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Study on the effectiveness of Kevlar and Polyethylene for radiation shielding in a spacecraft for long term space missions

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Abstract

In long duration space missions, astronauts will be exposed to galactic cosmic rays (GCR) and solar particle events (SPE). The interaction with space radiation will lead to both severe and late effects on the crew members. The use of shielding materials that attenuate High Charge and Energetic (HZE) particles, also known as passive shielding, is one of the viable ways for reducing space radiation dose. This paper presents the effectiveness of Kevlar and Polyethylene for radiation shielding using Monte Carlo simulations performed with Geant4.The shielding properties were investigated for proton, alpha, and Fe ions with energies of 500MeV for a specific thicknesses of Kevlar and Polyethylene. In terms of particle flux and total ionizing dose, Kevlar and polyethylene exhibited almost similar properties. The findings are also compared with other theoretical and experimental studies.

1. Background

One of the most essential concerns to address in order to allow human travel of outer space is radiation risk mitigation [1]. The Galactic Cosmic Rays (GCR), the radiation associated with solar events, such as Solar Particle Events (SPEs), and the secondary radiation generated by the interaction of GCR and SPEs with the space habitat hull and any intervening material make up the radiation in a deep space habitat (such as a space suit).

Passive shielding [1,2] is considered as a viable approach. As it is not technically feasible to completely stop High Charge and Energetic (HZE) particles in a shielding material, one manageable and realistic approach is to absorb relatively low energy particles in the material and break up the HZE particles into lighter particles, whose Linear Energy Transfer (LET) and dose contribution are less than primary heavier nuclei. Shielding qualities of various materials such as aluminum (Al) and polyethylene (PE) have been investigated utilizing particle accelerators in ground-based experiments [3, 4].Hydrogen is widely recognized as the most effective element for shielding protons and heavy nuclei. However, since hydrogen is not chemically stable and not easy to handle, hydrogen-rich materials such as PE and Kevlar were proposed and tested as shielding materials on the International Space Station (ISS) [5, 6].

2. Objectives

The aim of the study is to investigate the shielding effectiveness of a 10cm layer of Kevlar and PE for different particles (H, He, Fe at 500MeV/n) after a Al slab as the spacecrafts are usually made of Al. Monte-carlo simulations are performed by Geant4 toolkit. Nuclear stooping power are calculated by SR NIEL(Bragg's rule) [7]

3. Nuclear Stooping Power

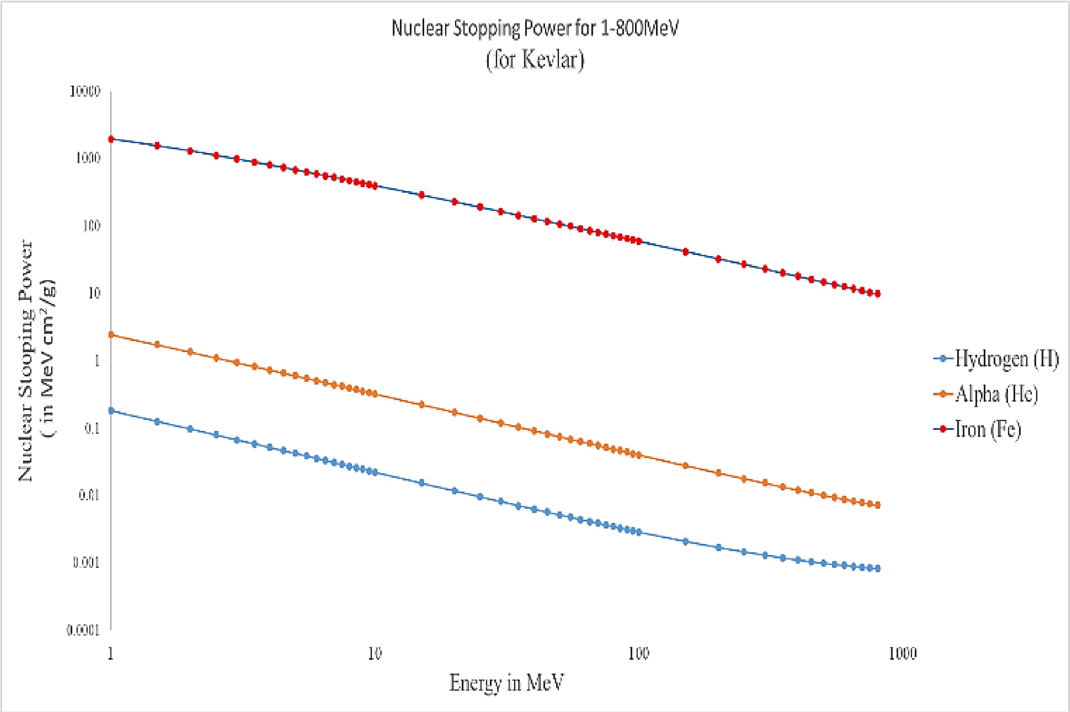

Figure 1: Nuclear stopping power (for Kevlar) within the energy range 1-800MeV

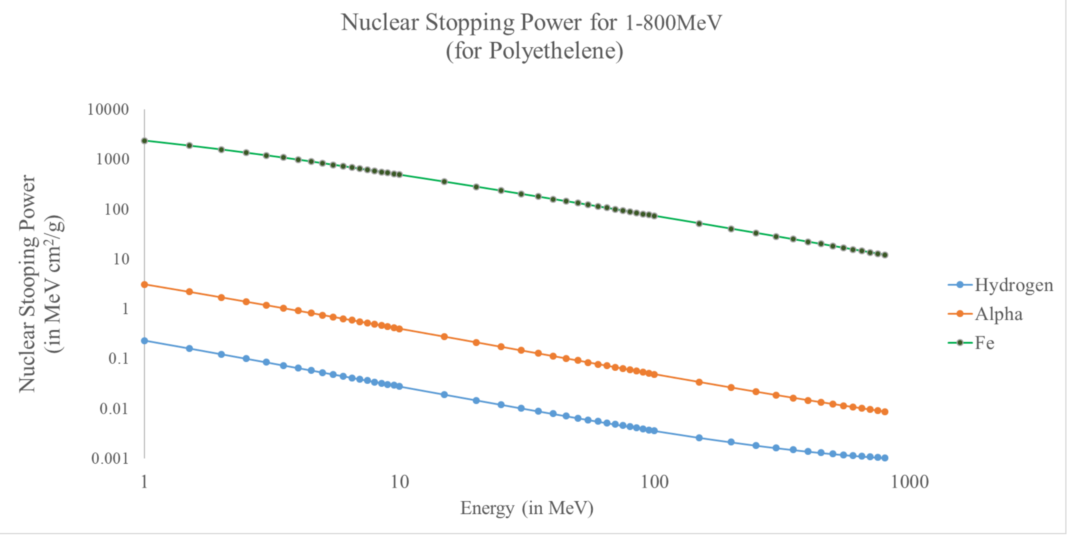

Figure 2: Nuclear stopping power (for Polyethylene) within the energy range 1-800MeV

Table 1: Nuclear stopping power for different particles for Kevlar and polyethylene (500Mev)

Particle	Kevlar Nuclear stopping power (MeV cm^2/g) (at 500 MeV)	Polyethylene Nuclear stopping power (MeV cm^2/g) (at 500 MeV)
Hydrogen (H)	0.00095604	0.0012331
Alpha (He)	0.0094268	0.012287
Iron (Fe)	14.859	18.22

4. Simulation Setup

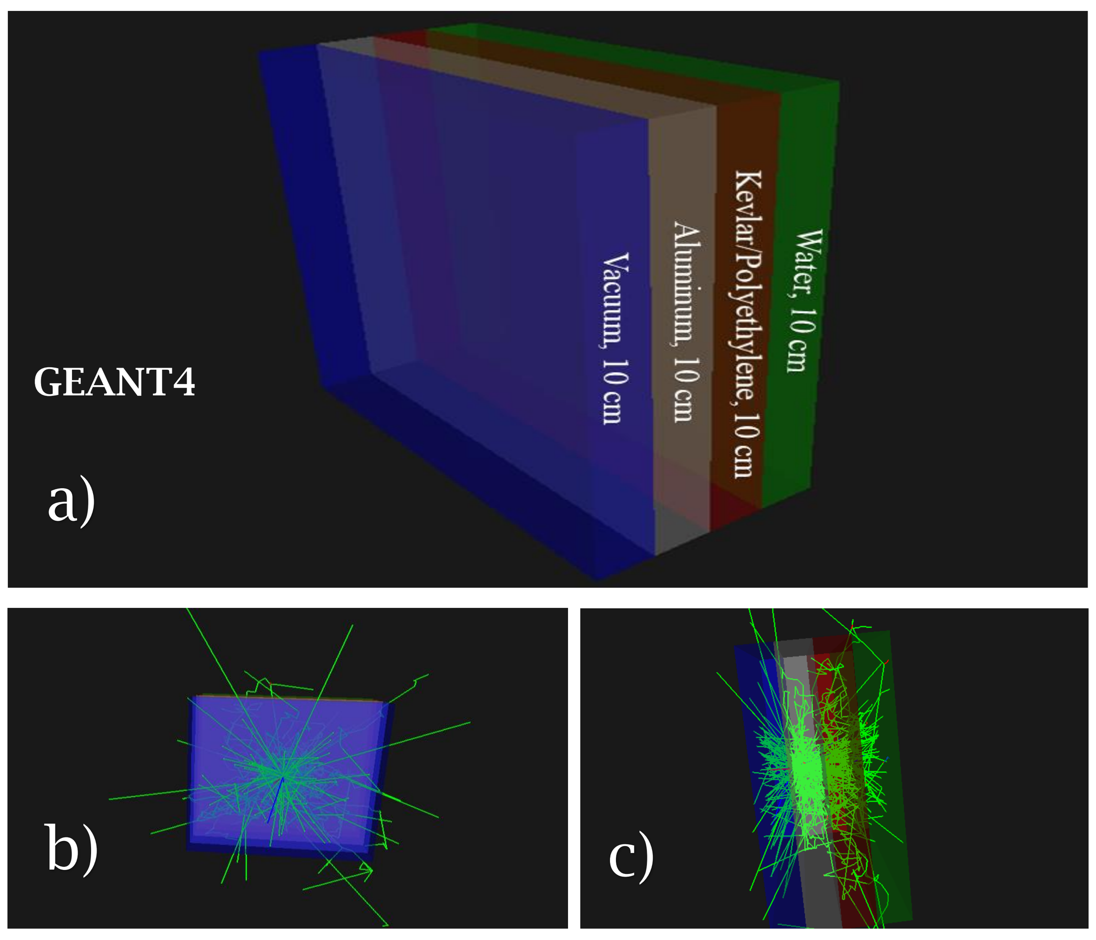

Figure 3: a) simulation setup. (b, c) visualization of the particle tracks

5. Results

5.1. Fluence Analysis

5.1.1. Kevlar

Proton fluence

For proton (H)

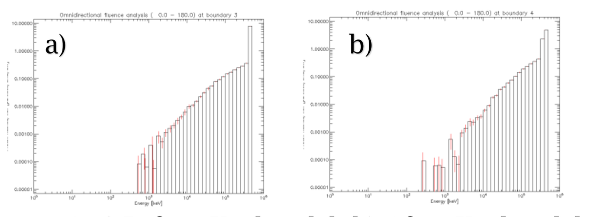

Figure 4: a) Before Kevlar slab b) After Kevlar slab

For Alpha (He)

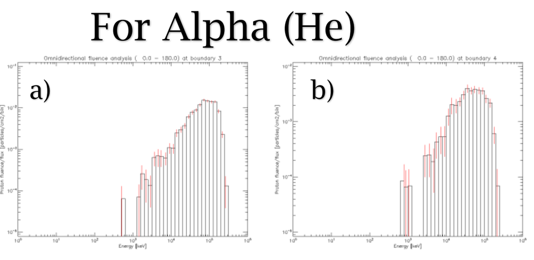

Figure 5: a) Before Kevlar slab b) After Kevlar slab

For Iron (Fe)

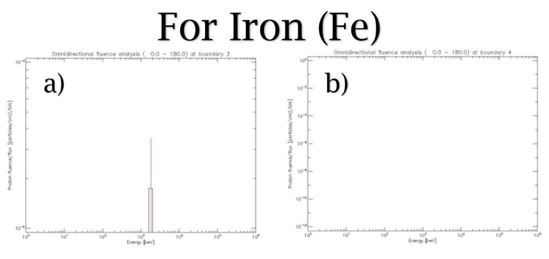

Figure 6: a) Before Kevlar slab b) After Kevlar slab

Neutron fluence

For proton (H)

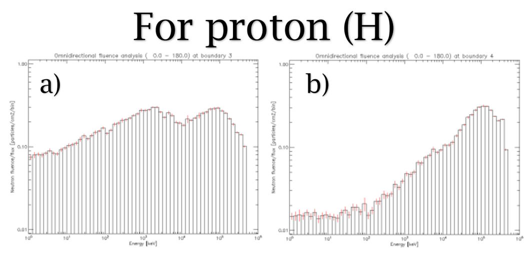

Figure 7: a) Before Kevlar slab b) After Kevlar slab

For Alpha (He)

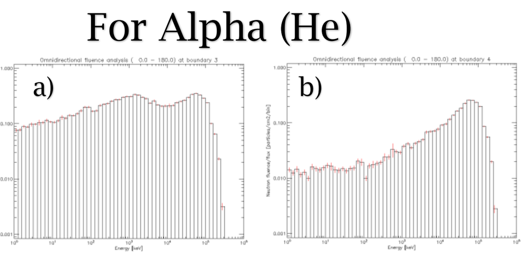

Figure 8: a) Before Kevlar slab b) After Kevlar slab

For Iron (Fe)

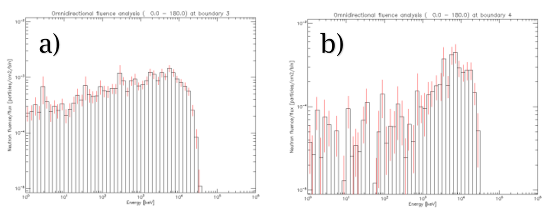

Figure 9: a) Before Kevlar slab b) After Kevlar slab

5.1.2. Polyethylene

Proton fluence

For proton (H)

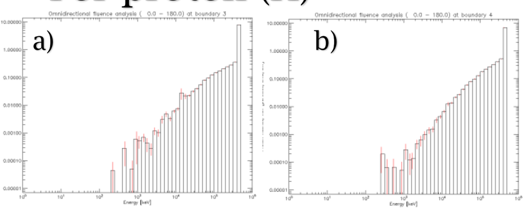

Figure 10: a) Before PE slab b) After PE slab

For Alpha (He)

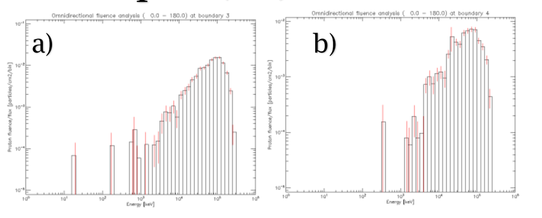

Figure 11: a) Before PE slab b) After PE slab

For Iron (Fe)

**Entirely blocked by the Aluminum slab

Neutron fluence

For proton (H)

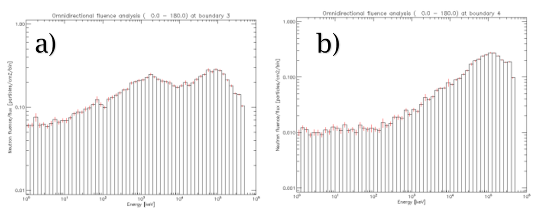

Figure 12: a) Before PE slab b) After PE slab

For Alpha (He)

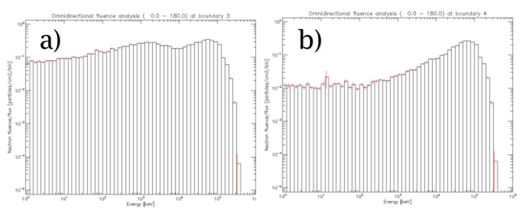

Figure 13: a) Before PE slab b) After PE slab

For Iron (Fe)

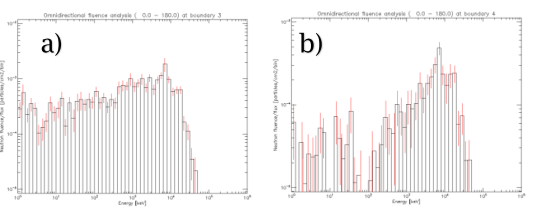

Figure 14: a) Before PE slab b) After PE slab

5. 2. Total Ionizing dose (TID)

5.2.1.Kevlar (for alpha)

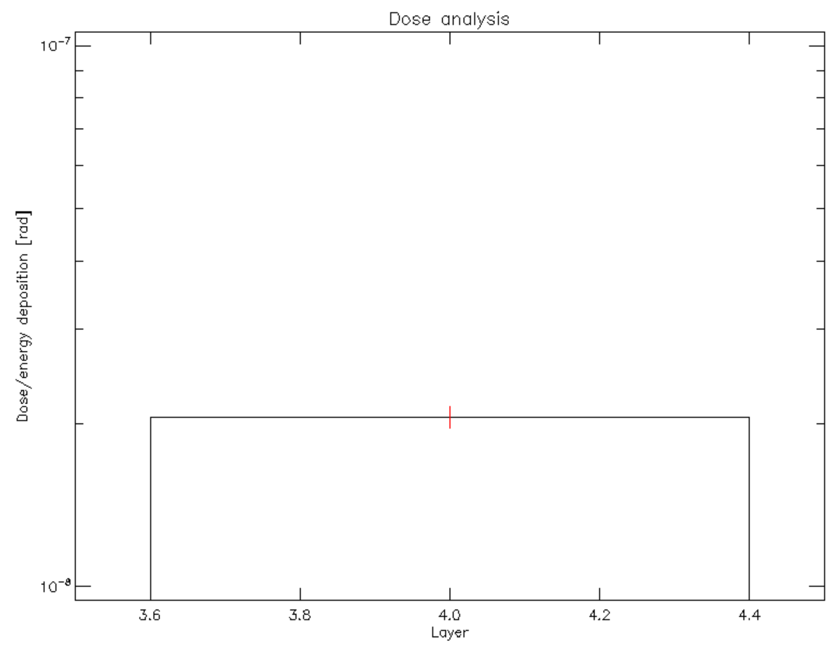

Figure 15: Total ionizing dose for Kevlar (For alpha)

5.2.2 Polyethylene (for alpha)

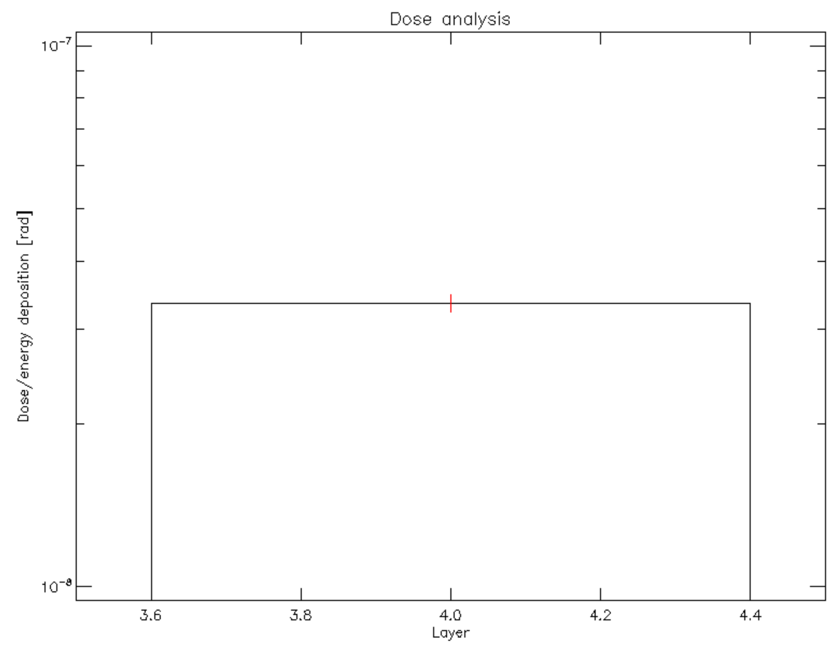

Figure 16: Total ionizing dose for Polyethylene (For alpha)

6. Observations and comparisons

Nuclear stopping power for different particles for Kevlar and polyethylene (500Mev) are shown (Table 1). Geant4 Monte Carlo simulations (Figure 4-14), show that the low-energy particles are getting stopped by both the materials. With the increase of atomic number (Z) of the incident particles, the stopping rate also increased and for iron (Fe) the amount is comparatively greater (Figure 6, 9, 14). The layer of Kevlar or polyethylene is also generating low-energy neutrons. The total ionizing dose/ energy deposition for Kevlar and polyethylene is also similar and in the range 〖10〗^(-8) rad. The results are in coherence with the experiments done in the ISS [6].

For detailed numerical values and graphs, please scan the QR code

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