Multispacecraft observation of solar particle events contribution in the space radiation exposure on electronic equipment at different orbits

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In the paper we determined solar proton fluxes for different events in 2012 at geostationary orbit according to measurements of Electro-L and GOES spacecrafts as well as at 20000 km, polar and ISS orbits. Absorbed dose values from solar proton exposure were calculated for different events in different orbits using real sensors shielding configurations. These values were compared with experimental ones during these events. Single events rate values were calculated for different events in different orbits using measured and calculated solar proton spectra.

1. INTRODUCTION

Space radiation environment is the main exposure factor which determines the active shelf life of spacecrafts: faults and failures due to space radiation exposure were observed in ~60% space missions [1]. There are two main radiation effects caused by space radiation: dose and single event effects. The former is caused by exposure of trapped electrons and protons (only for near-Earth orbits), solar protons and galactic cosmic protons (only for interplanetary missions). The latter is caused by trapped protons, solar protons and ions, galactic protons and ions. So it is very important for spacecraft and equipment designers to know the real space radiation exposure, which influence on equipment's electronic components.

2. SPACECRAFTS AND INSTRUMENTS

We use proton's fluxes data from following spacecraft on geostationary orbit (GSO): GOES [2] (proton flux with energy more than 1 MeV, 10 MeV and 100 MeV) and Electro-L [3] (proton flux with energy from 13.7 to 23 MeV, from 23 to 42 MeV, from 42 to 112 MeV). Also we use proton's and electron's fluxes data from Meteor-M, functioning on polar orbit (protons with energy more than 15 MeV and electrons with energy more than 0.7 MeV, protons with energy more than 25 MeV and electrons with energy more than 1.5 MeV, protons with energy more than 600 MeV and electrons with energy more than 6 MeV) [3]. Finally, we use dose sensor's data from Medium- and Low-Earth orbits (MEO and LEO).

3. SPE SPECTRA IN GSO, POLAR, MEDIUM- AND LOW-EARTH ORBITS

We carry out of analysis of three big solar proton event (SPE) in 2012: from the 23th to 26th of January ("event1"), from the 27th of January to 1st of February ("event2") and from the 5th to 16th of March ("event3"). Using direct measurements of proton fluxes in GSO on two spacecrafts and power low approximation we extract SPE spectra for all SPE events (fig. 1, 2, 3). One can see a good agreement between Electro-L and GOES data of proton fluxes.

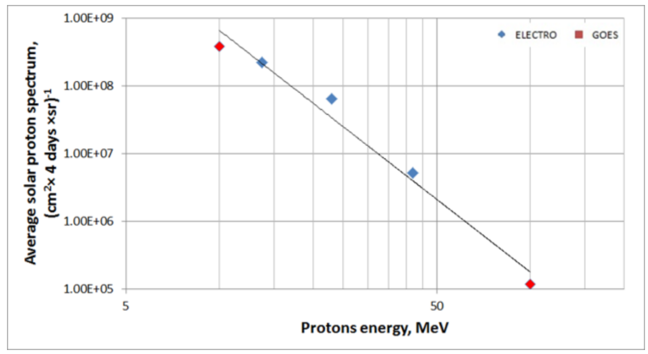

Figure 1: SPE spectrum in GSO for "event1".

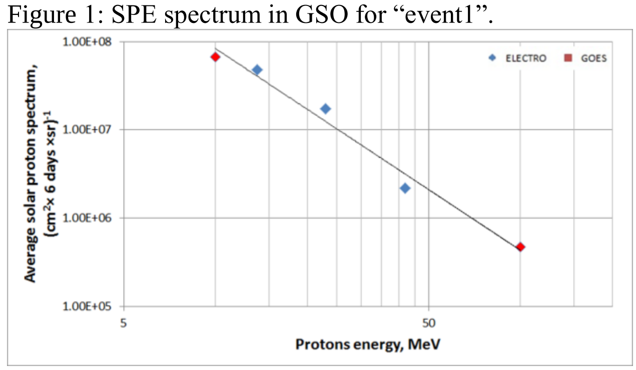

Figure 2: SPE spectrum in GSO for "event2".

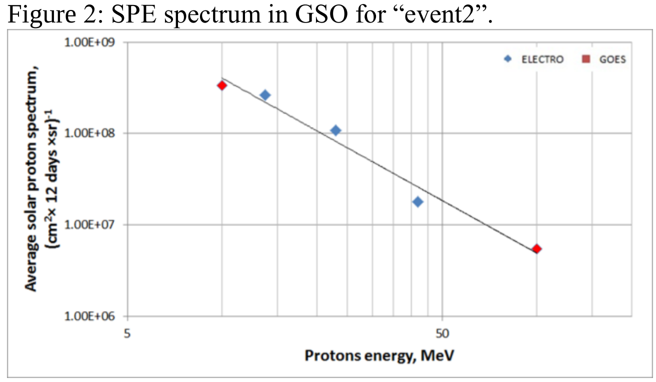

Figure 3: SPE spectrum in GSO for "event3".

To determine SPE spectra during SPE events in polar orbit we use direct measurements of proton and electron fluxes of Meteor-M. To determine charge particle's spectra during SPE we use the approach, which is described in [4]. Results of SPE spectra determination in polar orbit during the events are shown in figure 4.

Figure 4: SPE spectra determination results on polar orbit for "events1- 3".

To determine SPE spectra during SPE events on MEO and LEO we use SPE spectra on GSO and take into account a geomagnetic cutoff rigidity by algorithm, which is described in [5]. The later algorithm takes into account only average annual Kp index (2-3), more careful geomagnetic cutoff rigidity consideration will lead to shifting of low-energetic part of SPE spectrum (it can be done in future work). Results of SPE spectra determination in MEO and LEO during the events are shown in figure 5 and 6.

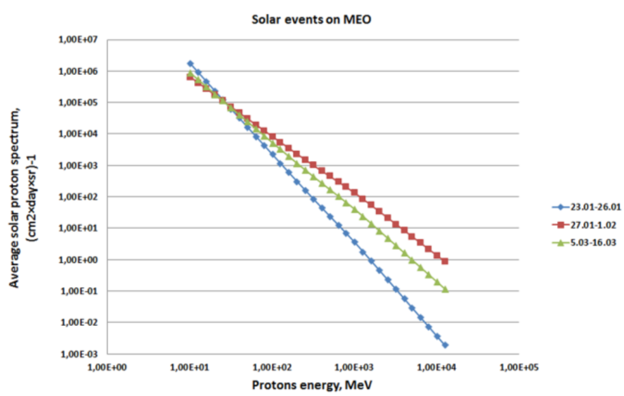

Figure 5: SPE spectra calculation results for MEO during "events1- 3".

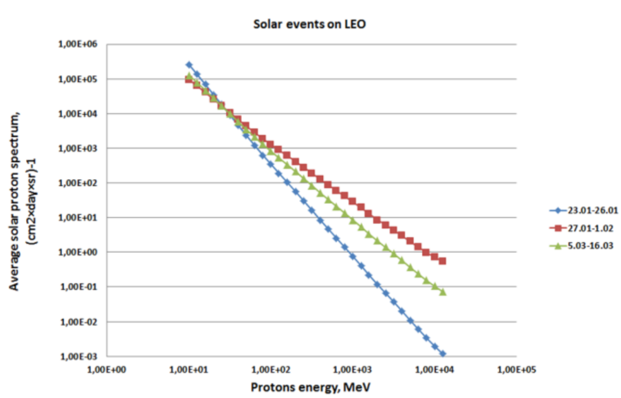

Figure 6: SPE spectra calculation results for LEO during "events1- 3".

4. ABSORBED DOSES IN MEDIUM- AND LOW-EARTH ORBITS

To calculate (on software OMERE [6]) of absorbed dose we use SPE spectrum in given orbit and information about shielding geometry for each dose sensor.

4.1. Calculation of absorbed dose in MEO

Results of absorbed dose calculation for MEO are presented in Table 1. Experimental dose value is measured by dose sensors and include total contribution of electrons and protons. Calculation dose value includes only SPE contribution.

Table 1: Experimental and calculation dose values in MEO

Event	Experimental, a.u./day	Calculation, a.u./day
Event1	8.5	3.9
Event2	8.7	1.5
Event3	90	3.6

The main source of discrepancies between experimental and calculation dose values is the fact that electron exposure gives the most valuable contribution in total dose value in this orbit. Besides, the annual experimental dose value is equal to 143 a.u./day and maximum dose value is equal to 1900 a.u./day. These values are much more than SPE dose. One can conclude that the main contribution in dose value gives trapped electron and SPE gives valuable dose in absence of high-energy electrons flux increasing.

4.2. Calculation of absorbed dose in LEO

Results of absorbed dose calculation for LEO are presented in Table 2. Experimental dose value is calculated as the differential of total values of measured dose during events and a week before. Calculation dose value includes only SPE contribution.

Table 2: Experimental and calculation dose values in LEO

Event	Experimental, a.u./day	Calculation, a.u./day
Event1	143	1840 (769 if E>100 MeV)
Event2	202	260 (56 if E>100 MeV)
Event3	154	125 (117 if E>100 MeV)

Discrepancies between experimental and calculation dose values can be explained by inaccuracy of SPE absorbed dose determination, consideration only average annual Kp index (the value in brackets in the table show decreasing of dose value in case of spectrum cutoff up to 100 MeV) and gaps in measurement data. The annual experimental dose value is equal to ~30 a.u./day, contribution of galactic protons is equal to ~9 a.u./day, and maximum dose value is equal to 202 a.u./day. These values are comparable with SPE dose. One can conclude that the main contribution in dose value gives trapped protons, solar and galactic protons (dose per day during events are comparable (and sometimes more) with average value for a long time and dose peak value), and SPE gives valuable dose, but not for all events.

5. SINGLE EVENT RATES IN GSO, POLAR, MEDIUM- AND LOW-EARTH ORBITS

We calculate (on software OSOT [7]) single events rates (SER) using SPE spectra and conservative sensitive parameters of electronic components during the events for different orbits. The calculation results are presented in Table 3.

Table 3: Single events rates values caused by SPE

Event	GSO	MEO	Polar	LEO
Event1	11.3	6.0	8.6	0.86
Event2	9.7	5.1	3.7	0.74
Event3	53	28	7.5	4.1

One can see that:

- Single events rate from solar protons is decreasing with decreasing of orbit altitude (due to geomagnetic cutoff rigidity)
- Single events rate varies for event to event (in several times)
- SPE contribute decisively in single events rate in GSO and MEO (in case of absence of trapped protons)
- SPE gives valuable contribution in single events rate in polar orbit and LEO

6. CONCLUSIONS

Solar protons fluxes for different events in 2012 were determined using onboard measurements in different spacecrafts and calculated for MEO and LEO. Absorbed dose values from solar protons were calculated and compared with onboard measurements. Solar proton events give valuable dose value in LEO and MEO, which is comparable with average dose value (during absence of high-energy electrons flux increasing in MEO). Solar proton events contribute decisively in single event rate value in GSO and MEO and gives valuable contribution in polar orbit and LEO. It ought to be note that it is necessary (for spacecraft and equipment manufacturers as well as for scientific community) to place space radiation characteristics and exposure sensors on spacecrafts in different orbits.

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References

[1] Committee on the Societal and Economic Impacts of Severe Space Weather events: A Workshop Report, 2008

[2] http://www.ngdc.noaa.gov/stp/satellite/goes/dataaccess.html

[3] V. S. Anashin, G. A. Protopopov, P. V. Shatov, S. V. Tasenko, V. D. Popov, O. S. Kozyukova, and I. A. Lyakhov, “Analysis Results of In-Flight Measurements in Geostationary and Polar Orbits in 2014-2015,” 2015 15th European Conference on Radiation and Its Effects on Components and Systems (RADECS), Sep. 2015.

[4] Protopopov, Grigory et al. Solar particle events contribution in the space radiation exposure on electronic equipment at the polar orbit. PoS ICRC2015 (2016) 147.

[5] V. S. Anashin, G. A. Protopopov, O. S. Kozyukova, and N. N. Sitnikova, “Solar particle events contribution in the space radiation exposure on electronic equipment,” Journal of Physics: Conference Series, vol. 632, p. 012077, Aug. 2015.

[6] http://www.trad.fr/OMERE-Software.html.

[7] Anashin Vasily, Protopopov Gregory, and Milovanov Yury, “SEE testing for exposure of space ionizing radiation on radio-electronic equipment,” Proceedings of 5th International Conference on Recent Advances in Space Technologies - RAST2011, Jun. 2011.