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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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Foreword

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

This second edition cancels and replaces the first edition (ISO 17520:2016), which has been technically revised.

The main changes are as follows:

— basic tables for epoch 2015 and 2020 calculated using IGRF model are added.

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

This document describes principal requirements for determination of the effective vertical cut-off rigidity of penetration of charged particles inward the Earth's magnetosphere. This model provides for calculations of cut-off rigidity in arbitrary point of the magnetosphere at given local time. The document is applicable 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 model satisfying these requirements depending on geomagnetic disturbances described by the K_p-index is presented in Annex B. 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.

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 document describes the effective vertical cut-off rigidities of charged particles for near-Earth space and establishes principal requirements for their calculation 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 spacecrafts and other equipment in the near-Earth space.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

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

3.1
internal magnetic field
main magnetic field
magnetic field produced by the sources inside the Earth's core

Note 1 to entry: Internal magnetic field is described in ISO 16695[2].

Note 2 to entry: It can be presented by the *International Geomagnetic Reference Field (IGRF) model* (3.2).

3.2
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 [3].

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 document.

3.3
external magnetic field
magnetic field produced by magnetospheric sources

Note 1 to entry: It can be described by different models, e.g. Tsyganenko-89[4] and more recent models presented in References [5], [6], and [7].

3.4
geomagnetic field
sum of *internal magnetic field* (3.1) and *external magnetic field* (3.3)

3.5
particle charge
Z
$+ne$, (n=1, 2, 3....), where e is the value of electron charge ($1{,}60\times10^{-19}$ C)

3.6
particle magnetic rigidity
R
value related to a particle's momentum and its charge, calculated by:

$$R = pc/Z \quad (1)$$

where

- p is the particle momentum;
- c is the speed of light;
- Z is the *particle charge* (3.5)

Note 1 to entry: The magnetic rigidity of protons and nuclei is related to the particle's energy in accordance with Formula (2).

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

where

- E is the kinetic energy in GeV/u;
- A is the particle's mass in Dalton (atomic mass unit);
- M_0 is the rest mass of proton equal to 0,931 GeV

3.7
cut-off rigidity
location of a transition, in rigidity space, from allowed to forbidden trajectories as rigidity is decreasing

3.8
lower cut-off rigidity
R_L
rigidity value of a particle lower than which access for penetration from outside of the Earth's magnetic field is forbidden

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.

3.9
upper cut-off rigidity
main cut-off rigidity
R_U
rigidity value of a particle higher than which access for penetration from outside of the Earth's magnetic field is allowed

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.

3.10
penumbra
rigidity range lying between the *lower cut-off rigidity* (3.8) and the *upper cut-off rigidity* (3.9)

3.11
effective cut-off rigidity
R_{eff}
numerical value which specifies the equivalent total accessible cosmic radiation within the *penumbra* (3.10) in a specific direction

3.12
effective vertical cut-off rigidity
EVRC
effective cut-off rigidity (3.11) for a particle arriving to a fixed point in the vertical direction (radially to the centre of the Earth)

Note 1 to entry: The total effect of the *penumbra* (3.10) structure in a given direction may be represented, for a number of purposes, by the effective cut-off rigidity.

3.13
K_p-index
three-hour quasi-logarithmic index of geomagnetic activity based on data of from 13 stations distributed around the world

Note 1 to entry: The K_p-index is originally derived at GeoForschungsZentrum in Germany (http://www.gfzpotsdam.de/en/research/organizationalunits/departments/department-2/earthsmagnetic-field). It is also available at www.swpc.noaa.gov.

Note 2 to entry: The range is from zero to nine.

4 General concepts and assumptions

4.1 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 [8], [9], and [10]. 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 cut-off 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 model for a given set of initial points are presented in Tables B.1 to B.4.

4.2 Models of the employed geomagnetic field

The models for the geomagnetic field should reflect the changes of the internal magnetic field (IGRF model for each five-year period) as well as changes of the external magnetic field caused by current flowing in the magnetosphere and on its surface. All models available (Tsyganenko or other extensions[4],[5],[6],[7]) may be used.

4.3 Effective vertical cut-off rigidity databases (libraries)

In addition to direct computation of cut-off rigidities, the world grids of calculated values of vertical cut-off rigidities can be used to evaluate the radiation conditions for different spacecraft and manned station orbits. Sometimes, that kind of database is calculated for many different levels of magnetosphere disturbances and different local (or universal) time groups. These databases are put together a “library”[9],[11]. That kind of “library,” together with the associated cut-off rigidity interpolation software, provides a tool for general use in space physics applications.

4.4 Method for effective vertical cut-off data generalization

In these libraries, the effective vertical cut-off rigidity world grids are tabulated versus the discounted magnetosphere disturbance levels and local (or universal) time. Spacecraft and manned station orbits are variable, which means that the disturbance levels are not integers, but are subdivided. The same is true for the local (or universal) time. Therefore, it is not convenient to tabulate the detailed library needed to store all this data. The sheer size of the tabulation can make it unusable. However, the content of the library can be generalized in the form of a unique world grid of effective vertical cut-off rigidities calculated with the IGRF model for altitude H_0=450 km, and a set of analytic equations describing the EVCR values as a function of IGRF rigidity values, altitude, magnetosphere disturbance, and local time. A working example of the simplest model describing magnetosphere disturbances via the sole parameter, namely the K_p-index, is presented in Annex B.

5 Model requirements

5.1 General

The model for determination of the effective vertical cut-off (referred to below as "model") presents the effective vertical rigidity cut-off calculation.

The model determines an effective vertical cut-off at the altitudes from 250 km to 20 000 km over the mean Earth radius r_E=6 371,2 km.

5.2 Parameterization

The cut-off rigidities depend on the following parameters: geographic latitude (λ) and longitude (φ), altitude (H) over the Earth radius, the geomagnetic disturbance, and local time T.

