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On the Prediction of Great Flare Energetic Particle Events to Save Electronics on Spacecrafts

L.I. Dorman

IZMIRAN, 142092 Troitsk, Moscow, Russia; Technion, Haifa & Israel Cosmic Ray Center of Tel Aviv University, Qazrin 12900, Israel

Abstract

The problem of influence of Solar Flare Energetic Particles (FEP) on micro-electronics code on space-crafts is very important. Single Event Phenomena (SEP) are especially dangerous; they can destroy computer memories; according to Barak et al. (1995, 1996) in periods of great energetic particle fluxes it is necessary to switch off some parts of electronics to protect computer memories from SEP. How to predict these events? In principle it could be done by using high energy particles coming from the Sun much earlier than the main part of middle energy particles which is the most dangerous for electronics. The flux of these high energy particles is very small and cannot be measured with enough accuracy on space-crafts, but it is measured continuously by ground-based neutron monitors and muon telescopes with very high accuracy due to their great effective surfaces. These predictions can be done approximately by data of one-two cosmic ray stations, but much more exactly by the International Cosmic Ray Service proposed by Dorman et al. (1993), which could be organized on the basis of world-wide network of cosmic ray observatories. For prediction of dangerous FEP events it is necessary to use 1-minute on-line data of neutron monitors and muon telescopes. It is important that the accuracy of prediction increases with increasing the dangerous level of FEP. We describe the method and demonstrate its application for some historical events.

1 Introduction:

The problem of influence of solar Flare Energetic Particles (FEP) on microelectronics code is very important and was developed deeply by many authors: see Levinson et al. (1993), Barak et al. (1996), Tylka et al. (1997), and references therein. Single Event Phenomena (SEP) are particularly dangerous; they can destroy computer memories on ground and in airplanes, and with much higher probability in satellite, rocket and balloon systems. According to Barak et al. (1995), in the periods of great energetic particle fluxes it is necessary to switch off some part of electronics to protect computer memories from SEP. How to predict this very rare (one in year or one in a few years in dependence of the level of solar activity, see Dorman et al., 1993a; Dorman and Pustil'nik, 1999) and very short (from about half hour to few hours), but dangerous period of time? In principle it can be done by using high energy particles (few GeV/nucleon and higher) which are characterized by much bigger diffusion coefficient than for small and middle energy particles. Therefore, high energy particles reach the Earth much earlier (8-20 minutes after acceleration and escaping into solar wind) than the main part of smaller energy particles particularly dangerous for electronics (about 30-60 minutes later). The flux of high-energy particles is very small and cannot be dangerous for electronics. The problem is that this very small flux cannot be measured with enough accuracy on satellites or on space-probes (it needs very great effective surfaces of detectors and great weights). On the other side, particles with this high-energy are measured continuously by ground-based neutron monitors and muon telescopes with great effective surfaces (many square meters), thus providing very small statistical errors. We will show on the basis of data in periods of great historical FEP events (as the greatest one of February 23, 1956 and many tenths of others), that one-minute on-line data of high energy particles can be used for forecasting the incoming dangerous flux of particles with much smaller energy. The method of coupling functions (Dorman, 1957, 1963, 1974) allows to reconstruct very easily and quickly by ground based data the expected flux out of the atmosphere, and out of the Earth's magnetosphere. We will consider three possibilities for the use of this method: 1) by one station with continuous measurements of at least 3 cosmic ray components with different coupling functions, 2} by two stations with continuous measurements on each station of at least 2 cosmic ray components with different coupling functions and 3) by the International Cosmic Ray Service (ICRS), described by Dorman et al. (1993) which could be organized in a near future on the basis of the already existing world-wide network of cosmic ray observatories.

2 Testing of Forecasting Methods by Data of Great Historical FEP Events:

Let us consider the period of the greatest FEP event of February 23, 1956. The maximum of Hα was observed on the Sun at 3.33 UT. According to many investigations (see review in Dorman, 1957), this moment corresponds approximately to accelerated particle ejection into interplanetary space. Let us calculate the time for this event starting from this moment. At first let us consider data of muon detectors - ionization chambers shielded by 10 *cm* Pb (very high energetic part of FEP). In Tbilisi (R_C=6.91 *GV*) the increase started after 8 min (time of light arriving) by 1%, after 9 min - by 10%, in the next minute - 80%. In Moscow (R_C=2.46 *GV*) the increase also started after 8 min (0.5%), after 9 min - 2%, after 11 min - 18%, after 11.3 min - 50%, after 11.7 min - 100% and after 12 min - 200%. In Figure 1 we show as an example the data for Cape Schmidt (R_C=6.91 GV). From Figure 1 it can be seen that the increase starts about

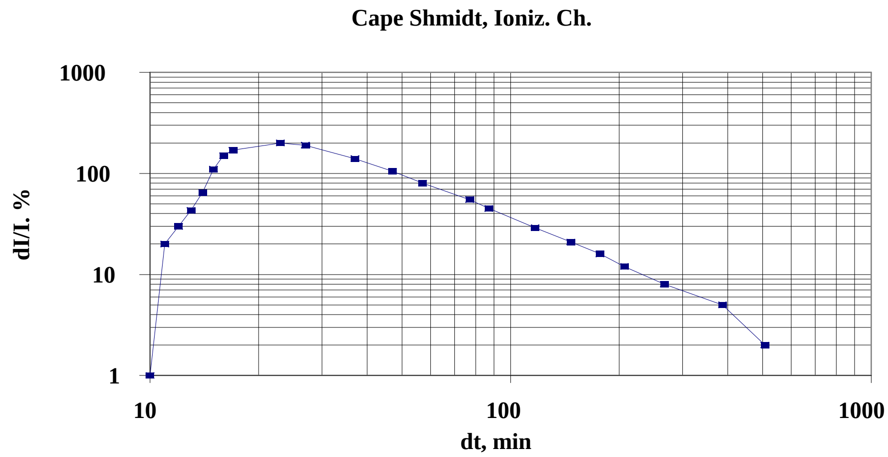

Figure 1: FEP event of February 23, 1956, Cape Schmidt, ionization chamber

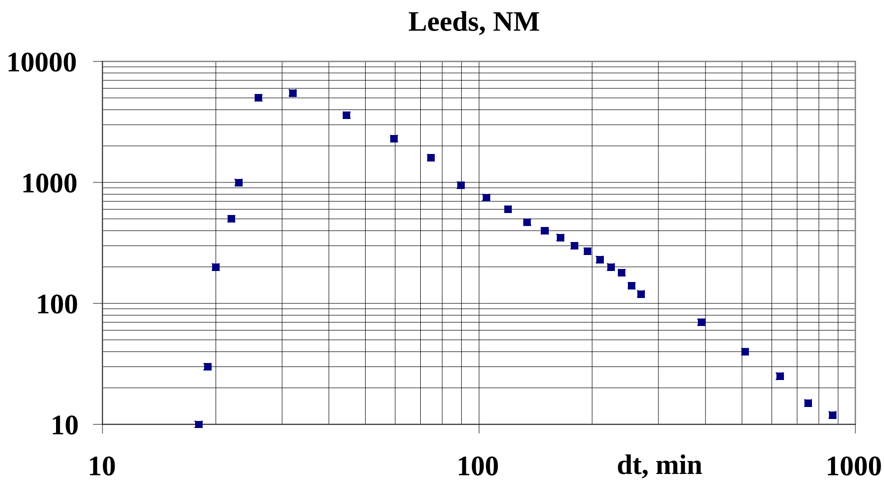

Figure 2. FEP event of February 23, 1956, neutron monitor, Leeds.

2 minutes later than at low and middle latitude stations, and the increase is more gradual. All these data can be used to forecast FEP in lower energy range (the statistical error of 1-minute data was ~ 0.5%).

In neutron monitor data the increase was much bigger, but it starts later: in Leeds after 18 min, maximum 5500% after 32 min; in Climax - after 22 min, maximum 2800% after 42 min; in Ottawa after 27 min, maximum 3000% after 67 min; and in Chicago after 28 min, maximum 2150% after 47 min. As an example, in Figure 2 we shown data of Leeds neutron monitor. Being the statistical error of one minute data of neutron monitor is about 1%, an event as February 23, 1956 can be forecasted by using data of the first 2-3 minutes of increase. The problem is that this event in the beginning was very anisotropic, and only after 20-30 minutes became quasi isotropic. It means that for a good forecasting of the properties of this event it is necessary to have on-line data of the world-wide network of cosmic ray stations: that can be realized by the foundation of ICRS, as suggested by Dorman et al. (1993).

3 How to predict great FEP events by cosmic rays:

For prediction of great FEP events some programs “FEP Search-1 min”, “FEP Search-2 min”, “FEP Search-3 min”, “FEP Search-4 min”, and “FEP Search-5 min” should work continuously; by the use of 1 min, 2 min, 3 min, 4 min, and 5 min data, correspondingly. Each minute the program “FEP Search 1 min” will be the first to start working. If at any observatory it will be observed a cosmic ray intensity increase bigger than 3 StDev (where StDev is the statistical error of 1 min data) the program "FEP Preliminary Alert-1 min" will start: it will compare this increase with data of other observatories and with the situation in the next 1 min. If it will be a real beginning of FEP event, the program "FEP Alert-1 min" will start: it will take into account the position and properties of solar flare (if this information will be available) and determine the preliminary model of FEP event (by calculating the energy spectrum of FEP, parameters of FEP source on the Sun, and propagation parameters in corona and in interplanetary space). On the basis of this model will be possible to estimate the expected radiation hazard after 20-60 minutes and its space-time distribution. In the case if the expected level of radiation will be dangerous for microelectronics, it will be sent the "FEP Final Alert-1 min, 1st Approximation". The program "FEP Alert-1 min" will continue to work with the incoming new 1 min data and do corrections on the preliminary model to obtain more and more exact models of FEP event. In this way after few minutes it will be sent "FEP Final Alert-1 min, 2nd Approximation", then "FEP Final Alert 1 min, 3rd Approximation" and so on.

If the program “FEP Search-1 min” gives negative result, the program “FEP Search 2 min” will start, then the program “FEP Search 3 min”, and so on. If all programs “FEP Search-k min” (where k=1,2,…5) give negative result, it means that in the nearest 20-30 min will be free from radiation hazard (this information can be also useful). If some programs “FEP Search-k min” gives positive result, the program "FEP Alert-k min" will start, then "FEP Final Alert-k min, 1st Approximation", then "FEP Final Alert-k min, 2nd Approximation", and so on. The work of programs “FEP Search-k min” (where k=1,2,…5), "FEP Alert-k min", "FEP Final Alert-k min, 1-st Approximation", and others, can be demonstrated on the basis of historical great FEP events data, described in details in (6-12).

4 The Use of On-Line Cosmic Ray Data from Single Observatory:

Let us suppose that we have on-line one-minute data from single Observatory with detection of at least 3 cosmic ray components with different coupling functions (if the period is magnetically disturbed), or at least 2 components (in the quiet period of time). Let us consider, as an example, our Emilio Segre' Observatory (ESO) at the height of 2025 m, with cut-off rigidity 10.8 GV. Here we have different components: total and multiplicities m = 1, 2, 3, 4, 5, 6, 7, and ≥ 8. According to data of latitude surveys of Aleksanyan et al. (1985), the normalized to pole coupling functions for total counting rate and different multiplicities m can be approximated by the Dorman (1969) function:

$$W_{om}(R) = a_m k_m R^{-(k_m+1)} \exp\left(-a_m R^{-k_m}\right), \quad (1)$$

where $m = tot, 1, 2, 3, \ldots$. Normalized coupling functions at a point with cut-off rigidity R_C will be

$$W_m(R_c, R) = a_m k_m R^{-(k_m+1)} \exp\left(-a_m R^{-k_m}\right) / \left(1 - \exp\left(-a_m R_c^{-k_m}\right)\right), \text{if } R \geq R_c, \; W_m(R_c, R) = 0, \text{if } R \leq R_c \quad (2)$$

Coefficients a_m and k_m determined by Aleksanyan et al. (1985) are in good agreement with theoretical calculations by Dorman and Yanke (1981), Dorman et al. (1981). In a first approximation the spectrum of primary variation of FEP event can be described by the function

$$\Delta D(R) / D_o(R) = bR^{-\gamma}, \quad (3)$$

and the expected variation in total counting rate or in multiplicity m will be

$$\Delta I_m(R_c) / I_{mo}(R_c) = -bF_m(R_c, \gamma), \quad (4)$$

where

$$F_m(R_c, \gamma) = a_m k_m b \left(1 - \exp\left(-a_m R_c^{-k_m}\right)\right)^{-1} \int_{R_c}^{\infty} R^{-(k_m+1+\gamma)} \exp\left(-a_m R^{-k_m}\right) dR. \quad (5)$$

The comparison between observed FEP increase and the expected one according to (4) in different multiplicities can give important possibility to determine parameters b and γ in (3) for the primary variation of FEP event out of the Earth's magnetosphere.

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