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# Space environment (natural and artificial) — Cosmic ray and solar energetic particle penetration inward the magnetosphere — Method of determination of the effective vertical cut-off rigidity



*Systèmes spatiaux (naturel et artificiel) — Rayons cosmiques et pénétration de particule énergétique solaire dans la magnétosphère — Méthode de détermination de la rigidité de coupure verticale effective*



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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

 

# Contents

Page

# Foreword

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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.



 

# Introduction

This International Standard describes principal requirements for determination of the effective vertical cut-off rigidity of penetration of charged particles inward the Earth's magnetosphere. This International Standard establishes procedure for calculation of the effective vertical cut-off rigidities for altitude, geographical coordinates (latitude and longitude), and for conditions of geomagnetic disturbances described by the *Kp*-index, as well as for local time. The model that satisfies these requirements is described in the Annex through a series of examples. This International Standard is intended for estimation of penetration into the Earth's magnetosphere by charged particle fluxes from interplanetary space, which is important for developing and testing of influence to hardware and biological objects onboard spacecraft and orbital stations. Procedures for performing simplified calculations of rigidities are proposed.

# Space environment (natural and artificial) — Cosmic ray and solar energetic particle penetration inward the magnetosphere — Method of determination of the effective vertical cut-off rigidity

## 1 Scope

This International Standard describes the effective vertical cut-off rigidities of charged particles for near-Earth space and establishes principal requirements for their calculation. In Annex A, the calculation technique is verified using a typical example. This International Standard can be used to develop calculation techniques based on different models of Earth's geomagnetic field.[1] The techniques are useful for determination of penetrating into the Earth's magnetosphere by charged particle fluxes, as well as for test and estimations of the impact on spacecraft and other equipment in the near-Earth space.

This International Standard is valid for calculating the particle penetration by any of the component of interplanetary charged particles (Galactic, Solar, and Anomalous) with rigidities above 0,2 GV. The main goals of the present standardization for the determination of the effective vertical geomagnetic cut-off rigidities are as follows:



— provide an unambiguous procedure for calculation of the cut-off rigidities inside of the Earth's magnetosphere reflecting dependences on geomagnetic disturbances and local time;

— provide means of estimation of the impact of charged particle fluxes in interpretation and analysis of space experiments;



— provide efficient calculations of the transmission functions of low-altitude orbits of spacecraft and manned space-station;

— determine impact of solar energetic particle flux on spacecraft instrumentation and astronauts using results of independent online measurement of interplanetary particle fluxes.

## 2 Terms and definitions

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

**2.1**
**internal (main) magnetic field**
magnetic field produced by the sources inside the Earth's core

Note 1 to entry: See ISO 16695.

Note 2 to entry: It can be presented by the International Geomagnetic Reference Field (IGRF) model.

**2.2**
**International Geomagnetic Reference Field model**
**IGRF model**
geomagnetic reference field in the form of a series of spherical harmonic functions

Note 1 to entry: See Reference [2].

Note 2 to entry: The expansion coefficients undergo very slight changes in time.

Note 3 to entry: The International Association of Geomagnetism and Aeronomy (IAGA) is responsible for IGRF model development and modifications and approves its coefficients every five years. The internal magnetic field is not the subject of this International Standard.

**2.3**
**external (magnetospheric) magnetic field**
magnetic field produced by magnetospheric sources

Note 1 to entry: It can be described by different models, e.g. Tsyganenko-89[3] and more recent models.[4][5]

**2.4**
**Tsyganenko-89 geomagnetic field model**
model described in Reference

[SOURCE: 3]

**2.5**
**Geomagnetic field**
sum of internal and external magnetic fields

**2.6**
**particle charge *Z***
charge $Z$ of a particle is equal to $+ne$, ($n$ = 1, 2, 3,....), where $e$ is the value of electron charge ($1{,}60 \times 10^{-19}$ C).

**2.7**
**particle magnetic rigidity**
magnetic rigidity of particle $R$ is related to particle momentum $p$ and its charge by:

$$R = pc/Z$$


where $c$ is the speed of light, and $Z$ is the charge of a particle


Note 1 to entry: The magnetic rigidity of protons and nuclei is related to the particle's energy as

$$R = \frac{A}{Z}\sqrt{E(E + 2M_0)}$$



where $E$ is the kinetic energy in GeV/u, $A$ is the particle's mass in amu, and $M_0$ is the rest mass of proton equal to 0,931 GeV.

**2.8**
**cut-off rigidity**
location of a transition, in rigidity space, from allowed to forbidden trajectories as rigidity is decreasing

**2.9**
**lower cut-off rigidity**
***R*$_L$**
access of particles of all rigidity values lower than the lower cut-off rigidity is forbidden for penetration from outside of the Earth's magnetic field

Note 1 to entry: $R_L$ is the calculated lowest cut-off value, i.e. the rigidity value of the lowest allowed/forbidden transition obtained in computer simulations.

**2.10**
**main (upper) cut-off rigidity**
***R*$_U$**
access of particles of all rigidity values higher than the main cut-off rigidity is allowed for penetration from outside of the Earth's magnetic field

Note 1 to entry: $R_U$ is the rigidity value of the calculated upper cut-off value, i.e. the rigidity value of the highest allowed/forbidden transition obtained in computer simulations.

**2.11**
**penumbra**
rigidity range lying between the main (upper) and the lower cut-off rigidities

**2.12**
**effective cut-off rigidity**
***R*eff**
total effect of the penumbral structure in a given direction may be represented for a number of purposes, by the "effective cut-off rigidity", a single numerical value which specifies the equivalent total accessible cosmic radiation within the penumbra in a specific direction

**2.13**
**effective vertical cut-off rigidity**
**EVRC**
effective cut-off rigidity value for a particle arriving to a fixed point in the vertical direction (radially to the centre of the Earth)

**2.14**
**index of magnetosphere disturbance**
***K***
three-hour quasi-logarithmic local index of geomagnetic activity relative to on assumed quiet-day curve for a specific recording site

Note 1 to entry: The range is from zero to nine. The *K* index measures the deviation of the most disturbed horizontal component.

**2.15**
***Kp*-index**
three-hour planetary geomagnetic index of activity based on the *K* index from 13 stations distributed around the world



Note 1 to entry: The *Kp*-index is originally derived at GeoForschungsZentrum in Germany. The web address should be http://www.gfzpotsdam.de/en/research/organizationalunits/departments/department-2/earthsmagnetic-field. It is also available at www.swpc.noaa.gov.



**2.16**
**attenuation quotient**
**Δ(*R*0,*Kp*,*T*)**
determines how much the vertical cut-off rigidity value in a real geomagnetic field for a given *Kp*-index, at a local time *T,* decreased relative to values calculated with the IGRF model ($R_0$)

Note 1 to entry: Some of these terms are also defined in Reference [6].

## 3 General concepts and assumptions

### 3.1 Determination of effective vertical cut-off rigidity

The geomagnetic cut-off rigidities are determined by tracing particle trajectories in the geomagnetic field. For a more detailed description of the method, see Annex A and References [7] and [8]. The method determines the trajectory of negatively charged particles emitted from the given coordinate point in the vertical direction in an effort to estimate whether the particle escapes the magnetosphere. As a result of tests of particles with different rigidities, it is possible to determine upper and lower rigidities for given magnetospheric conditions. From these data, the effective value of the vertical cut-off rigidity can be determined.

The calculation technique should be detailed enough to determine the effective cut-off values with an accuracy better than 2 %. Results of application of this type of calculation technique to IGRF data for a given set of initial points are presented in Table C.1.

### 3.2 Models of the employed geomagnetic field

The models for the geomagnetic field should reflect the changes of the internal field (IGRF model for each five-year period), as well as changes of the external (magnetosphere) magnetic field caused by