Investigating of influence of cosmic rays on SEU on station "MIR"

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Abstract - In that paper the reasons single event upset (SEU) of semiconductor memory cells by results of the experiments carry out on OC "Mir" were investigated. The rating of radiation of a space and a fluency of nucleus of cosmic rays (CR) inside station in view of probability of nuclear interaction in a material of protection are carry out. It is shown, that at predicting intensity of SEU of memory cells it is necessary to take into account complex influence of various factors of a Space.

Keywords: space weather, SEU, memory sell.

1. INTRODUCTION

Recently there was a new area of researches «space weather», influencing on a Space, biosphere and functionality of onboard equipment. «Space weather» includes such factors of space, as intensity and solar burst, solar cosmic rays (SCR), magnetic storms and other displays of solar activity.

It is necessary to note, that SEU of semiconductor memory cells of the onboard equipment, can be caused the various reasons, one of which - solar activity. During solar burst intensity of SCR , in the main of protons and электронов, increases. The most probable energy of the maximal intensity of protons makes ~ 30 МэВ, and электронов - about 2 МэВ. These SCR make so-called zones of radiation of the Earth (Van Allen). Intensity of heavy ions in SCR is much less. If to speak about radiation of Space it is necessary to take into account and galactic space rays (GSR), which mass spectrum from Z>2 up to nucleus of uranium and >10 ГeV/nucleon reaches energy [1].

As has shown experiences of last years, during active development of space a lot of satellites, for example, to series "Electron", "Exploler-14,15", "Telstar-1" and others have prematurely worsened the operational parameters because of radiating and other factors of Space. SEU occur, in the main, in the computer's systems, including memory cells. The reasons can be various. So, on the "Harris" 72 SEU for 731 day of flight of the satellite from group of heavy nucleus of cosmic rays have been registered [2]. From them 47 were single, 9-double, etc. In all multiparticles interaction there were 19 %, influences appeared 58. Intensity of SEU appeared 7.9×10^{-2} day. Authors of paper [3] connect refusals failures of the equipment on more than 300 satellites with various orbits for the period of 1971-1994 with solar activity. Authors of paper [4] save up a significant statistical data on SEU from satellites SPOT (1986-1991). Numerous cases of SEU of memory cells also on OC "Mir" are registered. For example, in May, 1998 as a result of testing CCM-1 two blocks in which, there was a error have been revealed. The crew has replaced the left computer on new.

Errors of onboard equipment influence not only satellite systems, but also ground systems. So, in June, 1998 after undocking SS "Discovery" and OC "Mir" in Houston have found errors in one of the basic onboard computers of Global navigating system GPC "Discovery" which help solved of navigating tasks. In result the Program of definition of position "Discovery" with help GPC gave out the result distinguished from nominal mode. After transfer of all navigating functions to a reserve computer, nominal mode of onboard systems was restored [5]. In June, 1998 because of SEU in the basic processor on SS "Galacxy–7", some the ground channels using this satellite, at some o'clock have been switched - off [6].

In spite of the statistical data on SEU in Space practically not enough given about correlation of results in Space and tests on accelerators. The predicted values received in ground modeling experiment, considerably miss the data received in Space. So, value of interaction cross-section CR with protection received in flight, exceed the laboratory data in 100 times [2]. Basically it is connected to discrepancy between of modeling and real experiments. In a Space complex interaction of several factors, such as takes place: micro gravitation, energy and mass spectrum CR, falling in 4π - geometry; properties of materials of protection and condition of protection, fragment nucleus, solar and antisolar orientation of station, change of radiation outside of and inside of station, dynamic operations of station, uninominal mode. At ground modeling it is impossible to create the research complex including simultaneously all specified components of Space. Unusing these factors at predictability of SEU of memory cells at long-term space flights can lead to significant errors. For predicting reliability of the memory cells of the onboard equipment in conditions of long-term space flights it is necessary to have the information on complex influence of all specified factors on intensity, character and localization of SEU to study the reasons and the mechanism in Space.

2. REGISTRATION OF SEU ON OC "MIR"

In that paper the estimation of the contribution of influence of CS for SEU of memory cell by results of the experiments **"Error/Eqseq"** on OC "Mir" is executed. Experiments **"Error/Eqseq "** was carried out with the purpose of studying change of intensity, and also the reasons of occurrence of SEU on OC "Mir". At performance of experiment on OC "Mir" installation "Eqseq" developed by France, and in ground modeling experiments - system " SPACE " developed in Kazakhstan was used. In September, 1994 on OC "Mir" the new devices in which as experimental systems are used by the semiconductor memory cell with a high degree of integration has been established. Registration of SEU was carried out on OC "Mir" with 1995 on 1997 [7].

In figure 1 cartogram OC "Mir" is shown at the moment of SEU.

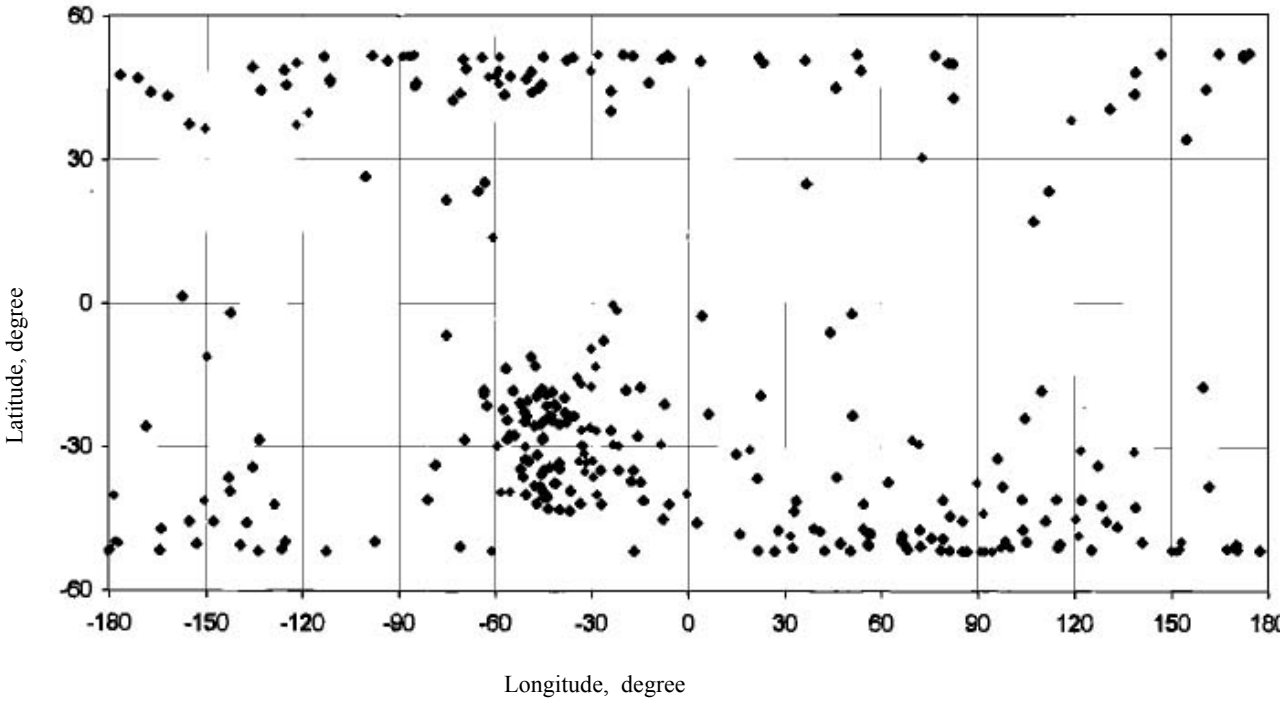

Figure 1. Cartogram OC "Mir"

Together with experts RCC "Energy" it has been developed timeline of experiment which provided registration of SEU in various conditions.

During flight (29 months) 386 SEU of semiconductor memory cell that makes 0.44 errors in day are received. Predicted SEU in view of probability of hit of a particle in sensitive volume of a cell makes 10^{-6} h^{-1}, therefore with very small probability, all registered SEU on OC "Mir" are caused by single hits of primary nucleus. Therefore other factors which can bring in the contribution to increase in intensity of SEU are analyzed also.

For interpretation of the received data are carry out an estimation of intensity of CR at different altitude and a intensity of the nucleus past through protection OC in view of probability of nuclear interaction in a material of protection.

3. PASSAGE OF HEAVY NUCLEUS OF COSMIC RAYS IN SOLID

Primary nucleus CR with energy it is not less $3 \cdot 10^9$ eV/nucleon when sections of inelastic interactions of nucleus with nucleus within the limits of an error of measurements become practically constants, at passage to substance up to 20 g/sm ^{2} test insignificant ionization losses. Thus specific losses of the energy dependent only from a charge of a particle, are proportional Z^2. Average value of range before elastic collision corresponds to his geometrical section [8]

$$\lambda_i = \rho / \delta_i n_i , \qquad (1)$$

where ρ_i - density of solid;
n_i - number of atoms in 1 sm^3 .

The free range determined under the formula (1), for example for a nucleus $^{26}Fe_{56}$ in Si, makes 20 g/sm ^{2} [8]. For nucleus with $Z \geq 26$ this changes insignificantly. Nucleus with energy $E < 10^9$ eV/nucleon at passage up to 20 g/sm^2 are braked in substance owing to ionization losses. Thus it is necessary to mean, that for a nucleuss broken in substance, there is a final probability inelastic nucleus - nuclear interactions. In table 1 values of probability of nucleus - nuclear interaction of heavy nucleus CR with various energies with silicon of protection are submitted. The probability was estimated by use of the data of paper [9].

Table 1. An energy range and probability of nuclear interaction of various nucleus CR in Si

Nucl.	Energy, E (MeV/nucleon) protection 1 g/sm ^{2}	Energy, E (MeV/nucleon) protection 20 g/sm ^{2}	Probabil. nuclear interact.
$^8O_{16}$	70,1	394	0,05 0,5
$^{13}Al_{26}$	82	523	0,075 0,55
$^{26}Fe_{56}$	126	1000	0,08 0,75

If passage of a particle is considered in the same environment losses of energy determined under the formula [1]

$$\frac{dE}{dx} = \frac{4\pi e^4 z^2}{mv^2} NB = \frac{Z^2}{V^2} F \quad , \qquad (2)$$

where e - a charge of electron,
m- mass of electron,
v - velocity of a particle,
N - number of atoms in unit of volume of substance,
B - brake number for the given particle.

This formula is fair for a particle moving with velocity, considerably surpassing velocity orbital electrons solid.

in areas of high latitudes. Rather big density of events is observed in area of southern Atlantic anomaly, there is a dependence of change of SEU by rigidity of a geomagnetic cutoff.

For a rating of the contribution of a geomagnetic field in the intensity of SEU OC "Mir" it has been developed (together with Institute of mathematics) the Program of construction of geomagnetic fields on different altitude. In figure 2 account of heterogeneity of a real geomagnetic field is expressed through change of density of magnetic lines which take place both in regions with magnetic anomalies, and in area of tectonic breaks of an earth's crust.

For calculation and graphic display of the main geomagnetic field of the Earth the epoch of 1995 has been used. On the developed algorithm the regular grid of supervision and on

Table 2. Intensity CR, pass through protection, in view of probability nuclear interaction

Z	Energy, MeV/nucleon	Fluency nucl/sm^2 h	Ioniz. range, g/sm^2	Толщ. защиты g/sm^2	Fluency nucl/sm^2 h, after protection	Altitude	Ref.
4	570	31,45± 1,29	60,32	20	16,35	At top of an atmosphere	[10]
10	570	3,20 ± 0,02	12,04	10	2,56	At top of an atmosphere	[10]
5÷10	11÷28	17	0,25	-	-	At altitude 435 km	[11]
26	500÷1900	$2,9 \cdot 10^{-2} \pm 0,13 \cdot 10^{-2}$	33,17	20	0,018	Atmosphere 4 g/sm^2	[12]
26	190	0,519± 0,04	2,73	1	0,488	At altitude 300 км	[13]
26	150	1,062± 0,08	1,85	1	0,93	Outside magnetosphere	[13]
26	1000	0,519± 0,04	33,17	20	0,182	Outside magnetosphere	[13]

If the particle goes in substance with the velocity comparable with velocity orbital electrons, it is necessary to take into account change of a charge and other effects.

The rating of an intensity of the heavy nucleus CR past through protection (for Si) has been carried out, in view of probability nuclear interaction. In table 2 values of an intensity of nucleus CR with various CR energies at various altitude are submitted. These values are approached as on station thickness of protection is determined by a set of various materials.

The analysis of the data has shown that the nucleus which will pass through protection OC will be protons with energy more than 100 MeV and heavy nucleus GCR (C, N, O, Fe) with энергиями more than 1000 GeV/nucleon. The fluency of such nucleus in view of probability of hit in a sensitive cell makes about 10 % from all nucleuses.

The received results have shown that during flight OC SEU of the equipment occur both in southern Atlantic anomaly, and

her - a map isocurlus has been constructed. We shall notice, that the constructed map is the module of a modeling magnetic field of the Earth.

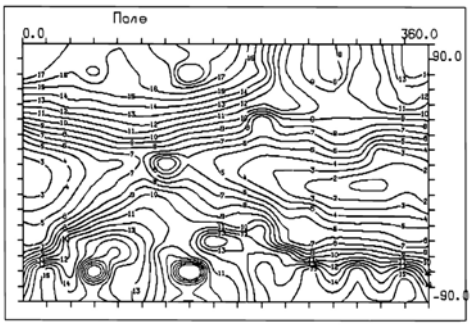

Figure 2. A map of a magnetic field of the Earth at altidude of 400 kms as isocurlus

The following stage of a task was construction of "Field of SEU". To the data dates, time and coordinates of onboard SEU registered onboard OC "Mir" are initial. In figure 3 the “Field of SEU” as a map isocurlus is submitted.

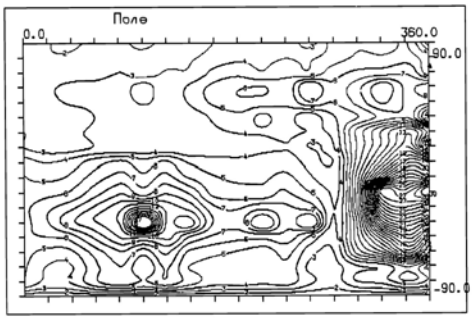

Figure 3. A field of SEU on OC "Mir"

The field was under construction on a map of the Earth with coordinates on a longitude of 0-360 degrees and on latitude from-90 up to 90.

The field was conditionally broken into clusters on a longitude and latitude. The quantity of the SEU which have got in each cluster, was summarized. As a result of it the data on quantity of SEU above various areas of the Earth are received. Clusters have been in regular intervals constructed on all range of definition**.** The developed program allows to spend the analysis and comparison isoline distributions of density of SEU and isoline geomagnetic lines in places in which SEU have been registered.

4. CONCLUSION

The received results are used for development of physical model of the mechanism of SEU in conditions of microgravitation; predictability of intensity errors of the onboard equipment in conditions of long-term space flights.

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