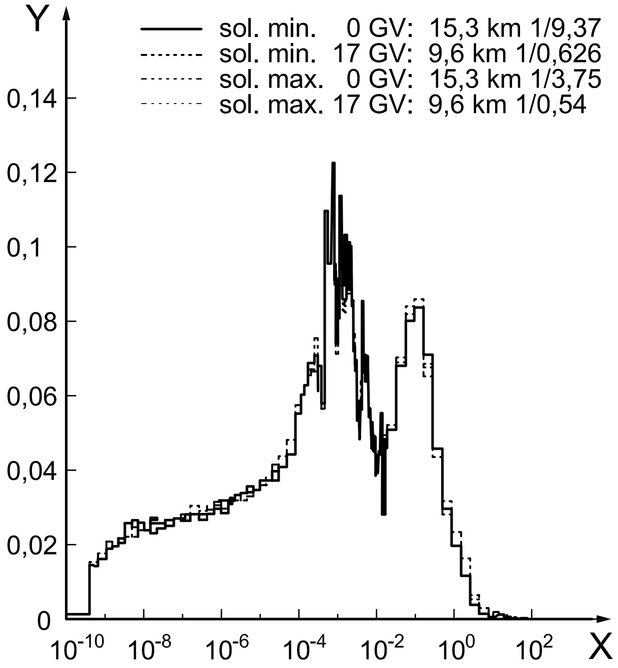
— minimum and maximum geomagnetic cut-off rigidity $r_c$ = 0 GV and 17 GV, respectively;

— minimum and maximum standard barometric flight altitude of 9,6 km and 15,3 km, respectively.

The minimum and maximum solar activity can vary from one solar cycle to the other. Therefore, the indicated values may be used to interpolate for the actual conditions.

In each figure, the energy distribution of particle fluence rates (cm$^{-2}$ s$^{-1}$ GeV$^{-1}$), i.e. particle fluence per time interval, d$t$, and energy interval, d$E$, are multiplied with the energy $E$, and normalized to the energy integrated fluence rates (the normalization factor is given in each figure for the respective curves).

NOTE Figures A.1 to Figures A.6 are reproduced, with permission, from Reference [6].

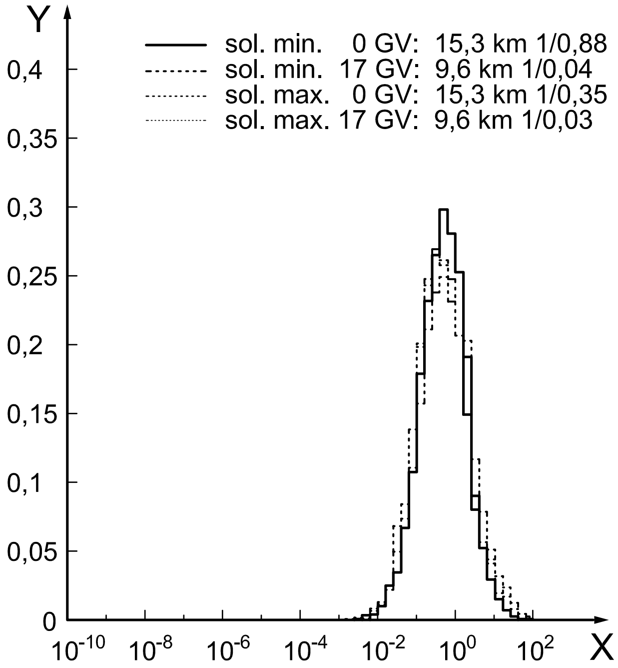


**Key**

X energy (GeV)

Y normalized fluence rate

**Figure A.1 — Normalized energy distribution of neutron fluence rate**

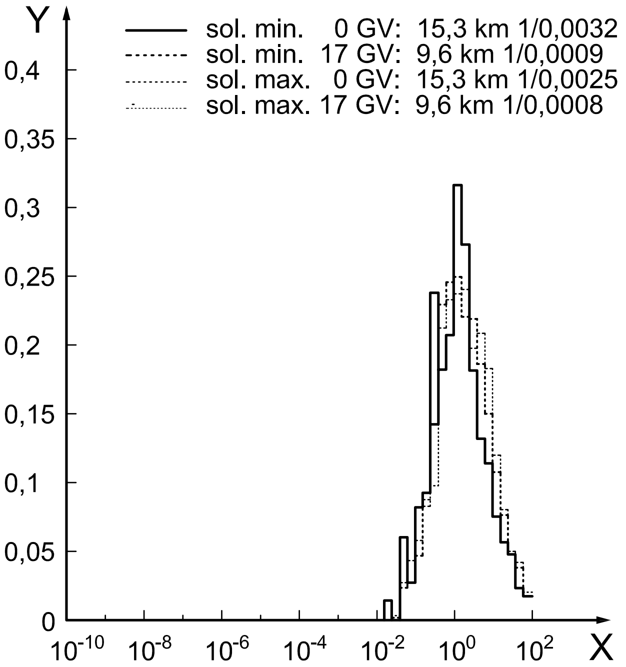


**Key**

X energy (GeV)

Y normalized fluence rate

Figure A.2 — Normalized energy distribution of proton fluence rate

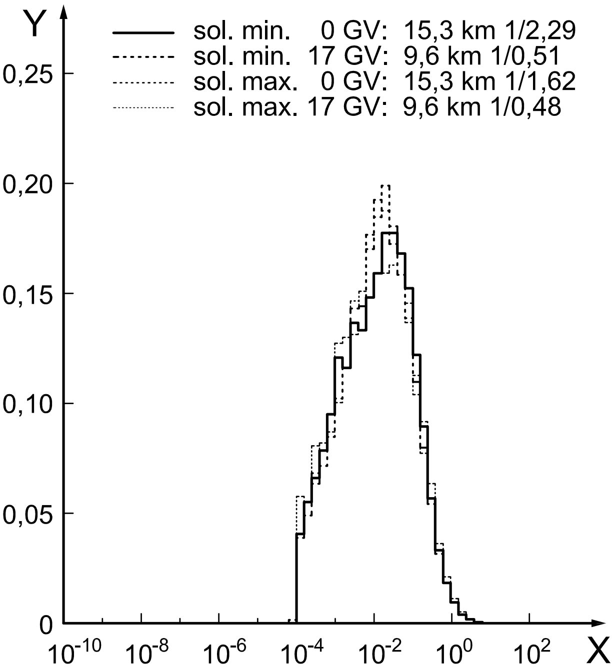


**Key**

X energy (GeV)

Y normalized fluence rate

Figure A.3 — Normalized energy distribution of fluence rate of charged pions

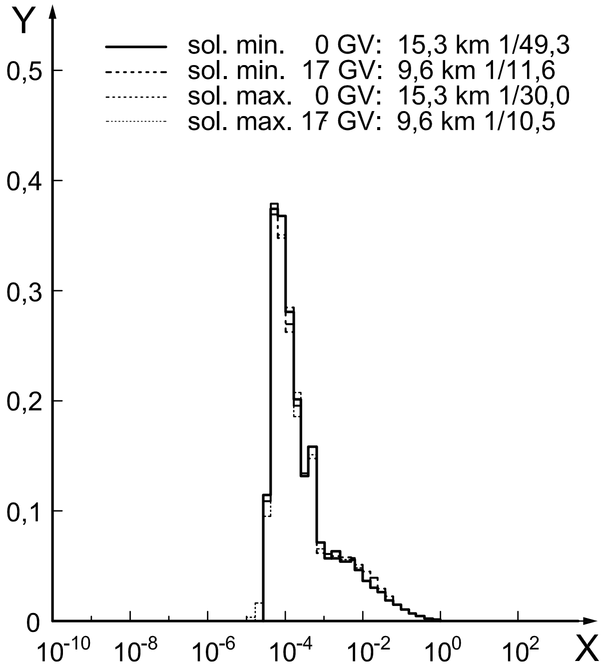


**Key**

X energy (GeV)

Y normalized fluence rate

Figure A.4 — Normalized energy distribution of fluence rate of electrons

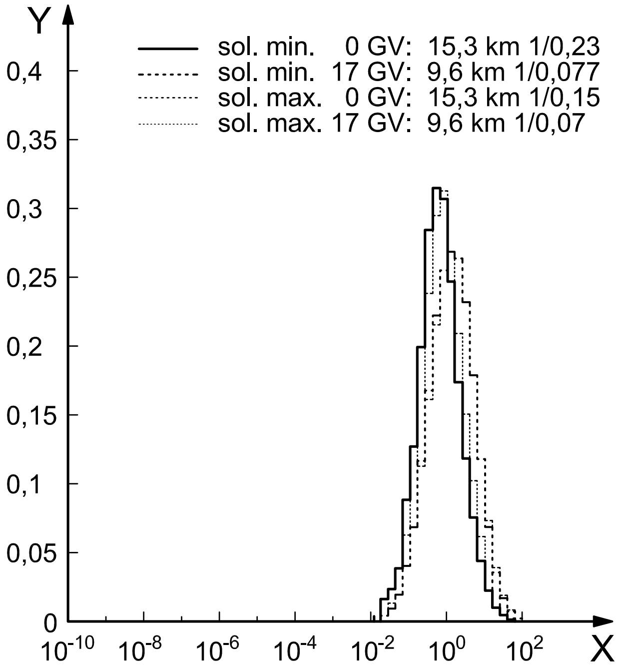


**Key**

X energy (GeV)

Y normalized fluence rate

Figure A.5 — Normalized energy distribution of fluence rate of photons



**Key**

X energy (GeV)

Y normalized fluence rate

Figure A.6 — Normalized energy distribution of fluence rate of muons

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