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Space environment (natural and artificial) — Model of high energy radiation at low altitudes (300 km to 600 km)

Environnement spatial (naturel et artificiel) — Modèle de radiations à énergie élevée à basses altitudes (300 km à 600 km)

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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

The International Standard is intended for the estimation of high energy charged particle fluxes at low altitudes (300 km to 600 km) in the Earth's magnetosphere. Detailed information on high energy charged particle fluxes is essential for developing spacecrafts and spacecraft equipment.

High energy galactic cosmic rays[1] approaching the Earth interact with the atmosphere resulting in a production of secondary particles. The flux of secondary particles is composed mainly by electrons, protons, neutrons and gamma-rays which execute their trajectories in the Earth's magnetic field.[2] An appreciable fraction of charged secondary particles with rigidity less than geomagnetic cut-off[3] can travel backward in space along the Earth's magnetic field lines and can reach the satellite altitudes forming a high energy radiation halo in the Earth vicinity. The other fraction of secondary protons is trapped by geomagnetic field for years forming the inner radiation belt. These protons with kinetic energies greater than some tens of MeV mainly originated from the β-decay of albedo neutrons according to the so-called "Cosmic Ray Albedo Neutron Decay" (CRAND) mechanism.[4] According to this mechanism, the Earth is surrounded in its equatorial region by shaped ring of high radiation. Because of a shift of geomagnetic dipole with respect to the Earth centre, in South Atlantic Anomaly (SAA) trapped particles are observed at low altitudes approximately 300 km.

On the basis of the data primarily taken from mid-sixties to early seventies of the last century, the model of the Earth's trapped proton radiation has been provided by the NASA AP-8 models.[4] Significant improvements of radiation environment modelling in low Earth orbit (LEO) was carried out thanks to data from satellite experiments, such as CRRES, SAMPEX/PET and the TIROS/NOAA series.[5][6][7] These models can be used for estimations of radiation environment for energies below ~100 MeV with some procedures taking into account secular variations of the geomagnetic filed and drift of SAA for current epoch (e.g. Reference [8]).

Modern, more accurate measurements of the high energy (Ekin above ~100 MeV) cosmic ray radiation in LEO have been reported by the PAMELA mission.[9] These new measurements including trapped component and charged albedo components are the basis of this International Standard.

Space environment (natural and artificial) — Model of high energy radiation at low altitudes (300 km to 600 km)

1 Scope

This International Standard describes the fluxes of charged particles for near-Earth space on base of the PAMELA experiment data. This International Standard can be used to calculate fluxes of protons with energy more than 100 MeV up to geomagnetic cut-off rigidity at low altitudes (300 km to 600 km). The main goal of this International Standard is determining the impact of energetic charged particle flux upon spacecraft instrumentation and astronauts.

2 Terms and definitions

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

2.1
International Geomagnetic Reference Field model
IGRF model
geomagnetic reference field in the form of a series of spherical harmonic functions[10]

Note 1 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.[10]

2.2
particle magnetic rigidity
magnetic rigidity of particle, R, is related to particle momentum, p, and its charge, Z, by:

$$R = pc/Z$$

where c is the speed of light.[3]

2.3
cut-off rigidity
location of a transition for primary charged cosmic ray particles, in rigidity space, from allowed to forbidden trajectories as rigidity is decreased[3]

2.4
geomagnetic coordinates *L* and *B*
used to map differential fluxes j of energetic geomagnetically trapped particles

Note 1 to entry: B is absolute value of geomagnetic field in the point of observation. In the dipole approximation of the geomagnetic field, L-shell is distance to magnetic field line in equatorial plane.

Note 2 to entry: Geomagnetic coordinates L-shell and B are introduced by MacIlwain.[11]

2.5
Albedo trapped particles
part of cosmic ray charged radiation with rigidity below geomagnetic cut-off produced in interactions of high energy cosmic rays with residual atmosphere of the Earth which execute their trajectories in the Earth magnetic field

3 General concepts and assumptions

This International Standard determines the fluxes of high energy radiation at the altitudes from 300 km to 600 km over the Earth sea level which is recommended to use for an estimation of radiation environment. Tables A.1 to A.3 provide differential vertical fluxes of albedo trapped protons, j_p(Ekin) (Annex A, Tables A.1 and A.2), and albedo positron and electron, j_e(Ekin) (Table A.3), as a function of kinetic energy Ekin from Ekin~100 MeV up to a maximum energy corresponding to lowest geomagnetic cut-off.[3] Above maximum Ekin in Tables A.1 and A.2 primary cosmic ray dominates and for flux calculation, it is necessary to use ISO 15390. Tables of fluxes are based on smoothed PAMELA experimental data.[12][13][14][15]

To map differential fluxes of particles geomagnetic coordinates (*LB*)[11] calculated for IGRF model[3] are used.

The model presents vertical flux averaged over low altitude orbits for fixed geomagnetic coordinates. No longitudinal and time variations of fluxes are suggested for high energy trapped particles into inner magnetosphere.

Annex A
(informative)

Tables for proton and electron fluxes

Table A.1 — Differential fluxes of protons Jp(Ekin)for the 2006–2009 epoch averaged over altitude from 300 km up to 600 km, particles/(m^2 sr s MeV)[12][13][14]
Equatorial region

L-shell	0,90 to 1,2	0,90 to 1,2	0,90 to 1,2	0,90 to 1,2	1,2 to 1,5	1,2 to 1,5	1,2 to 1,5	1,2 to 1,5	1,2 to 1,5
B, Gs Ekin, GeV	0,9 to 0,2	0,2 to 0,21	0,21 to 0,22	>0,22	0,19 to 0,20	0,20 to 0,21	0,21 to 0,22	0,22 to 0,23	>0,23
	204,0	61,37	1,921	0,162	23,08	3,73	0,406	0,130	0,081
0,119	192,0	57,52	1,784	0,155	21,32	3,42	0,342	0,123	0,078
0,133	179,8	53,6	1,65	0,151	19,6	3,10	0,319	0,114	0,076
0,149	154,7	45,7	1,38	0,143	16,3	2,42	0,265	0,093	0,072
0,168	129,2	37,80	1,13	0,134	13,04	1,83	0,191	0,084	0,062
0,188	105,9	30,6	0,907	0,117	10,20	1,36	0,162	0,060	0,060
0,211	84,5	24,09	0,698	0,115	7,78	0,946	0,148	0,057	0,054
0,237	66,2	18,51	0,525	0,103	5,82	0,641	0,114	0,054	0,048
0,266	50,8	13,97	0,399	0,100	4,18	0,421	0,091	0,053	0,041
0,299	37,8	10,1	0,273	0,098	2,95	0,274	0,063	0,050	0,036
0,335	27,5	7,25	0,193	0,091	2,01	0,178	0,044	0,048	0,029
0,376	19,5	4,99	0,152	0,077	1,36	0,112	0,036	0,038	0,026
0,422	13,3	3,31	0,118	0,077	0,915	0,069	0,034	0,031	0,021
0,473	8,97	2,13	0,099	0,073	0,582	0,047	0,030	0,032	0,018
0,531	5,86	1,365	0,081	0,057	0,345	0,029	0,029	0,029	0,015
0,596	3,79	0,812	0,064	0,051	0,214	0,020	0,026	0,023	0,013
0,669	2,35	0,492	0,049	0,042	0,113	0,016	0,020	0,017	0,010
0,751	1,38	0,300	0,044	0,033	0,055	0,015	0,013	0,013	0,008
0,842	0,781	0,173	0,037	0,025	0,029	0,012	0,008	0,009	0,007
0,945	0,434	0,096	0,029	0,021	0,019	0,009	0,005	0,007	0,005
1,06	0,244	0,058 0	0,023	0,016	0,009 7	0,007 9	0,005 9	0,006 3	0,004 3
1,19	0,129	0,039	0,019 3	0,016 5	0,006 8	0,006 1	0,006 1	0,005 2	0,003 4
1,33	0,057 0	0,027	0,015	0,012	0,003 9	0,005 5	0,005 5	0,004 0	0,002 8
1,49	0,031 2	0,020	0,011	0,009 5	0,002 2	0,003 7	0,005 5	0,001 8	0,002 1
1,68	0,018	0,016 5	0,010	0,007 2	0,001 1	0,002 8	0,004 9	0,001 3	0,001 8
1,88	0,0140	0,012 8	0,008 9	0,006 3	0,001 6	0,002 4	0,003 4	0,001 9	0,001 4
2,11	0,012	0,007 9	0,006 7	0,004 6	0,001 6	0,002 2	0,002 5	0,001 1	0,001 2
2,37	0,007 89	0,005 2	0,005 1	0,004 2	0,001 3	0,001 9	0,002 5	0,001 1	0,001 1
2,66	0,004 77	0,003 9	0,004 1	0,003 4	0,001 3	0,001 3	0,002 0	0,001 5	0,001 0
2,99	0,003 49	0,002 3	0,002 3	0,002 2	0,001 8	7,9E-4	0,001 4	0,001 2	9,4E-4
3,35	0,002 37	0,001 2	0,001 9	0,001 5	0,001 6	9,8E-4	0,001 7	8,6E-4	9,5E-4

Table A.1 *(continued)*

L-shell	0,90 to 1,2	0,90 to 1,2	0,90 to 1,2	0,90 to 1,2	1,2 to 1,5	1,2 to 1,5	1,2 to 1,5	1,2 to 1,5	1,2 to 1,5
B, Gs Ekin, GeV	0,9 to 0,2	0,2 to 0,21	0,21 to 0,22	>0,22	0,19 to 0,20	0,20 to 0,21	0,21 to 0,22	0,22 to 0,23	>0,23
3,76	8,4E-4	9,3E-4	0,001 7	9,4E-4	0,001 4	0,001 0	0,001 5		9,0E-4
4,22	4,0E-4	4,8E-4	6,5E-4	5,4E-4	0,001 4				
4,73	4,4E-4	4,2E-4	5,2E-4	4,6E-4	0,001 2				
5,31		1,8E-4	2,7E-4	4,3E-4					
5,96			5,2E-5	2,2E-4					

Table A.2 — Differential fluxes of protons Jp(Ekin)for the 2006–2009 epoch averaged over altitude from 300 km up to 600 km, particles/(m² sr s MeV)[12][13][14]
Middle and pole latitudes

L-shell	1,5 to 2	1,2 to 1,2	1,5 to 2	1,5 to 2	2 to 2,4	2 to 2,4	2,4 to 3,0	3,0 to 4,0	4 to 5,5
B, Gs Ekin, GeV	0,2 to 0,21	0,21 to 0,22	0,22 to 0,23	>0,23	0,22 to 0,23	>0,23	>0,23	>0,23	>0,23
0,106	1,44	0,407	0,209	0,116	0,239	0,182	0,270	0,489	1,026
0,119	1,20	0,358	0,197	0,111	0,240	0,177	0,266	0,474	1,041
0,133	1,09	0,326	0,191	0,108	0,232	0,170	0,263	0,464	1,074
0,149	0,694	0,235	0,127	0,097	0,215	0,152	0,249	0,442	
0,168	0,515	0,167	0,111	0,084	0,196	0,132	0,236	0,413	
0,188	0,311	0,130	0,109	0,077	0,172	0,117	0,224	0,398	
0,211	0,233	0,108	0,092	0,069	0,151	0,098	0,207	0,389	
0,237	0,112	0,090	0,067	0,058	0,131	0,086	0,188	0,388	
0,266	0,077	0,085	0,061	0,048	0,108	0,075	0,167		
0,299	0,058	0,074	0,061	0,043	0,094	0,067	0,148		
0,335	0,055	0,066	0,049	0,036	0,089	0,059	0,131		
0,376	0,048	0,056	0,046	0,030	0,068	0,053	0,114		
0,422	0,045	0,042	0,045	0,024	0,054	0,043	0,099		
0,473	0,028	0,043	0,036	0,018	0,046	0,038	0,088		
0,531	0,017	0,038	0,030	0,014	0,035	0,033	0,076		
0,596	0,018	0,034	0,026	0,012	0,028	0,030	0,071		
0,669	0,016	0,027	0,017	0,009	0,027	0,026	0,079		
0,751	0,013	0,021	0,012	0,008	0,023	0,023			
0,842	0,016	0,014	0,013	0,007	0,021	0,021			
0,945	0,014	0,011	0,010	0,006	0,020	0,018			
1,06	0,010 4	0,010 7	0,009 1	0,006	0,017 3	0,015 3			
1,19	0,008 2	0,010 3	0,007 1	0,005 2	0,015	0,014			
1,33	0,006 8	0,009 9	0,004 7	0,004 5					
1,49	0,005 0	0,008 8	0,002 7	0,004 2					
1,68	0,005 0	0,007 0	0,003 1	0,003 7					
1,88	0,002 4	0,005 9	0,001 7	0,003 5					
2,11	0,001 4	0,006 1							
2,37	0,001 4								

Table A.2 *(continued)*

L-shell	1,5 to 2	1,2 to 1,2	1,5 to 2	1,5 to 2	2 to 2,4	2 to 2,4	2,4 to 3,0	3,0 to 4,0	4 to 5,5
B, Gs Ekin, GeV	0,2 to 0,21	0,21 to 0,22	0,22 to 0,23	>0,23	0,22 to 0,23	>0,23	>0,23	>0,23	>0,23
2,66	6,4E-4								

Table A.3 — Total positrons and electrons differential fluxes Je(Ekin) for the 2006–2009 epoch averaged over altitude from 300 km up to 600 km, particles/(m² sr s MeV) [13][15]

L-shell	0,9 to 1,2	0,9 to 1,2	1,2 to 1,5	1,5 to 2,0	2,0 to 2,4	2,4 to 3,0	3,0 to 4
B, Gs E, GeV	0,19 to 0,21	>0,23	>0,23	>0,23	>0,23	>0,23	>0,23
0,07	—	0,62	0,77	0,95	0,98	1	0,95
0,1	3,5	0,46	0,46	0,51	0,53	0,53	0,45
0,13	2,9	0,29	0,23	0,24	0,23	0,21	0,19
0,18	2,1	0,19	0,13	0,11	0,094	0,088	0,074
0,25	1,3	0,125	0,06	0,048	0,039	0,033	0,031
0,33	0,9	0,080	0,029	0,019	0,012	0,010	0,015 5
0,45	0,55	0,046	0,012	0,007	0,004 2	0,003 1	0,010
0,6	0,32	0,025	0,005 4	0,002 7	0,001 0	—	0,005 4
0,8	0,15	0,014	0,002 1	9,3E-4	4,5E-4	—	—
1,1	0,06	0,005 7	6,3E-4	—	1,8E-4	—	—
1,6	0,027	0,002 7	2,6E-4	—	—	—	—
2,1	0,011	0,001 07	1,4E-4	—	—	—	—
2,9	3,9E-4	3,85E-4	6,7E-5	—	—	—	—
3,9	1,3E-4	1,3E-4	3,3E-5	—	—	—	—
5,3	3E-5	3E-5	—	—	—	—	—
7,3	5,6E-6	5,6E-6	—	—	—	—	—