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Space environment (natural and artificial) — Method of the solar energetic protons fluences and peak fluxes determination

National foreword

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Environnement spatial (naturel et artificiel) — Méthode des fluences de protons énergétiques solaires et détermination des flux de pic





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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*.

Space environment (natural and artificial) — Method of the solar energetic protons fluences and peak fluxes determination

1 Scope

This Technical Report is intended for calculating the probability for solar energetic particle (SEP) to have an impact on materials, hardware, and biological objects.

This Technical Report establishes the differential energy spectra for the $(0,1/10^3)$ MeV SEP fluences and/or peak fluxes in the near-earth space, beyond the earth magnetosphere during the missions any duration under varying solar activity.

If additional prepositions are used, the method establishes the basic fluences and peak fluxes for their determination throughout the heliosphere. When the effect of the particle penetration into the magnetosphere is taken into account (see ISO/AWI 17520, *Cosmic ray and solar energetic particle penetration inside the magnetosphere: Determination of the vertical cutoff values*, draft standard), the method establishes the basic fluences and peak fluxes for their determination on the near-earth spacecraft and manned station orbits.

Because the occurrence of SEP is a process a probabilistic nature, fluences and peak fluxes calculation relate to the different levels of probability.

The method is intended for specialists engaged in determination of radiation conditions in space.

2 Definitions, notations, and abbreviations

Term	Notation	Abbreviation	Definition
Solar energetic particles (or solar cosmic rays)		SEP	High-energy (≥ 4 MeV/nucleon) charged particle of solar origin.
Mission duration	T		Calendar time period for the SEP peak flux or fluence is model calculated (months).
Wolf (sunspot) number	W		$W = k(10g+f)$, where g is sunspot group number; f is the total sunspot number on the visible solar disc. k is the coefficient adjusting various observation conditions.
Solar activity (SA) level	$\langle W \rangle$		13-month smoothed month sunspot number or predicted by NOAA month sunspot number. http://www.sec.noaa.gov/Data/
Solar activity condition	$\Sigma \langle W_i \rangle$		The sum of the smoothed month sunspot numbers during the space mission
Mission parameter	n		The parameter of the model, relative determined as the hypothetical mean number of SEP events with the fluences $F_{30} \geq 10^5 \text{ cm}^{-2}$ protons with energy ≥ 30 MeV expected during the missions duration.
Particle energy	E		Particle energy (MeV/nucleon).
Particle fluence	F		The total (time-integrated) number of particles in given space mission that traverse a unit area from all directions from solid angle 4π (particle/cm ²).

Term	Notation	Abbreviation	Definition
Differential proton fluence energy spectrum	dF/dE	$F(E)$	Differential particle fluence energy (E) distribution during the space mission [particle/(cm ² ·MeV)].
Integral particle fluence energy spectrum	$F(\geq E)$	F_E	Integral particle fluence energy (E) distribution (at E above a given level) during the space mission (particle/cm ²).
Particle peak flux	f		The time when a maximum number of particles traverse a unit area during the space mission, normally to a given observation, direction in unit time through unit solid angle [proton/(cm ² ·sr·s)]. NOTE The fluxes of particles with different energy reach maximum values at different times during the SEP event.
Differential particle peak flux energy spectrum	df/dE	$f(E)$	Differential particle peak flux energy (E) distribution during the space mission [particle/(cm ² ·sr·s·MeV)].
Integral proton peak flux energy spectrum	$f(\geq E)$	f_E	Integral particle peak flux energy (E) distribution during the space mission (or in a set of SEP events) [particle/(cm ² ·sr·s)].
SEP fluences and/or peak fluxes occurrence probability	P	Probability	The probability the given fluences and/or fluxes should be exceeded.
Small fluxes (fluences or peak fluxes)	S	Small	Fluxes, sizes that exceed probability 0,9, or fluxes occurred at the 0,1 confidence level.
Mean fluxes (fluences or peak fluxes)	M	Mean	Fluxes, with probability 0,5 (50/50 case), or at the 0,5 confidence level.
Large fluxes (fluences or peak fluxes)	L	Large	Fluxes, sizes that exceed probability 0,1 or occurred at the 0,9 confidence level.
Extremal fluxes (fluences or peak fluxes)	E	Extremal	Fluxes, sizes that exceed probability 0,01 or occurred above the 0,99 confidence level.
Worst case fluxes (fluences or peak fluxes)	W	Worst case	Fluxes, sizes that exceed probability 0,001 or occurred above the 0,999 confidence level.

3 Main principles of the method

3.1 The method establishes the sizes of the SEP fluences and/or peak fluxes, which are expected with probability P , to get exceeded within a time interval T at a given solar activity conditions.

3.2 Angular distribution of SEP fluxes beyond the earth's magnetosphere is taken to be isotropic.

3.3 The solar activity condition is described as sum of smoothed mean (or predicted) month sunspot (Wolf) numbers $\sum_{i=1}^m \langle W_i \rangle$ where m is the number of months with solar activity, $\langle W_i \rangle$, each during mission duration T .

3.4 The mission parameter, n , is determined to be equal as:

$$\langle n \rangle = 1,35 \times 10^{-2} \sum_{i=1}^m \langle W_i \rangle \quad (1)$$

The value $\langle n \rangle / 2$ is the mean SEP event (with the fluence, $F(E \geq 30 \text{ MeV}) \geq 10^6$ protons/cm²) number in the considered period.

3.5 The solar high energy protons ($E \geq 30$ MeV) distribution function by integral fluences is described as:

$$\psi(\geq F) = C \times F^{-\gamma} / \exp(F / F_0) \quad (2)$$

where the parameters are $C = 28,7$, $\gamma = 0,32$, and $\Phi_0 = 8,10^9$.

3.6 The differential energy spectra of the particle fluences (F) and/or peak fluxes (f) (referred to henceforth as energy spectra of Φ) for predicted missions are power-law functions of proton energy, E .

$$\Phi(E) dE = CE^{-\gamma} dE \quad (3)$$

where E is the protons kinetic energy in MeV.

In case of proton fluxes, the following spectral parameters are taken:

- E_k , the centre of the region in which the energy spectra of the broken off (the effect of the knee).
- DE_k , the energy region from $E_{\min} = E_k / DE_k$ to $E_{\max} = E_k \cdot DE_k$, wherein the spectral index is changing from γ_1 to γ_2 .
- D , differential fluence (or peak flux) at E_k .
- At $E < E_k / DE_k$, spectral index is proposed to be γ_1 .
- At $E > E_k \cdot DE_k$, spectral index is proposed to be γ_2 .
- In case of $E_{\min} \leq E \leq E_{\max}$, γ is proposed to change as:

$$\gamma = (\gamma_1 + \gamma_2) / 2 + (\gamma_1 - \gamma_2) / 2 \times S \quad (4)$$

where

$$S = \sin[\pi \times (\log(E) - \log(E_k)) / (\log(E_{\max}) - \log(E_{\min}))]$$

Finally, the differential energy spectra [Formula (3)] in range $(0,1/10^3)$ MeV are described by four parameters (1, 3, 4, 5). Therefore, the parameter DE_k is supposed to be constant and equal to 1,37.

4 Calculation technique

4.1 The present model includes the specifications of the differential energy spectra parameters for fluences and peak fluxes for the most frequently used integral probability sequence $P = 0,9$ (small), 0,75, 0,5 (mean), 0,25, 0,1 (large), 0,01 (extreme), and 0,001 (worst case). For the sequence of the mission parameters $\langle n \rangle = 1, 2, 4, 8, 16, 32, 64, 128, 256$, and 512 are used. The parameters, $n = 1/2$, describe the annual missions at the deep SA minimum; parameters, $n = 8, 16$, and 32, describe the annual missions in case of mean sunspot numbers $W = 50, 100$, and 200 accordingly; parameter, $n = 128$, describe the conditions at the full solar cycle (like 19, 20, 21, 22, and 23 cycles) mission period. In the case of approximation methods used, energy spectra for all possible mission duration at all possible solar active conditions can be described in more detail.

4.2 The standard method tabulates the parameters of differential spectra for fluences and peak fluxes.

E_k , D , γ_1 , and γ_2 for model parameters P (probability) and $\langle n \rangle$ (mission parameter eq. mean number of SEP events).

4.3 The particle fluence and/or peak flux calculations involve:

4.3.1 Calculation of the mission parameter, $\langle n \rangle$, by Formula (1).

In case of future missions, use the predicted sunspot number data from:

$\langle \text{http://www.swpc.noaa.gov/ftpdir/weekly/Predict.txt} \rangle$

or in accordance with the data of high activity SA cycle 19 (years 1954-1964) from:

$\langle \text{ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/INTERNATIONAL/yearly/YEARLY} \rangle$

4.3.2 Establish the probability (confidence) level needed.

4.3.3 Use the tabulated parameters data or calculation of four parameters using interpolation of the tabulated data (if needed). In case of parameter D for the interpolation, the logarithm values of D should be used.

4.4 Calculate the differential energy spectrum for needed values, $\langle n \rangle$, and P , using Formula (3) and Formula (4).

4.5 In case the integral proton energy spectra are to be calculated, use Formula (5):

$$\Phi(\geq E) = \int_E^{\infty} \Phi(E) dE \quad (5)$$

NOTE As the present model, the tabulated parameters, but not figures, are established. The figures, presented in Annexes, serve only as illustrations.

5 Base tables

Table 1 — The coefficients of the proton fluence spectrum $\log, D(\langle n \rangle/P)$

$\langle n \rangle/P$	0,9	0,75	0,5	0,5	0,1	0,01	0,001
1	-	-	6,041	7,241	7,991	8,732	9,442
2	-	6,076	7,041	7,775	8,253	8,983	9,600
4	6,378	6,972	7,870	8,173	8,571	9,236	9,732
8	7,324	7,874	8,220	8,520	8,820	9,442	9,860
16	8,140	8,380	8,630	8,859	9,010	9,647	9,982
32	8,640	8,820	8,986	9,137	9,367	9,810	10,190
64	9,037	9,176	9,322	9,465	9,671	9,978	10,210
128	9,441	9,556	9,658	9,799	9,942	1,127	10,320
256	9,829	9,899	9,989	10,104	10,199	10,360	10,440
512	10,143	10,233	10,303	10,405	10,479	10,577	10,613