Solar particle events contribution in the space radiation exposure on electronic equipments

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SPACE RADIATION EXPOSURE ON THE RADIO-ELECTRONIC EQUIPMENT ENGINEERING MONITORING SYSTEM

Elements of ROSCOSMOS monitoring system of space radiation exposure on the radio-electronic equipment operate successfully. The monitoring system consist of 2 parts: space-borne and ground segments. The main aim of the monitoring system is the increase the active shelf live of spacecraft

Engineering sample of the monitoring system ground segment was developed: www.kosrad.ru

Elements of space-borne segment: 38 TID sensors are placed on the 19 spacecrafts, which operates on the Medium-Earth orbit (MEO) ~ 20000 km

Sensitive element of TID sensor : MNOSFET

ABRUPT INCREASE OF DOSE RATE EVENT (CONTRIBUTION OF PROTONS AND ELECTRONS)

Date	Dose rate before the event a.u./s	Dose rate after event a.u./s	Increase of dose rate, times	Proton flux >10 MeV, 1/cm^2-day-sr (data from [1])	Electron flux >2 MeV1/sm^2-day-sr* (data from [1])
05.04.2010	1.22×10^{-5}	1.34×10^{-2}	700 times	1.6×10^{4}	5.4×10^{9}
03.08.2010	2.24×10^{-4}	3.08×10^{-3}	10 times	1.1×10^{5}	2.5×10^{8}
01.03.2011	2.23×10^{-4}	1.02×10^{-3}	20 times	1.4×10^{4}	7.8×10^{8}
02.05.2011	1.06×10^{-4}	1.89×10^{-3}	10 times	1.2×10^{4}	6.8×10^{8}
09.09.2011	2.32×10^{-4}	2.18×10^{-3}	9 times	4.2×10^{4}	3.2×10^{8}
23.01.2012	1.17×10^{-5}	1.59×10^{-4}	8 times	1.4×10^{8}	2.5×10^{8}
08.03.2012	2.94×10^{-4}	2.35×10^{-3}	8 times	2.0×10^{8}	5.9×10^{8}
08.10.2012	6.08×10^{-4}	9.90×10^{-3}	16 times	1.4×10^{4}	4.8×10^{8}

Table 1. The space weather characteristics on the date of the dose rate abrupt increasing

* Maximum value during the week

COMPUTATION ALGORITHM OF DOSE RATE VALUE FROM SOLAR PROTON FOR ORBIT 20000 KM

1. Determination of solar proton integral spectrum during the event

Figure 1. GOES data from [1]

2. The calculation of solar proton differential spectrum during the event.

It' s considered the energy range from 1 to 100 MeV (the main contribution to the dose rate). Differential spectrum ($MeV^{-1}*s^{-1}*cm^{-2}$) is calculated using the formula:

- in range 1-10 MeV – $\frac{F_1-F_{10}-F_{100}}{3,3*4\pi}$;
- in range 10-100 MeV – $\frac{F_{10}-F_{100}}{9*4\pi}$;
- in range >100 MeV – $\frac{F_{100}}{90*4\pi}$,

Where F1, F10, F100 are the integral fluxes

3. The calculation of solar proton differential spectrum for the orbit 20000 km with the use of the correction factors

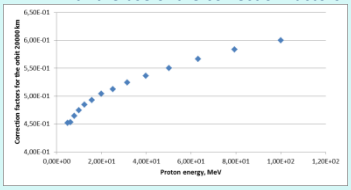

Figure 2. The correction factors of proton fluxes with fixed energy from the orbit 36000 km to 20000 km

4. The calculation of dose rate values

Data of the solar cosmic rays events	Proton flux > 10 MeV, 1/(p.f.u)	Proton flux > 100 MeV, 1/(p.f.u.)	Dose rate from solar cosmic rays protons r.u./s	Contribution to the total dose %
25.09.2001	12900	30	4,3E-04	~5*
06.11.2001	31700	200	9,52E-04	~10*
24.11.2001	18900	4	1.59E-04	~1*
02.10.2001	2360	0,2	1,08E-05	~0,1*
28.10.2003	29500	200	1,15E-03	~11*
24.01.2012	6310	2	4,28E-05	~0,5* (27**)
08.03.2012	6530	70	4,82E-04	~6* (21**)

Table 2. The calculation of dose rate values on software «OMERE» [2]
*** - comparison with the maximum dose rate value for all period of measurements**
**** - comparison with the dose rate value measured for certain day**

Using this algorithm the dose rate values from solar protons were found

CONTRIBUTION TO ABSORBED DOSE OF SOLAR PROTONS ACCORDING TO DIFFERENT MODELS

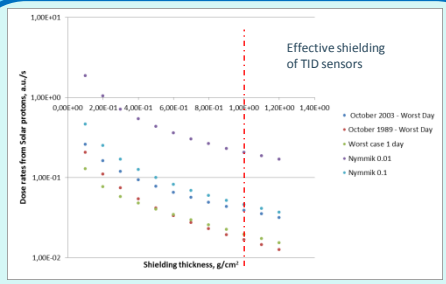

Figure 3. The dose rates from solar protons vs. the shielding thickness for different model of the events

The dose rate from solar protons can reach the values~ 10^{-2}-10^{-1} a.u./s

DEFINITION OF FLARE CLASS, WHICH CAN CAUSE ABRUPT INCREASE OF DOSE RATE

It is possible to determine the classes of solar proton events in terms of obtained data which can deposit important contribution (>10 % from the maximum dose rate value) in dose rate increase on the MEO – S4-S5 upon condition of proton flux >100 MeV excess of the value 200 pfu.

Solar proton event		Integral flux >=10 MeV *	The annual event occurrence probability	
			Observed over a period 1994-2014 years [3]**	All events [4]
S 5	Extreme	100000	–	< 0.1 times during the year
S 4	Severe	10000	0.2 times during the year	0.3 times during the year

Table 3. The scale of solar proton events and their occurrence frequency
*Average value of integral flux within 5 minutes, pfu
** upon condition proton flux >100 MeV more then 200 pfu

Conclusion

The analysis of space-borne measurements of dose rate on the MEO and proton and electrons fluxes from the GEO for 2008 – 2013 years showed that the main contribution to the dose rate increase gives the electrons however the two solar proton events were seen (with class S3) which gave the contribution more then 20%. The dose rate calculation using the space-borne measurements and the model events (model events integrated to the «OMERE» software, Nymmik model [5] integrated to the «OSOT» software [6]) finds out the necessity of consideration of proton flux not only with the energy >10 MeV (which is used for event type classification), but with greater energy (first of all, 100 MeV) upon condition of flux more than 200 pfu. In this case solar protons give the contribution more than 10% in comparison with the maximum measured dose rate (space-borne measurements) and can contribute more than 50% in comparison with the same value (model events). The dose rate abrupt increase can cause the abnormal operation of on-board equipment because of the TID effect (close to its failure level region) and the stimulation of other effects (internal charging and etc.) . The dose rate effects are not likely. The assurance of reliable operation of onboard equipment demands of control of the S4 class event during the excess of proton flux >100 MeV value of 200 pfu. Further it is necessary to estimate the solar proton contribution to the dose rate on the other orbits (low-altitude orbit, polar orbit) on which dominates the influence of protons, not electrons

[1] http://www.swpc.noaa.gov
[2] http://www.trad.fr/OMERE-Software.html
[3] http://www.swpc.noaa.gov/ftpdir/indices/SPE.txt
[4] http://www.swpc.noaa.gov/NOAAscales/index.html#SolarRadiationStorms
[5] Probabilistic Model for Fluencies and Peak Fluxes of Solar Energetic Particles. // Rad. Meas. 1999. V. 30, P. 287-296
[6] V.S. Anashin, V. V. Emeliyanov, I. O. Ishutin, N. V. Kuznetsov, G. A. Protopopov, G. I. Zebrev "The software complex for SEU rate and radiation dose calculation", The conference on Radiation and its Effects on Components and Systems, Langenfeld, Austria, 20-24 September 2010, RADECS 2010 – Technical Program, PG3