

Contents

Page

European Foreword	13
Introduction	14
1 Scope	15
2 Normative references	16
3 Terms, definitions and abbreviated terms	19
3.1 Terms defined in other standards	19
3.2 Terms specific to the present standard	19
3.3 Abbreviated terms.....	27
4 Gravity	29
4.1 Introduction and description.....	29
4.1.1 Introduction	29
4.1.2 Gravity model formulation	29
4.1.3 Third body gravitation.....	31
4.1.4 Tidal effects.....	31
4.2 Requirements for model selection and application.....	31
4.2.1 General requirements for gravity models.....	31
4.2.2 Selection and application of gravity models.....	32
5 Geomagnetic fields	33
5.1 Introduction and description.....	33
5.1.1 The geomagnetic field and its sources	33
5.1.2 The internal field	33
5.1.3 External field: ionospheric components.....	33
5.1.4 External magnetic field: magnetospheric components.....	34
5.1.5 Models of the internal and external geomagnetic fields	34
5.2 Requirements for model selection and application.....	35
5.2.1 The internal field	35
5.2.2 The external field	36
5.3 Tailoring guidelines.....	37

6	Natural electromagnetic radiation and indices	38
6.1	Introduction and description	38
6.1.1	Introduction	38
6.1.2	Electromagnetic radiation and indices	38
6.2	Requirements	41
6.2.1	Electromagnetic radiation	41
6.2.2	Reference index values	41
6.2.3	Tailoring guidelines	42
6.3	Tables	42
7	Neutral atmospheres	44
7.1	Introduction and description	44
7.1.1	Introduction	44
7.1.2	Structure of the Earth's atmosphere	44
7.1.3	Models of the Earth's atmosphere	44
7.1.4	Wind model of the Earth's homosphere and heterosphere	45
7.2	Requirements for atmosphere and wind model selection	45
7.2.1	Earth atmosphere	45
7.2.2	Earth wind model	47
7.2.3	Models of the atmospheres of the planets and their satellites	47
8	Plasmas	48
8.1	Introduction and description	48
8.1.1	Introduction	48
8.1.2	Ionosphere	48
8.1.3	Plasmasphere	49
8.1.4	Outer magnetosphere	49
8.1.5	Solar wind	50
8.1.6	Magnetosheath	50
8.1.7	Magnetotail and L2	50
8.1.8	Planetary environments	51
8.1.9	Induced environments	51
8.2	Requirements for model selection and application	51
8.2.1	General	51
8.2.2	Ionosphere	52
8.2.3	Auroral charging environment	52
8.2.4	Plasmasphere	53
8.2.5	Outer magnetosphere	54
8.2.6	The solar wind (interplanetary environment)	54

8.2.7	Other plasma environments	54
8.2.8	Tables	55
9	Energetic particle radiation	56
9.1	Introduction and description	56
9.1.1	Introduction	56
9.1.2	Overview of energetic particle radiation environment and effects	56
9.2	Requirements for energetic particle radiation environments.....	59
9.2.1	Trapped radiation belt fluxes	59
9.2.2	Solar particle event models	61
9.2.3	Cosmic ray models.....	63
9.2.4	Geomagnetic shielding.....	63
9.2.5	Neutrons	63
9.2.6	<<deleted>>	63
9.2.7	L2 and the Deep Magnetotail Environment	63
9.3	Preparation of a radiation environment specification.....	63
9.4	Tables.....	65
10	Space debris and meteoroids.....	66
10.1	Introduction and description	66
10.1.1	The particulate environment in near Earth space	66
10.1.2	Space debris	66
10.1.3	Meteoroids	67
10.2	Requirements for impact risk assessment and model selection	67
10.2.1	General requirements for meteoroids and space debris	67
10.2.2	Model selection and application	67
10.2.3	<<deleted>>	70
10.2.4	The meteoroid model	71
10.2.5	Impact risk assessment.....	71
10.2.6	Margins	72
11	Contamination	73
11.1	Introduction and description	73
11.1.1	Introduction	73
11.1.2	Description of molecular contamination.....	73
11.1.3	Transport mechanisms.....	74
11.1.4	Description of particulate contamination.....	74
11.1.5	Transport mechanisms.....	74
11.2	Requirements for on-orbit contamination assessment	75

Annex A (normative) Natural electromagnetic radiation and indices	76
A.1 Solar activity values for complete solar cycle	76
A.2 Tables.....	77
Annex B (normative) Energetic particle radiation	81
B.1 Historical dates of solar maximum and minimum	81
B.2 GEO model (IGE-2006)	81
B.3 ONERA MEOv2 model	81
B.4 FLUMIC model	82
B.4.1 Overview	82
B.4.2 Outer belt ($L > 2,5 R_e$)	82
B.4.3 Inner belt ($L < 2,5 R_e$)	83
B.5 NASA worst case GEO spectrum	83
B.6 ESP solar proton model specification.....	84
B.7 Solar ions model.....	84
B.8 Geomagnetic shielding (Størmer theory)	85
B.9 MOBE-DIC.....	85
B.9.1 Overview	85
B.9.2 Spectral form.....	85
B.9.3 L-shell profile.....	86
B.9.4 Magnetic latitude profile	87
B.10 Tables.....	88
Annex C (normative) Space debris and meteoroids.....	100
C.1 Flux models	100
C.1.1 <<deleted>>	100
C.1.2 <<deleted>>	100
C.1.3 <<deleted>>	100
C.1.4 Meteoroid streams	100
C.1.5 Grün meteoroid model	102
C.2 Tables.....	105
Annex D (informative) Gravitation	109
D.1 Gravity models: background	109
D.2 Guidelines for use.....	110
D.3 Availability of models	112
D.4 Tables.....	112
D.5 Figures	113
Annex E (informative) Geomagnetic fields.....	114

E.1	Overview of the effects of the geomagnetic field	114
E.2	Models of the internal geomagnetic field	114
E.3	Models of the external geomagnetic field	115
E.4	Magnetopause boundary	115
E.5	Geomagnetic coordinate system – <i>B</i> and <i>L</i>	116
E.6	Tables.....	118
E.7	Figures	120
Annex F (informative) Natural electromagnetic radiation and indices		122
F.1	Solar spectrum	122
F.2	Solar and geomagnetic indices – additional information	122
F.2.1	E10.7	122
F.2.2	F10.7.....	122
F.2.3	S10.7	122
F.2.4	M10.7.....	123
F.3	Additional information on short-term variation	123
F.4	Useful internet references for indices.....	124
F.5	Earth electromagnetic radiation	124
F.5.1	Earth albedo.....	124
F.5.2	Earth infrared	125
F.6	Electromagnetic radiation from other planets	126
F.6.1	Planetary albedo	126
F.6.2	Planetary infrared.....	126
F.7	Activity indices information.....	126
F.8	Tables.....	126
F.9	Figures	127
Annex G (informative) Neutral atmospheres.....		130
G.1	Structure of the Earth’s atmosphere	130
G.2	Development of models of the Earth’s atmosphere.....	130
G.3	NRLMSISE-00 and JB-2006 - additional information	131
G.4	The GRAM series of atmosphere models.	132
G.5	Atmosphere model uncertainties and limitations	132
G.6	HMW07 additional information	132
G.7	Planetary atmospheres models.....	133
G.7.1	Jupiter	133
G.7.2	Venus.....	133
G.7.3	Mars.....	134
G.7.4	Saturn	134

G.7.5	Titan.....	134
G.7.6	Neptune	134
G.7.7	Mercury.....	134
G.8	Reference data	135
G.9	Tables.....	136
G.10	Figures	140
Annex H (informative) Plasmas		144
H.1	Identification of plasma regions.....	144
H.2	Plasma effects on spacecraft.....	144
H.3	Reference data	144
H.3.1	Introduction	144
H.3.2	Ionosphere.....	145
H.3.3	Plasmasphere.....	145
H.3.4	Outer magnetosphere	146
H.3.5	Magnetosheath	147
H.3.6	Magnetotail and distant magnetosheath.....	147
H.3.7	Planetary environments	147
H.3.8	Induced environments.....	148
H.4	Tables.....	149
H.5	Figures	152
Annex I (informative) Energetic particle radiation.....		153
I.1	Trapped radiation belts	153
I.1.1	Basic data	153
I.1.2	Tailoring guidelines: orbital and mission regimes	153
I.1.3	Existing trapped radiation models	154
I.1.4	The South Atlantic Anomaly	156
I.1.5	Dynamics of the outer radiation belt	157
I.1.6	Internal charging	157
I.2	Solar particle event models.....	158
I.2.1	Overview.....	158
I.2.2	ESP model.....	158
I.2.3	JPL models	158
I.2.4	Spectrum of individual events	159
I.2.5	Event probabilities.....	160
I.2.6	Other SEP models	161
I.3	Cosmic ray environment and effects models.....	161
I.4	Geomagnetic shielding	161

I.5	<<deleted>>	162
I.6	Planetary environments	162
I.6.1	Overview	162
I.6.2	Existing models	162
I.7	Atmospheric albedo neutron models	163
I.8	Interplanetary environments	164
I.9	Tables	165
I.10	Figures	167
Annex J (informative) Space debris and meteoroids		173
J.1	Reference data	173
J.1.1	Trackable space debris	173
J.1.2	Reference flux data for space debris and meteoroids	173
J.2	Additional information on flux models	174
J.2.1	Meteoroids	174
J.2.2	Space debris flux models	175
J.2.3	Model uncertainties	177
J.3	Impact risk assessment	177
J.3.1	Impact risk analysis procedure	177
J.3.2	<<deleted>>	178
J.3.3	Damage assessment	178
J.4	Analysis tools	180
J.4.1	General	180
J.4.2	Deterministic analysis	180
J.4.3	Statistical analysis	181
J.5	Tables	182
J.6	Figures	188
Annex K (informative) <<deleted>>		190

Figures

Figure D-1	: Graphical representation of the EIGEN-GLO4C geoid (note: geoid heights are exaggerated by a factor 10 000)	113
Figure E-1	: The IGRF-12 field strength (nT, at 2015) and predicted change in intensity between 2015 and 2020 at the mean Earth radius. (Mercator projection from [RN.38])	120
Figure E-2	: The general morphology of model magnetospheric field lines, according to the Tsyganenko 1989 model, showing the seasonal variation, dependent on rotation axis tilt	121

Figure F-1 : Solar spectral irradiance (in red, AM0 (Air Mass 0) is the radiation level outside of the Earth's atmosphere (extraterrestrial), in blue, AM1,5 is the radiation level after passing through the atmosphere 1,5 times, which is about the level at solar zenith angle 48,19°s, an average level at the Earth's surface (terrestrial)).	127
Figure F-2 : Daily solar and geomagnetic activity indices over the last two solar cycles	128
Figure F-3 : Monthly (27-day) mean solar and geomagnetic activity indices over the last two solar cycles	129
Figure G-1 : Temperature profile of the Earth's atmosphere	140
Figure G-2 : Variation of the JB-2006 mean air density with altitude for low, moderate, high long and high short term solar and geomagnetic activities	141
Figure G-3 : Variation of the NRLMSISE-00 mean atomic oxygen with altitude for low, moderate and high long solar and geomagnetic activities	142
Figure G-4 : Variation of the NRLMSISE-00 mean concentration profile of the atmosphere constituents N_2 , O , O_2 , He , Ar , H , N and anomalous O with altitude for moderate solar and geomagnetic activities ($F10.7 = F10.7_{avg} = 140$, $A_p = 15$)	143
Figure H-1 : Profile of electron density for solar magnetic local time = 18 hr, solar magnetic latitude=0, $K_p = 0$ and 9 from the GCPM for 1/1/1999	152
Figure I-1 : Contour plots of the proton and electron radiation belts	167
Figure I-2 : Electron (a) and proton (b) omnidirectional fluxes, integral in energy, on the geomagnetic equator for various energy thresholds	168
Figure I-3 : Integral omnidirectional fluxes of protons (>10 MeV) and electrons (>10 MeV) at 400 km altitude showing the inner radiation belt's "South Atlantic anomaly" and, in the case of electrons, the outer radiation belt encountered at high latitudes	169
Figure I-4 : Comparison of POLE with AE8 (flux vs. Energy) for 15 year mission (with worst case and best case included)	170
Figure I-5 : Comparison of ONERA/GNSS model from 0,28 MeV up to 1,12 MeV (best case, mean case and worst case) with AE8 (flux vs. Energy) for 15 yr mission (with worst case & best case)	170
Figure I-6 : Albedo neutron spectra at 100 km altitude at solar maximum	171
Figure I-7 : Albedo neutron spectra at 100 km altitude at solar minimum	171
Figure I-8 : Jupiter environment model (proton & electron versions)	172
Figure J-1 : Time evolution of the number of trackable objects in orbit (as of May 2018). Regular updates available online: https://discosweb.esoc.esa.int/web/guest/statistics	188
Figure J-2 : Semi-major axis distribution of trackable objects in LEO orbits (as of May 2018)	188
Figure J-3 : Distribution of trackable objects as function of their inclination (as of May 2018)	189
Figure J-4 : The HRMP velocity distribution for different altitudes from the Earth surface	189

Tables

Table 6-1: Conversion from K_p to a_p	42
Table 6-2: Electromagnetic radiation values	43
Table 6-3: Reference fixed index values.....	43
Table 6-4: Reference index values for variations of a_p	43
Table 8-1: Worst-case bi-Maxwellian environment	55
Table 8-2: Solar wind parameters.....	55
Table 9-1: Standard field models to be used with AE8 and AP8	65
Table 11-1: Contamination levels - interaction with the space environment components	75
Table A-1 : Solar cycle 23 solar activity indices averaged over 30-day (1 month) intervals.....	77
Table B-1 : A and E_0 for three confidence levels.....	86
Table B-2 : Minima and maxima of sunspot number cycles	88
Table B-3 : IGE-2006 GEO average model – electron flux ($\text{kev}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year.	89
Table B-4 : IGE-2006 GEO upper case model - maximum electron flux ($\text{kev}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year.	90
Table B-5 : MEOv2 average case model - average electron flux ($\text{Mev}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year.	92
Table B-6 : MEOv2 upper case model - maximum electron flux ($\text{Mev}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$) according to year in the solar cycle (referred to solar min: 0) and for different energies for a mission duration of 1 year.	92
Table B-7 : Worst case spectrum for geostationary orbits.....	93
Table B-8 : Values of the parameters for the ESP model.....	93
Table B-9 : Values to scale fluence from >100 MeV to >300 MeV	94
Table B-10 : CREME-96 solar ion worst 5-minute fluxes in an interplanetary environment	94
Table B-11 : CREME-96 solar ion worst day fluxes in an interplanetary environment..	96
Table B-12 : CREME-96 solar ion worst week fluxes in an interplanetary environment	98
Table C-1 : Normalized meteoroid velocity distribution	105
Table C-2 : The annual meteor streams	107
Table D-1 : Degree power attenuation for an orbit at 25 000 km altitude	112
Table D-2 : Coefficients of the EIGEN-GL04C model up to degree and order 8×8 ...	113
Table E-1 : Magnetic pole positions since 1900 as determined from IGRF-12 in WGS84 geodetic latitude (taken from [RN.38])	118

Table E-2 : Sibeck et al. Magnetopause model	119
Table F-1 : Reference values for average planetary albedo and infra-red radiation ...	126
Table G-1 : Altitude profiles of the atmosphere constituents N ₂ , O, O ₂ , He, Ar, H, N and anomalous O for low solar and geomagnetic activities (NRLMSISE-00 model - $F_{10.7} = F_{10.7_{avg}} = 65, A_p = 0$).....	136
Table G-2 : Altitude profiles of the atmosphere constituents N ₂ , O, O ₂ , He, Ar, H, N and anomalous O for mean solar and geomagnetic activities (NRLMSISE-00 model - $F_{10.7} = F_{10.7_{avg}} = 140, A_p = 15$).....	137
Table G-3 : Altitude profiles of the atmosphere constituents N ₂ , O, O ₂ , He, Ar, H, N and anomalous O for high long term solar and geomagnetic activities (NRLMSISE-00 model - $F_{10.7} = F_{10.7_{avg}} = 250, A_p = 45$)	138
Table G-4 : Altitude profiles of total density ρ [kg m ⁻³] for low, moderate, high long and high short term solar and geomagnetic activities (JB-2006 model).....	139
Table H-1 : Worst-case 3-Maxwellian environment.....	146
Table H-2 : Regions encountered by different mission types	149
Table H-3 : Main engineering concerns due to space plasmas.....	149
Table H-4 : Ionospheric electron density profiles derived from IRI-2016 for date 01/01/2016, lat=0, long=0.....	150
Table H-5 : Profile of densities for solar magnetic local time = 18 hr, solar magnetic latitude=0, Kp = 5,0 from the GCPM for 1/1/1999.....	150
Table H-6 : Typical plasma parameters at geostationary orbit	151
Table H-7 : Typical magnetosheath plasma parameters.....	151
Table H-8 : Typical plasma parameters around L2	151
Table H-9 : Worst-case environments for eclipse charging near Jupiter and Saturn ..	151
Table H-10 : Photoelectron sheath parameters	152
Table H-11 : Some solar UV photoionization rates at 1 AU	152
Table I-1 : Example albedo neutron environment at 450 km altitude [RD.151].....	164
Table I-2 : Characteristics of typical radiation belt particles	165
Table I-3 : Recommended updated values of the parameters of the JPL model	165
Table I-4 : Proton fluence levels for energy, mission duration and confidence levels from the ESP model with the NASA parameters from Table B-8.	166
Table I-5 : Parameters for the fit to the peak fluxes from the October 1989 events.	166
Table J-1 : Approximate flux ratios for meteoroids for 400 km and 800 km altitudes..	182
Table J-2 : Cumulative number of impacts, N , to a randomly tumbling plate for a range of minimum particle sizes using the MASTER-8 model (version 8.0.0)....	183
Table J-3 : Cumulative number of impacts, N , to a randomly tumbling plate for a range of minimum particle sizes using the MASTER-8 model (version 8.0.0)....	184
Table J-4 : Cumulative number of impacts, N , to a randomly tumbling plate for a range of minimum particle sizes using the MASTER-8 model (version 8.0.0)....	185
Table J-5 : Cumulative number of impacts, N , to a randomly tumbling plate for a range of minimum particle masses	186
Table J-6 : Parameters (appearing in Eq.) to account for modified meteoroid fluxes encountered by spacecraft in circular Earth orbits at various altitudes.....	187