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Space environment (natural and artificial) — Observed Proton Fluences over long duration at GEO and Guideline for selection of confidence level in statistical model of Solar Proton Fluences

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO/TS 12208 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space environment (natural and artificial)*.

Introduction

This Technical Specification intended to use in engineering community.

It is well known that solar energetic proton (SEPs) damage spacecraft systems, that is, electronics and solar cells due to ionization and/or atomic displacement processes. This results in single-event upsets and latch-ups in electronics, and output degradation of solar cells.

Solar cells of spacecraft are obviously one of the key components of spacecraft systems. It is unavoidable that energetic protons degraded solar cells, which causes power loss of the spacecraft systems. The degradation of cells are crucial to its mission life. Therefore, an estimation of SEP fluences at GEO is needed for a designing solar cell panels.

Solar cell engineers use a statistical model, for example the JPL fluence model, for estimating solar cell degradation. However, in the point of view of solar cell degradation, it is well known that a statistical model predicts higher SEP fluences than the values actually experienced by spacecraft at GEO, especially after seven years from the launch. Nowadays, spacecraft manufacturers are very conscious of cost-minimum design of spacecraft because lifetime of spacecraft becomes longer (15-18 years) and the cost of manufacturing spacecraft is increasing. Therefore, the aerospace industry requires a more accurate SEP fluence model for more realistic design of solar cells.

Space environment(natural and artificial) — Observed Proton Fluences over long duration at GEO and Guideline for selection of confidence level in statistical model of Solar Proton Fluences

1.Scope

This Technical Specification(TS) describes a method to estimate energetic proton fluences at GEO for the long range (over the 11 year solar cycle), and describes guideline for selection of confidence level in statistical model of Solar Proton Fluences.

Many observed proton data at GEO are archived, for example GMS(Japan), METEOSAT(ESA) and GOES(USA). This method is a direct integration of these fluence data.

By this result, confidence level can be selected from statistical model of solar proton fluences.

This technical specificaiton is a engineering-oriented method for specific purposes such as solar panel degradation.

2.Terms and definitions

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

2.1

Confidence Level in this TS

A probability that a satellite does note experience energetic proton higher than the given fluence level.

2.2

Extreme rare event

A SEP event that occurs about once in a solar cycle, and whose fluence dominates that for the entire cycle. For example, August 1972, October 1989 and July 2000.

3.Symbols and abbreviated terms

EOL	End Of Life
GEO	Geosynchronous Orbit
RDC	Relative Damage Coefficients
SEP	Solar Energitic Proton

4.Principles of the method [1]

4.1 Cumulative fluence

The cumulative fluence for a given mission duration of *n*-years is estimated as follows:

(1) calculate *n*-year fluence by integrating observed daily fluences from achieves with shifting the integration windows day-by-day. (They are possible fluences that a spacecraft may experience during the mission life.)

A, B,C, …, Z in the figure below.

(2) take the maximum of the integrated fluences (F(t)) for the n-years mission duration. (Maximum fluence of n-year mission assuming a spacecraft is launched everyday!)

F(t)=max(A,B,C,…,Z)

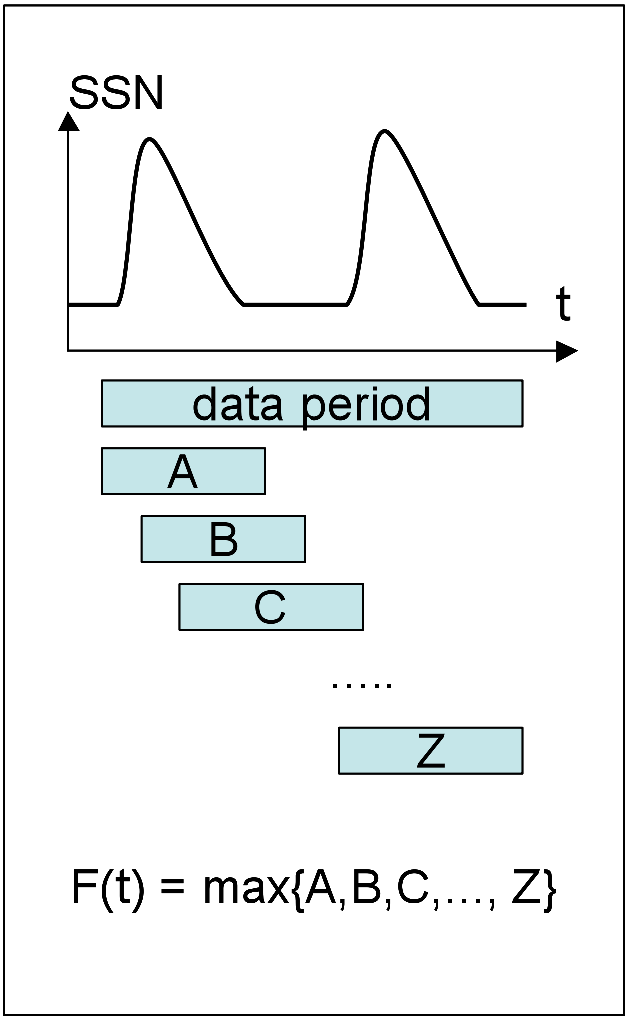

Figure 1 — Cumulative Fluences

4.2 Confidence level

The confidence level for a given mission duration of *n*-years is estimated as follows:

(1) Make a set of *n*-year fluences by Integrating proton fluxes data with shifting the integration window day-by-day.

(2) Build the occurrence distribution f(F) of the data set of fluences F.

(3) Normalize the distribution to have unity when integrated over fluence.

(4) Integrate the distribution from 0 to F' to take the confidence level p for *n*-year mission life.

Note: The confidence level goes to 100% because this method does not include extreme rare events which did not happen during the period.

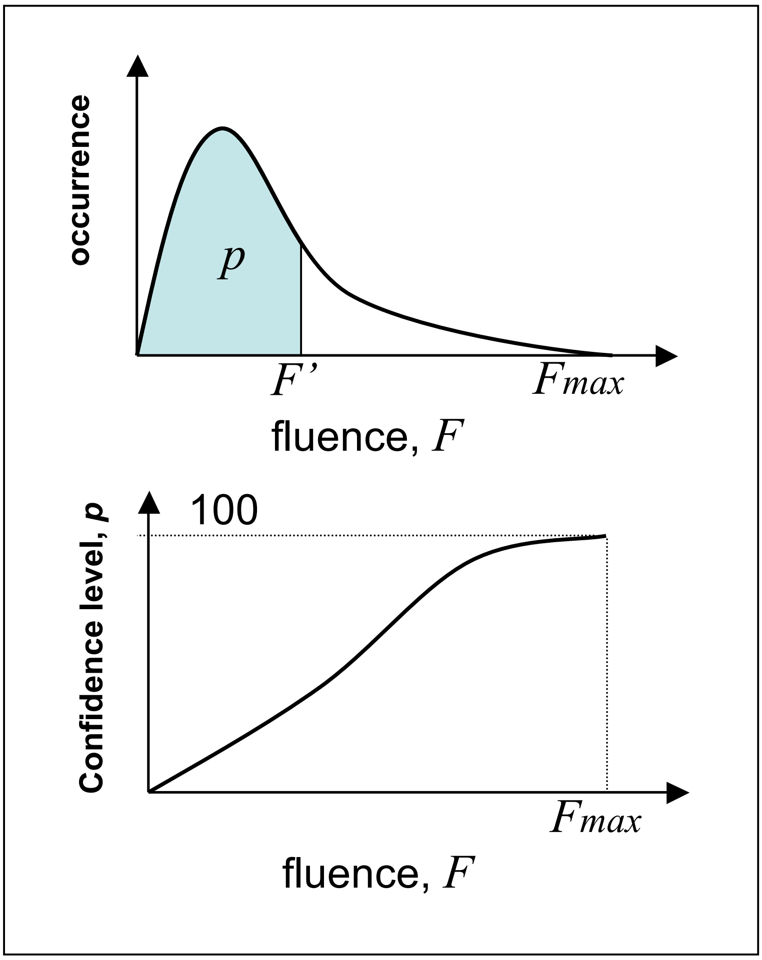

Figure 2 — Confidence Level

4.3 Achieves of observed energetic protons at GEO

Example of achieves and their longitudes at GEO.

- GMS(E140)
- METEOSAT(E63, E0)
- GOES(W75,W135)

4.4 Remarks

(1) Since this method based upon observed data, it cannot estimate any extreme rare events never observed before.

(2) Achieves of observed energetic protons at GEO will be will be maintained periodically. And if ‘extreme rare event’ was observed, they will be promptly updated.

(3) This method is good for long life (over the 11 years solar cycle) mission duration, for data of very large solar flare protons will be averaged.

5.Guideline for selection of confidence level in statistical model of Solar Proton Fluences

The confidence level is selected as follows:

(1) Predict solar proton fluences by confidence level with statistical model.

(2) Estimate cumulative fluence by the method 4.1.

(3) Select confidence level of (1) that will not exceed (2).

Annex A
(informative)

Example of Estimation and Selection

1. Background information

Design of solar panel is mainly limited by the end of life (EOL) output power, namely, that is estimated by predicted radiation environment during mission life. Therefore, radiation environment itself and estimation by radiation environment is essential.

Radiation environment that affect solar panel is electron and proton. At GEO, mainly trapped electron and solar energetic proton are factor. Trapped electron is generally steady state, and it is easy to estimate. However, solar energetic proton is very intense and occurs randomly, and it is hard to estimate.

Solar panel is constructed by panel, solar cell and cover glass that acts as shield materials for radiation environment, generally thickness is about 100 micro-meter. With this cover glass, cosmic ray, especially, proton energy is attenuated, and low energy proton is stopped within cover glass and not reached to solar cell. When degradation is estimated, off cause, attenuation by cover glass is included.

2. Degradation of solar cell by radiation

2.1 Mechanism of degradation

High energy charged particles (namely, electron or proton) is penetrate solar cell with losing its energy. They give damage to solar cell along a direction of thickness uniformly. At this time, cosmic ray does elastic/non-elastic collision with atom that consist solar cell as single crystal state, and does lattice defect. By this defect, characteristics of solar cell, short circuit current (Isc), open circuit voltage (Voc) and maximum power (Pmax) are degraded. Mechanism of degradation is called displacement damage, that is same with bulk damage of semiconductor devices, for example bipolar semiconductor.

2.2 Method of degradation estimate (relative damage coefficients method)

JPL handbook[2] adopts relative damage coefficients method, namely, accumulated electron and proton fluences during mission period are converted into numbers of 1 MeV electron that give damage equivalently, and then estimate degradation of solar cell with these numbers of 1 MeV electron.

Relative damage coefficient are obtained by measurements of degradation of solar cell by particles (electron and proton) of various energy.

Parameters needed to estimate degradation are (1) energy dependence of degradation by electron and proton, and (2) ratio of electron and proton degradation.

Base for degradation parameters are normalized fluence dependence of characteristics of solar cell parameters.

First, these normalized fluence dependence of characteristics are obtained from ground experiments of various energy of electron and proton. These experimental data are fitted to empirical curves. From these curve data, fluence that gives the same degradation is obtained for each energy and particles. These fluences are normalized for proton to 10MeV, for electron to 1MeV. These normalized values are called relative damage coefficients and are used as index for degree of degradation of solar cell.

Next, empirical curves of 10MeV proton and 1MeV electron give ratio (conversion factor) of 10MeV proton to 1MeV electron.

3. Estimation of Solar Cell degradation at GEO

3.1 Step1: Radiation sources at GEO and Prediction of their fluences

As shown below, Multijunction Solar Cell that is commonly employed today with cover glass of 100 micron degrades mainly by 3-10 MeV proton.

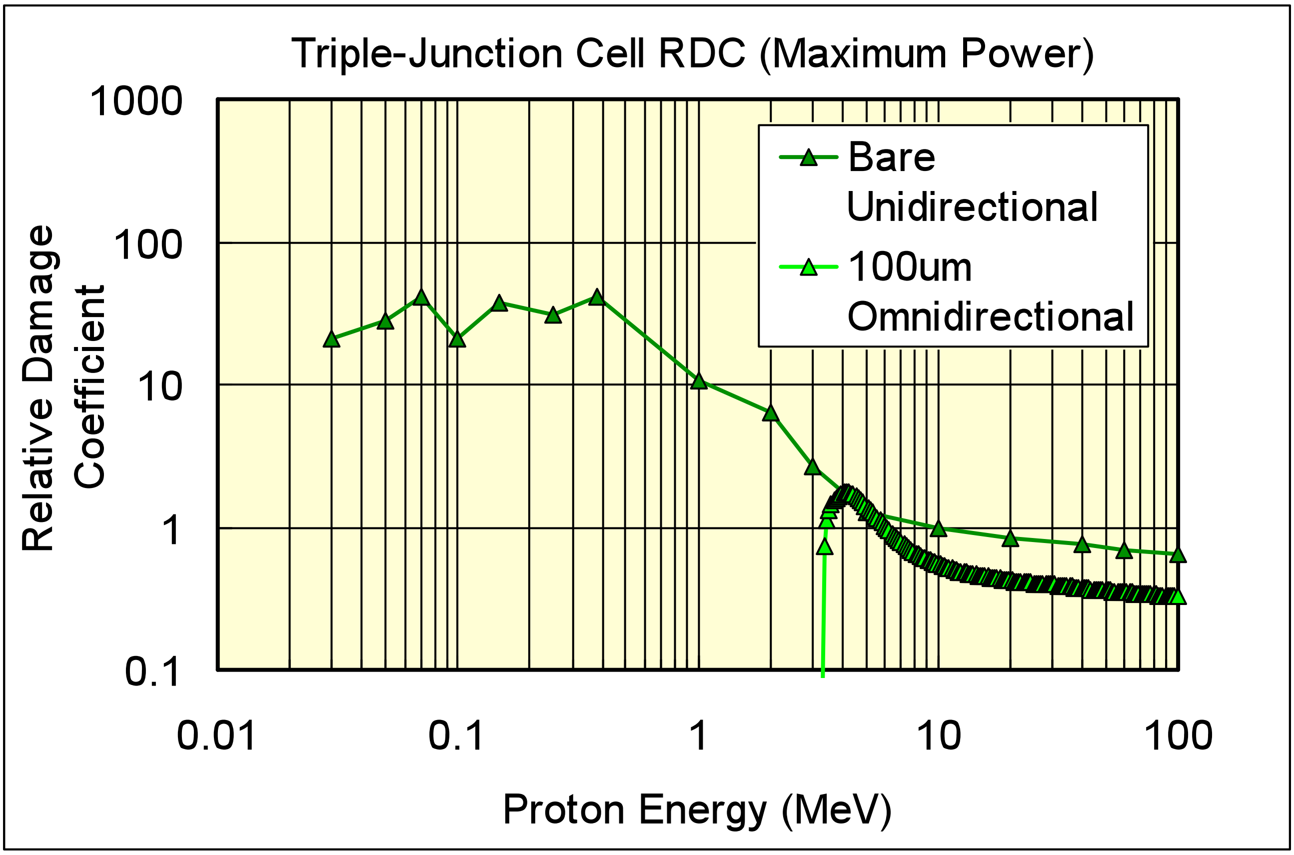

Figure A.1 — Relative Damage Coefficient of Triple-Junction Cell

Proton environment at GEO is galactic cosmic ray, trapped proton and solar energetic proton. Galactic cosmic ray can be ignored since its fluence is very small. Trapped proton can be absorbed by cover glass. Therefore, solar energetic proton is only player and can be estimated by this technical specificaiton method and/or statistical models.

Electron environment at GEO is trapped electron. Since trapped electron is generally steady state, and it is easy to estimate by AE-8 model that is commonly applied to all projects.

3.2 Step 2: Prediction of Solar cell degradation

Fluences distributions (that obtained by Step1) and relative damage coefficients (that are measured by separate experiments with solar cell of same type) are multiplied and integrated with energy, we can get equivalent fluence at GEO of mission duration. For electron 1MeV equivalent fluence and for proton 10MeV equivalent fluence. Then proton 10MeV equivalent fluence is converted to electron 1MeV equivalent fluence by conversion factor that obtained from experiments. This number is summed with electron 1MeV equivalent fluence, we get "gross electron 1MeV equivalent fluence".

Normalized fluence dependence of characteristics curves at 1MeV electron and "gross electron 1MeV equivalent fluence" give degradation for each characteristics during mission period.

4 Example of Estimation

4.1 Cumulative Fluences

The proton fluence(4-8MeV) estimation with GMS data (1982-1995) is shown below (solid line)[1] . And the JPL fluence model [3] (>4MeV) prediction (dotted lines) are also plotted for comparison. It is very clear that the JPL fluence model predicts too harshly for longer period.

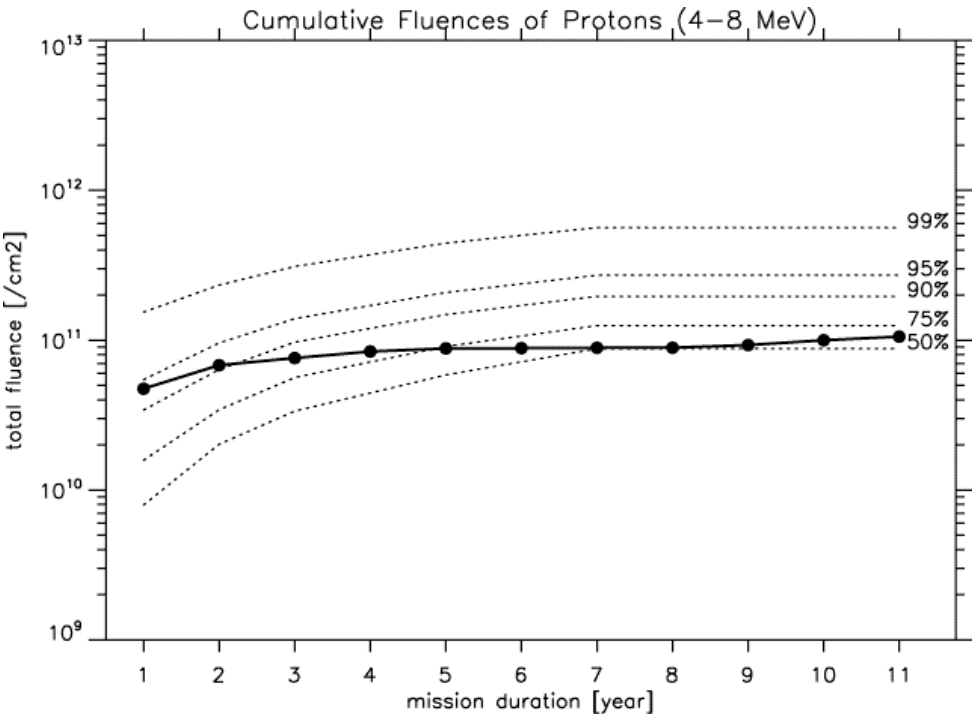

Figure A.2 — Example of Cumulative Fluences of Proton(4-8MeV) [1]

4.2 Confidence level

Confidence level of proton fluence(4-8MeV) for 1-year with GMS data (1982-1995) is shown below. Flat at 92-100% are the data that include solar event in Nov. 1989.

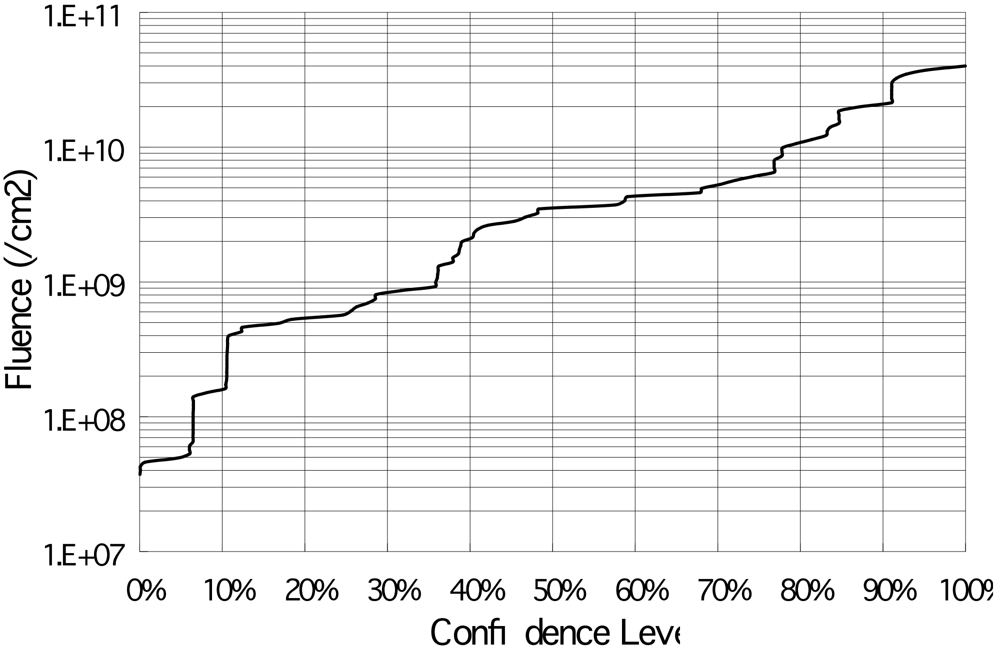

Figure A.3 — Example of Confidence Level of 4-8MeV Proton for 1-year duration

4.3 Guideline for selection of confidence level of statistical model

Predicted solar proton fluences with statistical model by confidence level and estimated cumulative fluence are shown in Figure A.2.

Confidence levels of statistical model are 95%(1 yr.) to 50%(7-9 yr.) depending upon mission duration.

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[3] Feynman J., A. Ruzmaikin and V. Berdichevsky, "The JPL proton fluence model: an update", Journal of ATPMOSPHERIC AND SOLAR-TERRESTRIAL PHSICS, 64, 1679-1686(2002)