Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Study the Radiation Flux in Space Radiation Environment for Space Applications

Kavita Lalwani[1], Amit Yadav[2]

[1]*Department of Physics, Malaviya National Institute of Technology Jaipur, Rajasthan, India*
[2]*Department of Electronics and Communication Engineering, RBS Engineering Technical Campus Agra, India*

The abstract summarizes the study's focus on simulating and analyzing proton and electron radiation flux at solar maximum and minimum, as well as Galactic Cosmic Ray (GCR) particles and solar particle events to assess the space radiation environment. Additionally, the research includes examining the impact of space radiation on shielding materials such as aluminium and polymers.

Keywords: Proton flux, Ionizing radiation, GCR, Solar maximum, Solar minimum, Geant4, Space radiation environment.

1. Introduction

Space Radiation Environment

In space, radiation is unavoidable. The space radiation environment encompasses all elemental ions, electrons, neutral particles, and photons, with energies ranging from very low to incredibly high. There are several primary sources of space radiation [1]. Galactic cosmic rays (GCRs) originate from outside our solar system, believed to be produced by supernovae and neutron star mergers throughout the galaxy [2]. Another source is the sun, whose activity follows an 11-year cycle of high and low periods, known as solar maximum and minimum, respectively.

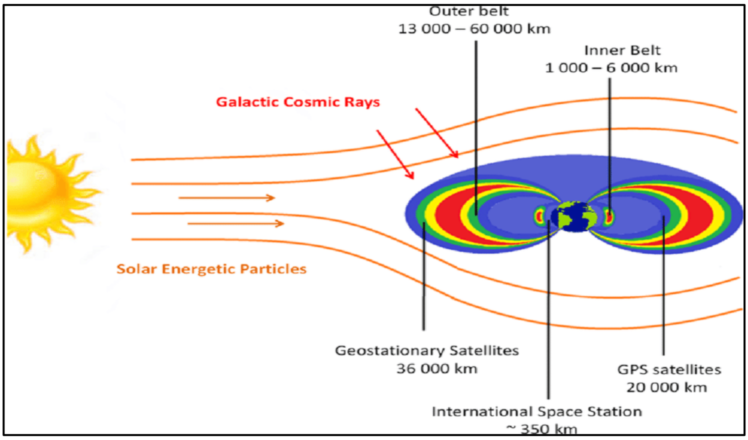

Figure 1: Sketch of Space Radiation Environment.

During solar maximum, the heightened solar activity invariably increases solar flare events, leading to solar energetic particle (SEP) occurrences. The SEPs emitted by the sun travel along the interplanetary magnetic field lines known as the Parker spiral. The third source of radiation pertains to planets with intrinsic magnetic fields, such as Earth or Jupiter, where these fields capture energetic charged particles and lower energy plasma in toroidal-shaped regions around the planet. Furthermore, planetary magnetic fields modulate lower energy GCRs and SEPs, necessitating consideration when calculating the effects of these charged particles within magnetospheres. Ultimately, charged particles can interact with planetary atmospheres, producing secondary particle showers and introducing additional complexities to flux computations in the atmospheres. Understanding space radiation environments and safeguarding space assets from mission-specific space environmental effects is imperative for ensuring success. Therefore, this paper models the space radiation environment by examining the various fluxes from trapped particles (protons and electrons), GCRs, and solar particle events.

2. Geant4-based simulation (SPENVIS)

The study utilized a robust mathematical simulation method based on Monte Carlo (Geant4) [3] to comprehensively analyse the interaction of charged particles with matter. Geant4, renowned for its powerful spatial modeling capabilities and extensive physical models, allows for accurately simulating various particles and their transport processes in detectors with complex geometries and materials. The software accurately tracks incident and secondary particles, making it ideal for simulating particle-matter interactions and transport processes. Additionally, it is widely utilized in particle, nuclear, space, and medical research due to its versatility. The initial approach involved conducting Monte Carlo simulations using the Multi-Layered Shielding Simulation Software (MULASSIS), specifically designed for particle fluence analysis associated with radiation shields. MULASSIS is integrated with the Space Environment Information System (SPENVIS software [4]) online tool, allowing for a comprehensive analysis of the space radiation environment and the associated radiation shielding.

3. Results

3.1 Simulation and Analysis of Radiation Flux

The space radiation environment in low earth orbit (LEO) is accurately modeled with specific parameters: orbital type = general, altitude = 650km, eccentricity = 0. Our analysis includes simulating and analysing the radiation flux for protons and electrons (both integral and differential flux) at both solar maximum (400) and solar minimum (1500) in the LEO using the MULASIS tool, integrated with the GEANT4 [3] toolkit—a powerful tool for simulating particle passage through matter—in SPENVIS [4]. The proton and electron flux are simulated using the AP8 and AE8 models [5-7]. The resulting proton flux data is visually represented in Figure 1 (left: solar minimum, right: solar maximum).

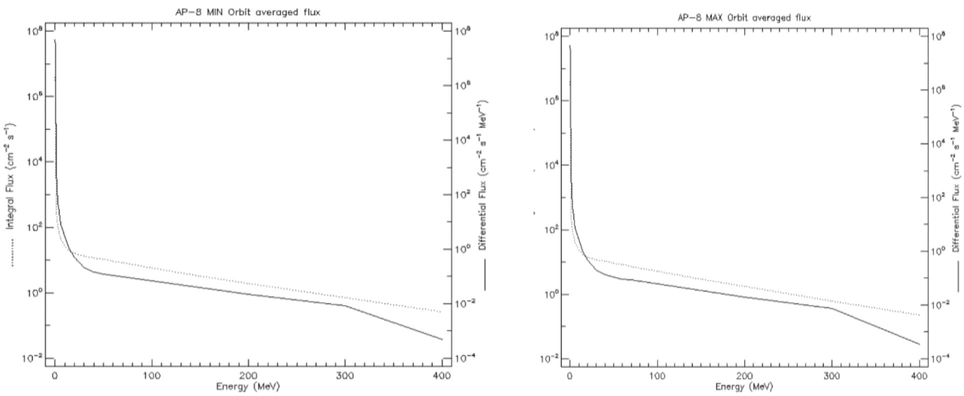

Figure 1: The proton radiation flux at the solar minimum (left) and the solar maximum (right).

The results for electron radiation flux (integral and differential flux) are shown in Figure 2 (left at solar minimum and right at solar maximum).

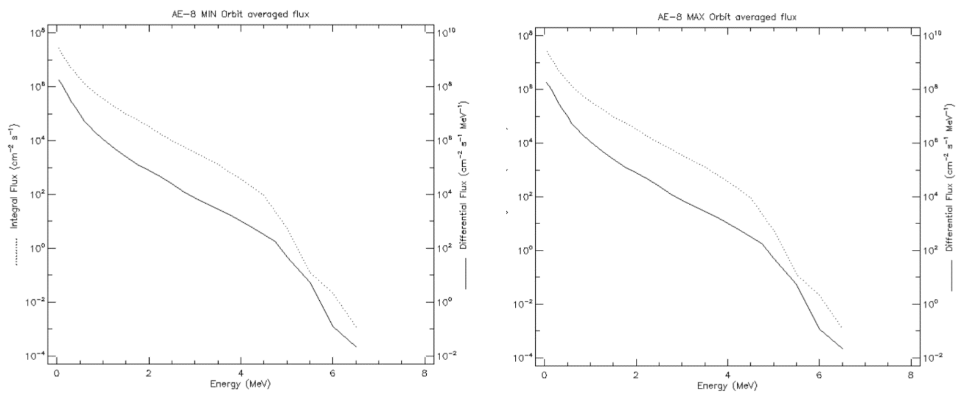

Figure 2: The electron radiation flux at solar minimum (left) and at solar maximum (right).

The results of radiation flux from Galactic cosmic rays (GCR) are shown in Figure 3. We can see that the radiation flux decreases towards the higher energies due to less interaction with detector material.

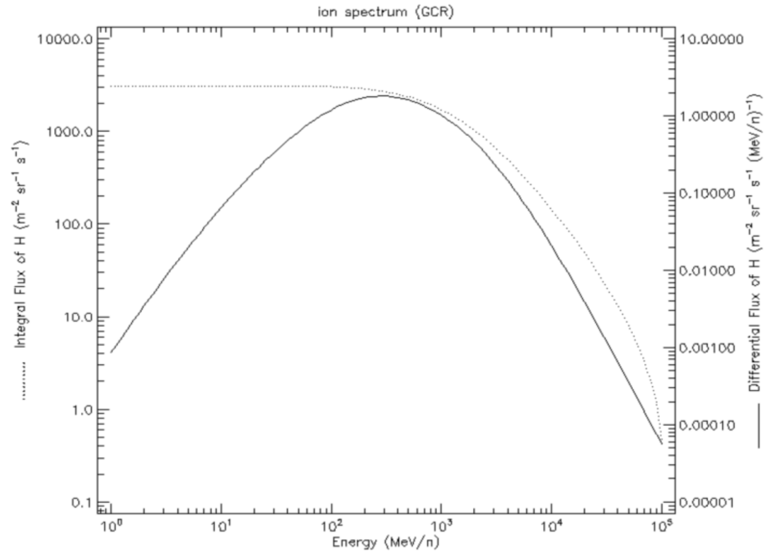

Figure 3: Integral and differential flux by GCR particles near LEO

Figure 3 shows the integral and differential flux by solar particle events: solar protons (left), and solar ions (right).

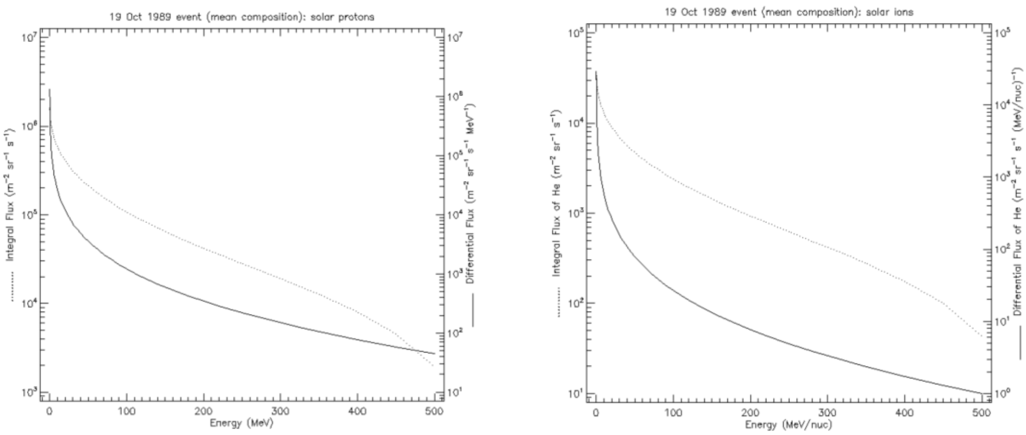

Figure 3: Integral and differential flux by solar particle events: solar protons (left), solar ions (right).

LET (Linear Energy Transfer) for the short-term single ion effect is systematically studied for Silicon target material with aluminium shielding having a thickness of 2mm. The results of LET spectra are shown in Figure 4

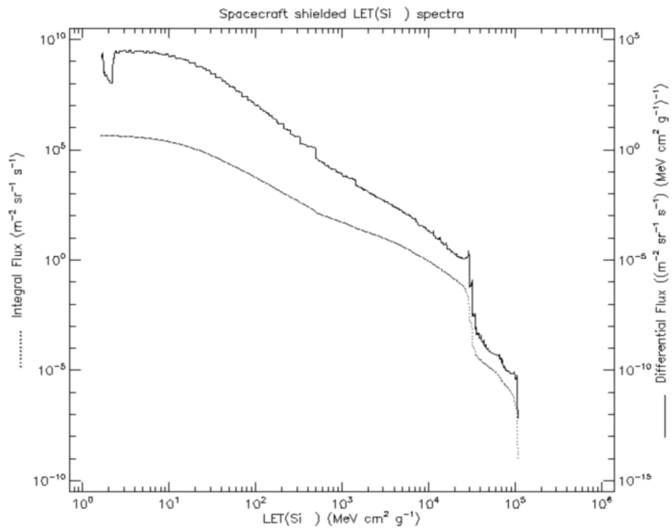

Figure 4: LET (Linear Energy Transfer) for the short-term single ion effect is studied for Silicon target material with aluminium shielding having a thickness of 2mm.

The dose in silicon slab with aluminium shielding is also measured, and results are shown in figure 5

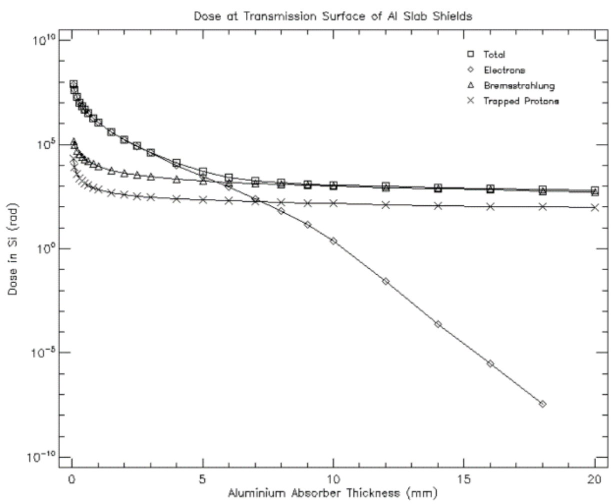

Figure 5: Radiation dose in silicon slab with aluminium shielding.

4. Summary and Future Work

In this study, the Geant4-based simulation software tool MULASIS, integrated with the SPENVIS tool, rigorously simulates and analyses proton and electron radiation flux at both solar maximum and solar minimum. Additionally, it comprehensively models and analyses radiation flux for GCR particles and solar particle events to gain a deep understanding of the space radiation environment. The LET spectra are meticulously examined for silicon material shielded with 2mm of aluminium. The study emphatically explores the impact of space radiation from trapped particles, GCR, and SPE by utilizing shielding materials such as aluminium. It meticulously investigates the dose transmitted to the detector after passing through shields of different pristine polymers and potential metals. The study leaves no stone unturned in evaluating the shielding performance of individual layers of various polymers and metal-based materials.

Acknowledgements

We thank MNIT Jaipur and RBS Engineering Technical Campus Agra for supporting the publishing of this research work.

References

1. A Review on Radiation Environment Pathways to Impacts: Radiation Effects, Relevant Empirical Environment Models, and Future Needs, Insoo Jun et al, Advances in Space Research, April 2024, DOI:10.1016/j.asr.2024.03.079
2. Blasi, P., 2013. The origin of galactic cosmic rays. Astron. Astrophys. Rev. 21, 70. https://doi.org/10.1007/s00159-013-0070-7.
3. https://geant4.web.cern.ch/ [Geant4 documentation].
4. SPENVIS: https://www.spenvis.oma.be/
5. Fung, S.F., Boscher, D.M., Bilitza, D., Tan, L.C., Cooper, J.F., 1996. Modelling the Low-Altitude Trapped Radiation Environment. In: Proceedings of the ESA Symposium On Environment Modelling For Space-Based Applications. NOORDWIJK, Netherlands.
6. Fung, S.F., Tan, L.C., Bilitza, D., Boscher, D., Cooper, J.F., 1998. An investigation of the spatial variations of the energetic trapped electrons at low altitudes. Adv. Space Res. 21, 1661–1664. https://doi.org/ 10.1016/S0273-1177(98)00010-6