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The Effect of Solar Particles in the Choice of Alloy Shielding in a Satellite

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Abstract.

The damages and logical failures in different parts of a satellite may occur during a solar event, when a bulk of solar energetic particles approaching the Earth. During solar events, these particles may cause extensive damages which are even permanent (hard errors). A way of damage reduction is designing a proper coating as the fuselage. As protons are the major component of solar particles and because the most of hard errors are caused by neutrons, in this work, we evaluated different shielding material against these type of errors. To avoid hard errors due to neutrons, we need to know solar energetic particles flux. During a solar flare a satellite receives the maximum flux of protons, so we used protons with an energy range of 100 MeV to 1 GeV which is the most sensitive energy range to the Sun activities. In the present work, we have calculated the flux of solar energetic particles which collides a typical satellite in low earth orbit. Using OMERE software, coordinates and specifications of a satellite were determined virtually and this typical satellite were used to calculate the typical values of particles fluxes received by satellite during different solar flares of different solar cycles during occurrence of solar flares. Then, we have used FLUKA software, to study 10 different material layers as typical fuselages assuming proton primaries collide with them in the above energy ranges. Then we calculated neutron fluxes produced when a proton interacts with these materials. At the final stage we have shown that in this energy ranges Aluminum makes the best shielding against solar particles and adding Magnesium to alloy may improve the fuselage protection against hard errors.

Keywords: Space weather, Cosmic Rays, Simulation, Solar flares, Shielding

1 Introduction

As a part of the universe, cosmic ray particles especially those highly populated and produced by the Sun, lead to change in climate. In space-weather language, the "climate change"includes a large variety of events which may affect the life and industry [1]. Consequently different aspects of related phenomena are of especial interest and mainly grouped in long and short term changes [2]. Here we have considered the effects concerning the industry.

During a solar event (i.e. flare, coronal mass ejection (CME)) the energy stored in a rather concentrated region of the Sun's atmosphere is suddenly released in an explosive manner. Extreme solar events like solar flares and CME increase microelectronic upset and failure rates by arriving a bulk of Solar Energetic Particles (SEP) [3, 4]. These events also create electrostatic discharge hazards. In addition, the received significant radiation doses may lead rapid satellite ageing due to enhanced drag on satellite [5, 6]. More than 47 satellites reported to have anomalies during CME of October 2003 [7]. One scientific satellite had been totally lost and 10 satellites suffered a loss of operational service for more than one day. In 2003, there were approximately 450 satellites in orbit [8, 9]. During another super storm, the best engineering estimate, based on the 2003 storm, is that around 10% of spacecrafts will experience an anomaly leading to an outage of hours to days but most of these will be restored to normal operations in due course. A few spacecraft might be lost entirely during the storm through a sudden damage mechanism such as electrostatic discharge. In the months after the extreme storm, old satellites such as those in life extension mode may start to fail as a result of the ageing (dose) effects [4, 9, 10]. Obviously the increased dependence to space instruments as well as the growing number of satellites leads to great raise in the costs during solar events. These costs may be avoided or lowered with evaluating the damages and considering better system designing.

In brief, SEP cause two further effects: The ionization in material from which the satellite is made, and displacement damage which disrupts the crystalline structure of materials used in microelectronic devices [9, 10]. The resulted defects reduce the performance of transistors and are especially important for optoelectronic devices such as opto-couplers where current transfer ratios are reduced and for solar cells where efficiency is degraded. Single event effects arises from the charge depositions of individual particles in the sensitive regions of microelectronics. Such depositions occur via direct ionization (dominant for the heavy ions) and nuclear interactions (dominant for protons and neutrons). Effects range from soft (correctable) errors to hard (permanent) errors, which can include burnout of some devices such as metal oxide semiconductors. With feature sizes reducing to tens of nanometers and critical charges reducing to femto Coulombs these are a growing problem and a number of systems have been damaged or compromised. Neutrons, generating electron-hole pairs (directly or indirectly) as they pass through a semiconductor device. Transistor source and diffusion nodes can collect these charges. A sufficient amount of accumulated charge may invert the state of a logic device, thereby introducing a logical fault into the circuit's operation. Because this type of fault does not reflect a permanent malfunction of the device, it is termed *soft* or *transient* [11].

A simple way to avoid these damages is to blockade the arriving radiation using a proper coverage. In this work, we evaluated shielding against damages caused by neutrons deduced by interactions of protons with different materials. In the following, we first estimate the energy range of protons then we calculate the flux of neutrons created by protons in these energy ranges. Then, we have studied 10 kinds of material layer as a sample coating assuming proton primaries collide with them in the above energy ranges to investigate which material makes the best shielding against solar particles.

2 Material and Methods

It is known that protons are the dominant particles usually recorded above the atmosphere (about 91%) so we considered the interactions of primary protons [11]. To determine the flux of solar protons versus energy, we have used Outil de Modelisation de I'Environnement Radiatif Externe (OMERE) [12]. OMERE is a tool to investigate the space environment and radiation effects on electronic devices. This software, designed for industrial uses, calculates the radiation constrains for a satellite in orbit. Using orbital parameters or any trajectory file, OMERE computes the charge particles environment and provide electrons, protons and heavy ions fluxes. Once the environment is known, OMERE estimates the radiation effects on electronics in term of cumulative effects (dose curves, displacement damage, solar cell degradation), and single event effects. Most of the international standard models are included in the software, for Environment: (trapped particles, solar particles, cosmic rays and their sub models) and for Radiation effects: (dose, displacement damage, single event effect, solar cells and their sub models). We used "mission"option in OMERE to determine orbit, altitude and the other specifies of the orbit and then, "solar flare model"were used to calculate solar protons flux. This will produce required data for 4 types of flares:

- Worst hour in August 2, 1972 flare.
- October 20, 1989 flare: (Worst 5 minutes, Worst hour and Worst day) which are measured by GOES7 satellite.
- July 14, 2000 (Bastil day): (Worst 5 minutes, Worst hour and Worst day) which are measured by GOES7 satellite.
- October 29, 2003 (Halloween day): (Worst 5 minutes, Worst hour and Worst day) which are measured by GOES11 satellite.

We arranged launching date of simulated satellite to be the same as the date of solar flares happening and then, used these 4 models to derive proton fluxes for a typical satellite in Low Earth Orbit (LEO).

LEO is an orbit around Earth with an altitude between 160 kilometers (orbital period of about 88 minutes), and 2,000 kilometers (about 127 minutes). Objects below approximately 160 kilometers will experience very rapid orbital decay and altitude loss. The orbital velocity needed to maintain a stable low Earth orbit is about $7.8km/s$, but reduces with increased orbital altitude.

Perigee and apogee of orbit is equal to $400.000Km$, orbit inclination 51.5 degrees and its period was 5545 seconds. Proton fluxes in these 4 big and famous flares vs. energy are shown in figures 1 to 3 for each model.

In figures 1 to 3, it is noticeable that even in the worst 5 minutes (i.e. the flare is in the strongest mood with the highest values of proton flux), the energies of protons reaching the LEO satellite don't extend over 100 to 1000 MeV. With the passage of time the energy of protons will reduce from an initial value which characterize each event. As a result, in following we have used the energy range of 100 to 1000 MeV.

Considering a coating of 10 different materials consist of magnesium, Aluminum, Iron, Copper, Silver, Gold, Tin, Titanium and Nickel and using FLUktuierende KAskade (FLUKA) [13] it is possible to estimate the number of neutrons produced during the passage of protons in these layer [10]. We have simulated production of neutrons in layers of these materials. When protons collide the satellites (of energies ranged between 100 to 1000 MeV), they produce neutrons in their interactions with these layer and consequently cause failures and damages which lead to satellite's failure. The thickness of these layers assumed to be 1 mm and neutron detectors hypothetically were assumed to be on a surface in the middle of these layers. The arrangement was surrounded by a vacuum to providing the same conditions of a real satellite in the space.

3 Results

The fluxes of neutrons created by collision of a proton (per a proton particle per square centimeter), for each material in different energies are obtained according to the table 1 (continued to table 2) and are shown in figure 4:

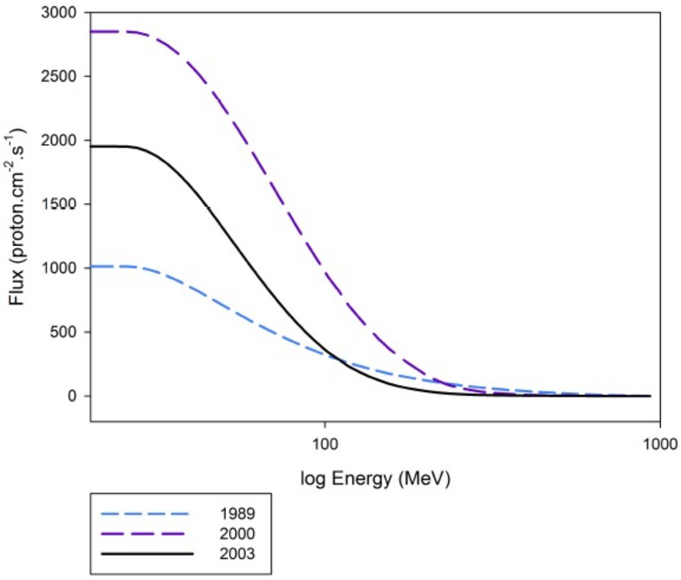

Figure 1: Proton fluxes in solar flares vs. energy (using OMERE [12]), worst 5 minutes of October 20, 1989 and July 14, 2000 and October 29, 2003

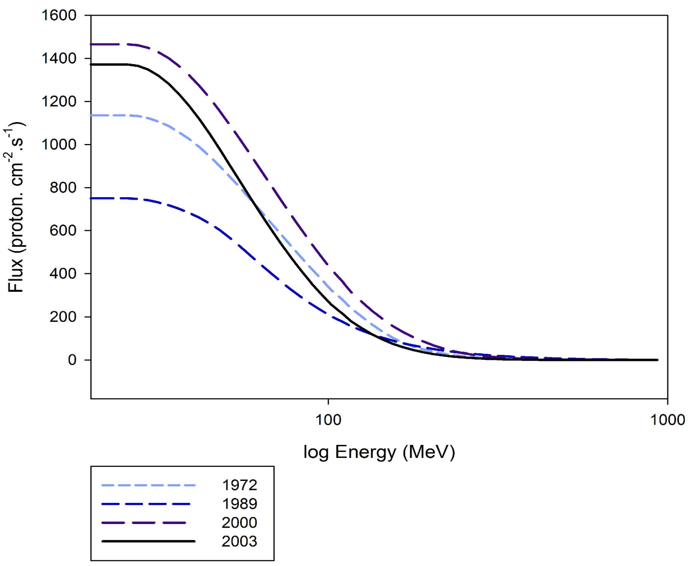

Figure 2: Proton fluxes in solar flares vs. energy (using OMERE [12]), worst hour of August 2, 1972 and October 20, 1989 and July 14, 2000 and October 29, 2003

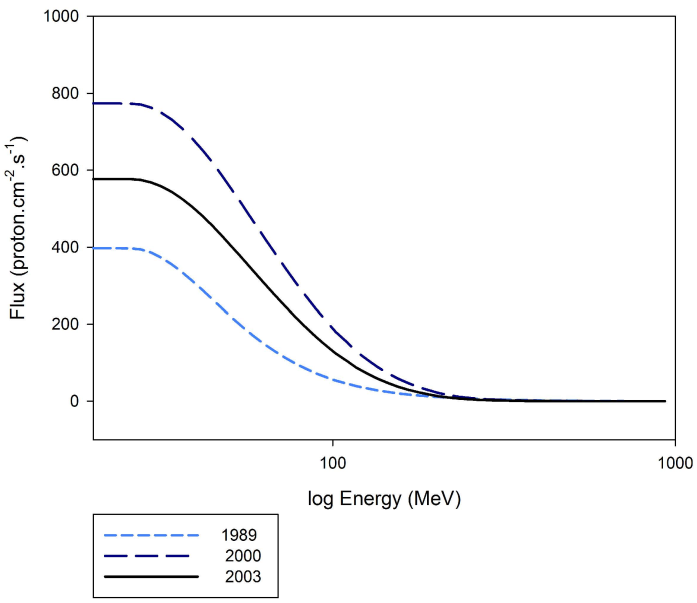

Figure 3: Proton fluxes in solar flares vs. energy (using OMERE [12]), worst day of October 20, 1989 and July 14, 2000 and October 29, 2003

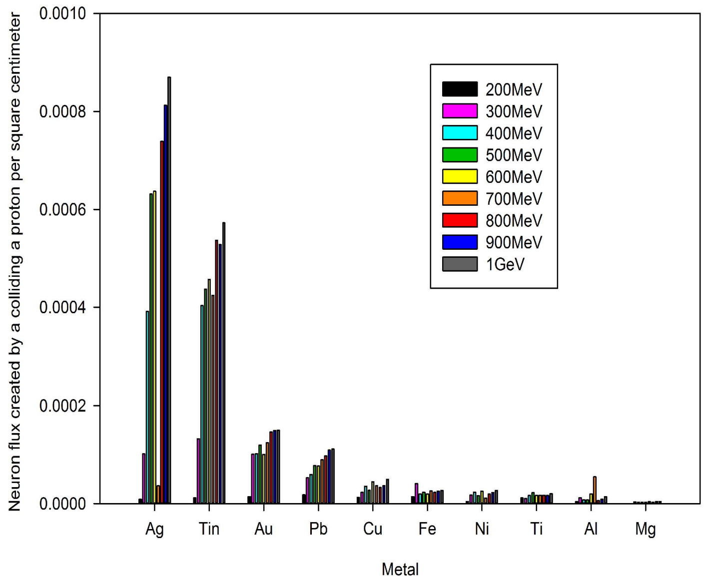

Figure 4: Neutron flux created by a colliding a proton per square centimeter for 10 materials in different energies

Table 1: Neutron fluxes created by collision of a proton (per a proton particle per square centimeter) for 10 materials in different energies, continued.

FluxMaterial	Ni	Ti	Tin	Au	Ag
200 MeV	4.271833 e-6	1.162813 e-5	1.160322 e-5	1.436841 e-5	8.787900 e-6
300 MeV	1.768370 e-5	1.068412 e-5	1.326517 e-5	1.006506 e-4	1.011771 e-4
400 MeV	2.336380 e-5	1.643354 e-5	4.031732 e-4	1.017626 e-4	3.914824 e-4
500 MeV	1.623749 e-5	2.226528 e-5	4.366664 e-4	1.198498 e-4	6.312046 e-4
600 MeV	2.541070 e-5	1.676867 e-5	4.571979 e-4	1.003790 e-4	6.367864 e-4
700 MeV	1.119230 e-5	1.714873 e-5	4.241573 e-4	1.244010 e-4	3.618308 e-5
800 MeV	1.930115 e-5	1.710972 e-5	5.369425 e-4	1.459736 e-4	7.389518 e-4
900 MeV	2.245292 e-5	1.659576 e-5	5.281194 e-4	1.492778 e-4	8.123303 e-4
1 GeV	2.701622 e-5	2.024203 e-5	5.727781 e-4	1.498595 e-4	8.700670 e-4

Table 2: Neutron fluxes created by collision of a proton for 10 materials in different energies.

FluxMaterial	Cu	Fe	Al	Mg	Pb
200 MeV	1.266518 e-5	1.428552 e-5	4.090092 e-6	6.408627 e-7	1.798762 e-5
300 MeV	2.301313 e-5	4.072233 e-5	1.202778 e-6	3.618733 e-6	5.251617 e-5
400 MeV	3.550447 e-5	1.954630 e-5	7.772066 e-6	2.777085 e-6	5.928323 e-5
500 MeV	2.734383 e-5	2.325465 e-5	7.476003 e-6	2.742033 e-6	7.750232 e-5
600 MeV	4.439282 e-5	1.973878 e-5	1.973878 e-5	2.711256 e-6	7.657847 e-5
700 MeV	3.618308 e-5	2.613391 e-5	5.453809 e-5	3.890534 e-6	8.946697 e-5
800 MeV	3.275610 e-5	2.286418 e-5	6.280109 e-5	2.997792 e-6	9.730089 e-5
900 MeV	3.628290 e-5	2.534859 e-5	9.096561 e-6	4.238023 e-6	1.089554 e-4
1 GeV	4.911466 e-5	2.660133 e-5	1.384405 e-5	3.691946 e-6	1.110931 e-4

4 Conclusion

As the obtained results show (Table 1 and figure 4), the flux of neutrons passing through magnesium layer is the lowest amongst other materials. In other words, the best coverage maybe obtained using magnesium. In comparison the second suitable alloy is aluminum. Both of them provide the best proper coverage against bulk of protons.

But because of the chemical properties of magnesium, this element is not suitable for coating as at the high temperatures it fires and burns. On the other hand, some other properties such as magnesium' sturdy and its light weight like aluminum, union and welding property better than aluminum (which is used for alloying elements) and having a density of about two-thirds of aluminum, makes it a good alloying agent that if used in case, the production, mechanical and welding characteristics of aluminum would improve. The density of Magnesium is only 65% of the density of commonly used aluminum alloys in the aerospace industry and therefore can be a breakthrough technology if used for low weight airframe structures.

Such a result also is mentioned in different research works. For example Hombergsmeier has mentioned that to use this low weight material several mechanical properties have to be increased and the technological behavior should be improved [14]. And it shows that the different method we have used here is also a good one to study properties of material as satellite coverage.

The aluminum alloys used today for aerospace applications are already optimized concerning aeronautic requirements such as strength, fatigue and damage tolerance properties. Therefore weight reduction is more and more difficult to be reached with only small progress in aluminum material development. Due to the importance of weight reduction for strengthening the competitiveness of the whole European aeronautic industry, several alternatives to obtain weight reduction have to be investigated. One alternative can be the use of new design principles like welded or bonded airframes or the use of laminates such as Glare or Metal Laminates. Another alternative could be the application of low density structural plastics or fiber reinforced composites. But the application of non-metallic materials is in some areas not possible due to limited properties under low or elevated temperatures, missing electric conductivity or low damage tolerance. Fiber reinforced plastics are a rather costly material only used for primary structure applications with highest requirements [15].

Anyhow our results shows that the family of magnesium alloys and especially magnesium wrought materials can be an excellent alternative. Aeronautic requirements and applications of wrought products have been evaluated only in some subtasks of a few projects. And as it also were shown by Landkof, Magnesium is a suitable engineering material which can be applied for weight savings up to 35% compared to aluminum [16].

Therefore, the main use of this alkaline earth metal is as an alloying agent to make aluminum-magnesium alloys that is eventually the best option to design shielding and make coating against the protons beams, based on the simulation results.

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