Variations in the Radiation Environment

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I. INTRODUCTION

The impact of radiation effects is growing more critical with the advent of newer technologies in the aerospace, commercial, and military sectors. The widespread increase of the use of non radiation-hardened devices in space systems has increased the susceptibility of systems to radiation damage. Thus, a firm grasp of the components of the radiation environment and its potential hazards is critical for any future space system to succeed.

Radiation effects that are important to consider for spacecraft design fall into three categories, total dose and degradation effects, single event effects (SEEs), and displacement damage. Trapped protons, trapped electrons, and solar event protons are primarily responsible for total dose and degradation. As electrons are slowed down, their interactions with orbital electrons of the shielding material produce a secondary photon radiation, bremsstrahlung, which also contributes to total dose. SEEs are induced by single particle strikes in sensitive regions of electronic devices. The main sources of SEEs are galactic cosmic rays (GCRs), particles from solar events, trapped protons, and secondary neutrons. Displacement damage is cumulative, long term non-ionizing damage due to trapped and solar protons and neutrons.

II. SOLAR PROCESSES

The Sun and its phenomena greatly impact interplanetary and near-Earth radiation levels. Solar flares and coronal mass ejections (CMEs), which affect solar wind density and velocity, are two processes that directly impact the radiation environment.

The solar wind, which originates from the Sun's outermost layer, the corona, consists mostly of protons, approximately 5% doubly charged helium ions, smaller fractions of other heavy ions, and electrons, which keep the plasma electrically neutral [1]. As the corona emits the solar wind outwards, its corresponding magnetic field lines stretch outwards also. The solar wind interacts with the Earth's magnetic field and is a source of trapped protons and electrons in the radiation belts. The solar wind not only affects the trapped radiation environment, but also affects the transient particles that exist outside the Earth's magnetosphere. These interactions as they apply to the evaluation of electronics effects will be discussed in more detail in the final paper.

III. THE RADIATION ENVIRONMENT

There are two categories of particles that exist in the natural radiation environment, transient particles and trapped particles. Transient particles originate outside the boundary of the Earth's magnetic field, the magnetosphere, and the trapped particles exist within the Earth's magnetosphere. These particles contribute to the various radiation effects, such as total ionizing dose, displacement damage, and single event effects, which may impose risks to various space systems.

A. Transient Particles

There are two types of transient particles, galactic cosmic rays and solar particle events. Galactic cosmic rays originate outside our solar system, but within our galaxy. GCRs are found everywhere in interplanetary space and are omnidirectional. As GCRs travel through the galaxy, they are stripped of all of their electrons and thus, are mostly fully ionized. GCRs pose a risk to space electronics because their high energies make them extremely penetrating. They pass through spacecraft shielding and strike sensitive regions in electronics causing SEEs. The Earth's magnetic field deflects some of the GCRs that enter the magnetosphere, providing some protection for spacecraft in low inclination orbits. The amount of protection provided by the magnetic field depends primarily on the inclination of the spacecraft, and secondly on its altitude. The higher the inclination and altitude of the spacecraft, the more it is susceptible to transient particles [1]. **Figure 1** shows the variation in GCR levels due to orbit.

Solar particle events consist of solar protons and heavier ions. Solar proton events, which contribute to total dose effects, displacement damage, and SEEs, originate from CMEs and solar flares. It is important to assess the effect of single event effects induced by a solar particle event because these particle fluences are orders of magnitude higher than the cosmic ray fluences. Heavy ions from solar particle events are partially ionized and therefore, have an increased ability to penetrate the magnetosphere. The final paper will compare GCR and solar particle levels and will show the dependence of solar particles on orbit and shielding.

B. Trapped Particles

There are three types of trapped particles that exist in the near Earth radiation environment, energetic protons, electrons, and heavy ions. The trapped heavier ions do not pose a problem for electronics in regard to SEEs because of their low energies; hence, they are not able to penetrate shielding. Both the trapped protons and electrons are a potential hazard for electronics in terms of total dose and degradation. Trapped protons also induce SEEs in some devices.

The trapped particles comprise the Earth's radiation belts, known as the Van Allen belts. The particles are divided into three sections, the inner belt, the outer belt, and the slot region. The slot region, which exists between the inner and outer belts, also contains high energy trapped particles. Although the number of particles is reduced in the slot region, it is not devoid of particles especially during large magnetic storms [1]. The inner zone particles are a fairly stable population, with occasional perturbations at the outer edge of the belt due to geomagnetic storms. At low altitudes (<1000 km), there is an area of enhanced radiation known as the South Atlantic Anomaly (SAA). The SAA is caused by the offset and tilt of the geomagnetic axis with respect to the Earth's rotational axis, which brings the trapped particles to lower altitudes.

i. Trapped Proton Variations

Energetic protons, with an estimated energy range of 40 KeV to 500 MeV, are the prime component of the "inner" radiation belt to consider when evaluating radiation effects on electronics. Trapped protons are a hazard to electronics due to their ability to induce total dose, displacement damage, and SEEs Therefore, these orbital differences must be carefully considered when evaluating chip effects.

Trapped proton levels vary widely due to orbital altitude and inclination. **Figure 2** shows the variation in trapped proton spectra due to orbit. The final paper will show storm-induced variations.

ii. Trapped Electron Variations

The most important component of the "outer" radiation belt to consider when evaluating radiation effects on electronics is the trapped electrons. The trapped electrons have an energy range up to approximately 10 MeV. The electrons are injected into the outer zone as a result of geomagnetic storms and substorms and they are a more dynamic population than the inner zone protons. The final paper will show variations in electrons due to orbit and storms.

As with the trapped protons, the trapped electrons and their secondary bremsstrahlung radiation contribute to total dose. The final paper will show the dependence of total dose on orbit.

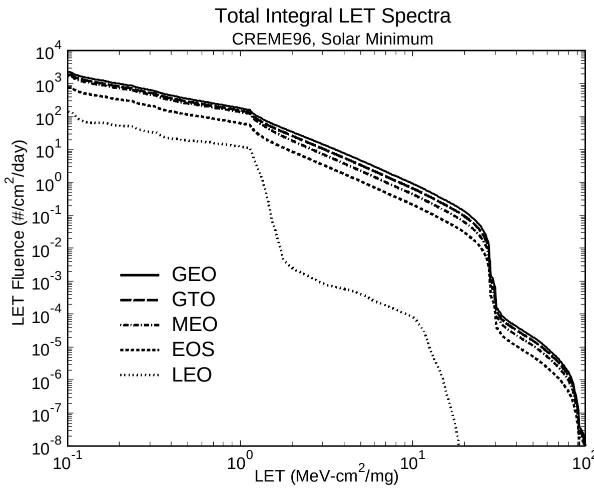

Figure 1: Total integral LET spectra for 5 orbits. The attenuation by the magnetosphere is only effective for low inclination, low altitude orbits.

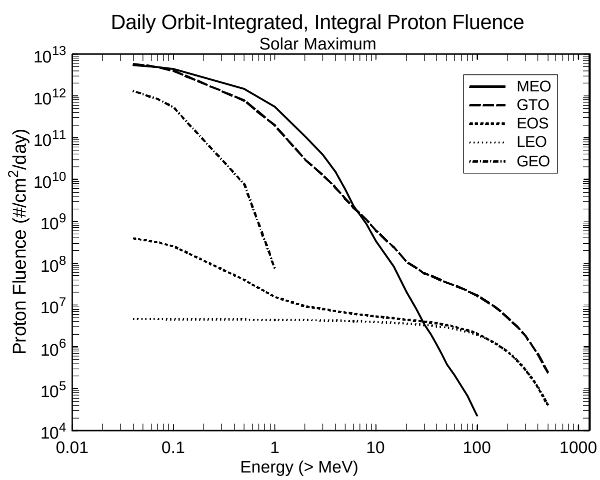

Figure 2: Proton fluence levels have large orbit-dependent variations. Note that, for the GEO orbit, the protons cut off at high energies.

IV. REFERENCES

[1] J. L. Barth, "1997 IEEE NSREC Short Course," pp. 1-83, July 1997.