

Study the Space Radiation Environment (GCR) and Effective Shielding Materials on the Mar's surface using OLTARIS

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To spend life on Mars, it is necessary to study the effective shielding materials on Mars using simulations. In this work, various shielding materials, namely Kelvar, Polystyrene, and LiH, are simulated in spherical geometry around the martial regolith using OLTARIS software. The effective dose equivalent is simulated and studied by varying the material thickness for different GCR particles and ions. In addition, LET spectra are also systematically investigated.

Keywords: Mars Shielding Materials, Radiation Protection, Simulations.

1. Introduction

Mars, the fourth planet from the sun, has been the subject of extensive scientific scrutiny due to its similarities to Earth's rotation period, tilt, days, and seasons. These similarities have piqued the interest of researchers and space agencies in studying the planet's unique topography and landforms, with the long-term goal of potential colonization. However, one major obstacle to sustained human presence on Mars is the planet's harsh radiation environment [1, 2]. In contrast to Earth, Mars lacks a robust magnetic field that serves as a protective shield against solar particle events and Galactic Cosmic Rays. The scarce atmosphere of Mars is insufficient to deflect harmful cosmic radiation, resulting in an average natural radiation level approximately 100 times higher than that experienced on Earth's surface [3]. The elevated levels of radiation pose significant health risks to potential human inhabitants, including the threat of Acute Radiation Syndrome, increased cancer risk, and possible damage to the central nervous system [4,5]. Given these challenges, it is imperative to explore and develop feasible strategies to mitigate the impact of space radiation on future

missions to Mars. Among the potential solutions, passive shielding methods are being investigated to provide protection from cosmic radiation and safeguard the well-being of astronauts and potential inhabitants.

In spacecraft shielding, it's crucial to consider how HZE (high atomic number and energy) particles dissipate their energy. These particles either lose energy through interactions with atomic nuclei and electrons or break into smaller nuclei and nucleons. Despite its challenging handling and temporal stability, hydrogen is recognized as the most effective element for achieving high shielding effectiveness per mass density. Numerous materials have displayed promising shielding capabilities in accelerator beam experiments. These include aluminum (Al), polyethylene (PE, $(C_2H_4)_n$), Kevlar, Nextel, and Lucite. On the International Space Station (ISS), studies have shown that water blocks, PE blocks, and packages made of wet sanitary towels have effectively reduced radiation exposure. Low-density hydrides, such as ammonia borane, have also provided superior dose reduction compared to polyethylene. Both Kevlar and polyethylene exhibit similar shielding capabilities and have shown promise in radiation protection. Moreover, lunar soil and Martian regolith are viable materials for mitigating radiation exposure in space and on the Martian surface. Additionally, astronauts can seek protection from harmful radiation by utilizing Martian caves and deep underground habitation systems.

Bond et al.[6] have comprehensively analyzed the whole-body effective dose equivalent for 59 common aerospace materials, specifically focusing on their suitability for deep-space travel. The paper delves into a thorough investigation of the effectiveness of radiation shields made from Martian regolith and other lightweight, hydrogenous materials with specific characteristics such as high tensile strength, low thermal conductivity coefficients, and flexibility. In this work, we will discuss an in-depth exploration of the radiation environment on Mars, offering detailed insights into the study's modeling, materials, parameters, and simulation setups and results of effective dose and LET spectra for different shielding materials for GCR particles.

The global map of Mars shows (figure 1) the estimated radiation dosages from cosmic rays reaching the surface, a serious health concern for any future human exploration.

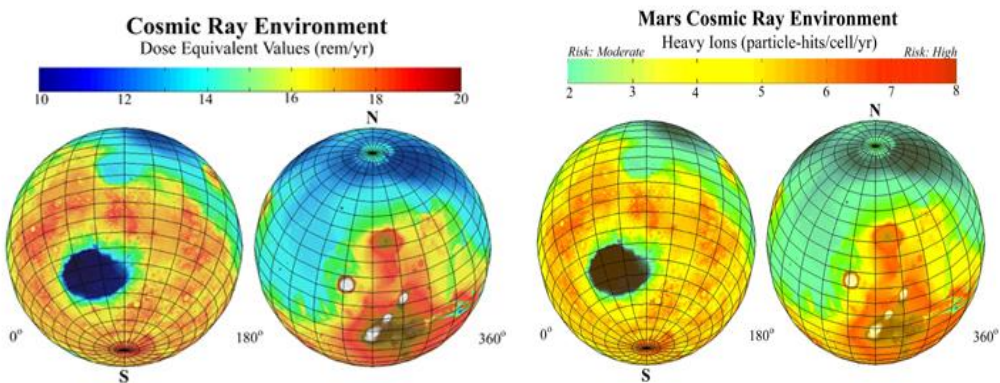


Figure 1: Cosmic Ray environment on Mars [7].

2. Simulation of effective dose equivalent and LET Spectra

In our OLTARIS project [8], we deliberately chose to utilize the sphere geometry option to design the necessary setup meticulously. This decision was driven by the need to accurately capture the Galactic Cosmic Rays (GCR) spectrum on the surface of Mars during the 2010 solar minimum event. To achieve this, we strategically employed the Badhwar O'Neill model [9], explicitly considering the MarsGram parameter at an elevation of 0.0 km over 20 days. In this work, the results have been produced for one day mission.

Our primary focus was calculating the precise, effective dose equivalent for a female adult voxel (FAX) phantom. Additionally, in Figure 2, we've provided a comprehensive visual representation of the program and data flow for OLTARIS. Each box in the diagram represents distinct components or modules within the system. This deliberate modular design has been implemented to ensure seamless integration and to facilitate easier maintenance and upgrades. It enables the easy incorporation of new algorithms, methods, and capabilities as they are developed, further enhancing the system's adaptability and scalability.

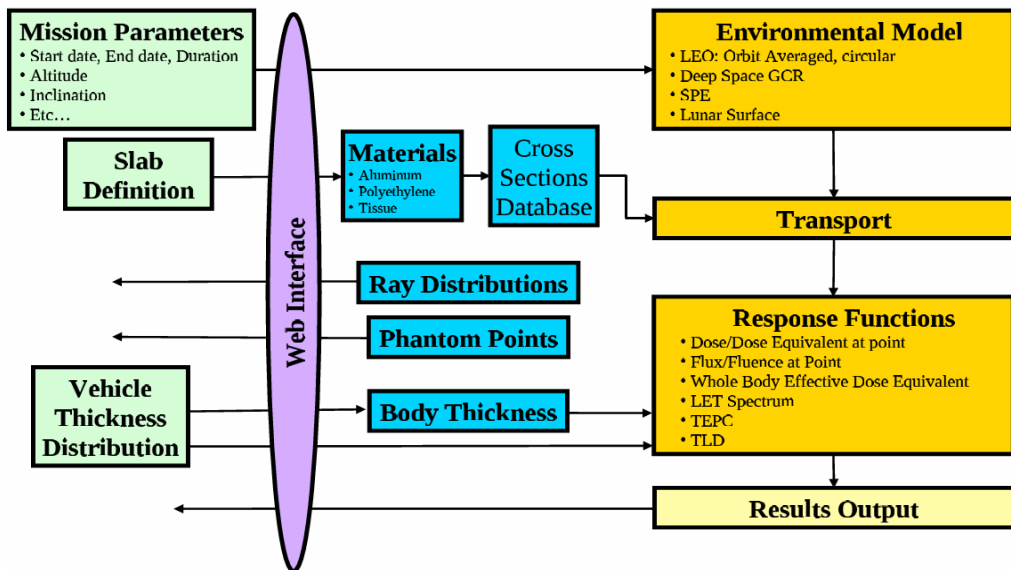


Figure 2: Flowchart of OLTARIS.

Table 1 shows the different materials used for shielding purposes.

Sr. No	Material	Chemical Formula	Density
1.	Martian regolith	H ₂ O(7.4%). Al ₂ CaK ₂ MgNa ₂ O ₇ (32.1%). Fe ₂ O ₃ (9.3%). O ₂ Si (51.2%)	1.70
2.	Kevlar (poly-para-phenylene terephthalamide)	C ₁₄ H ₁₄ N ₂ O ₄	1.44
3.	Polystyrene	C ₈ H ₈	1.06
4.	Lithium hydride	LiH	0.82

Table 1: different materials used for shielding purposes on Mar’s surface.

In this work, two spheres are simulated. The first outer sphere is made up of martial regolith, and the second inner sphere is made up of shielding material of various thicknesses (1-5gm/cm²), namely Kevlar, polystyrene, and LiH. At the center of the setup, the portion represents the female adult voxel (FAX) in Oltaris framework.

3. Results

3.1 Absorbed Dose

The absorbed dose is defined by the radiation energy (E) absorbed per unit mass of tissue and is given by equation (1)

$$D = \frac{E}{m}.$$

.....(1)

3.2 Effective Dose equivalent

The effective dose equivalent (ED) is determined by first finding the average dose equivalent for specific organs and tissues [10, 11], and it is calculated using Equation (2) with tissue weighting factor from NCRP-132.

$$ED = \sum_T W_T \cdot H_T,$$

...(2)

W_T is the NCRP-132 tissue weighting factor, and H_T is the organ or tissue averaged dose equivalent.

The average dose equivalent for different components of the human female phantom is shown in Figure 3.

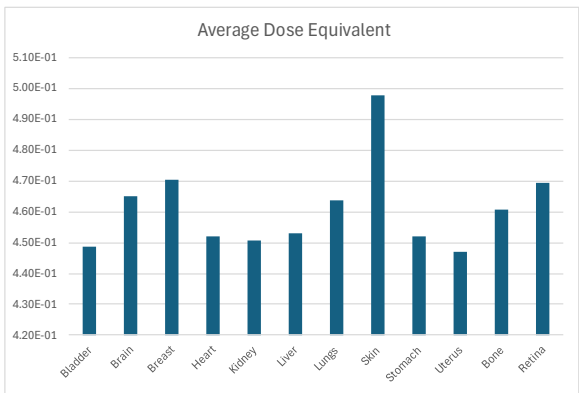


Figure 3: Average dose equivalent for different components of Female phantom (FAX).
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Figure 4 shows the simulated effective dose equivalent for GCR proton from Oltaris for different thicknesses of shielding material.

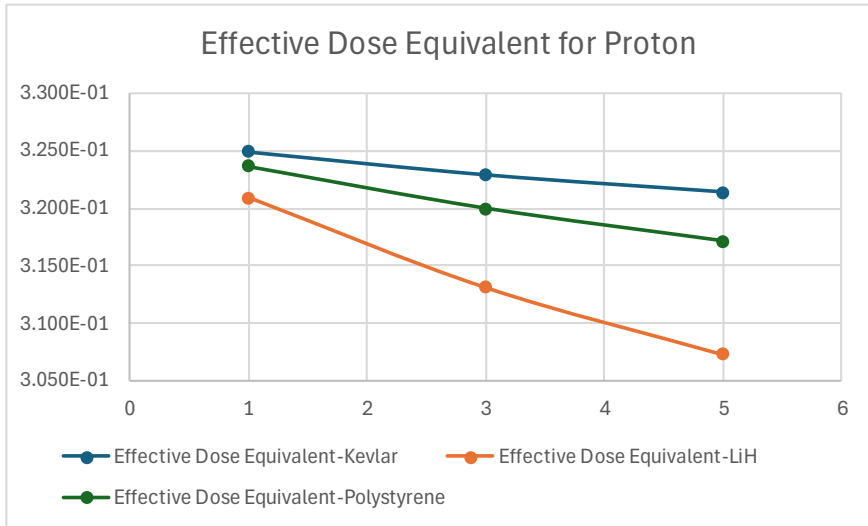


Figure 4: Effective dose equivalent for GCR proton particle for different shielding material.

It can be seen from Figure 4 that LiH performs better as a shielding material due to the less effective dose equivalent compared to Kevlar and polystyrene for proton.

Figure 5 shows the simulated effective dose equivalent for GCR alpha particle from Oltaris for different thicknesses of shielding material.

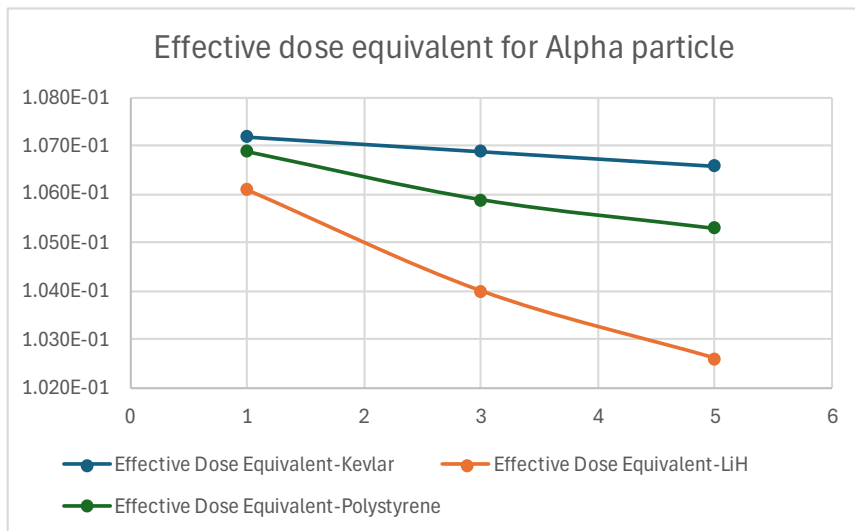


Figure 5: Effective dose equivalent for GCR alpha particle for different shielding material.

It can be seen from Figure 5 that LiH performs better as a shielding material due to the less effective dose equivalent compared to Kevlar and polystyrene for alpha particles.

Figure 6 shows the simulated effective dose equivalent for GCR iron from Oltaris for different thicknesses of shielding material.

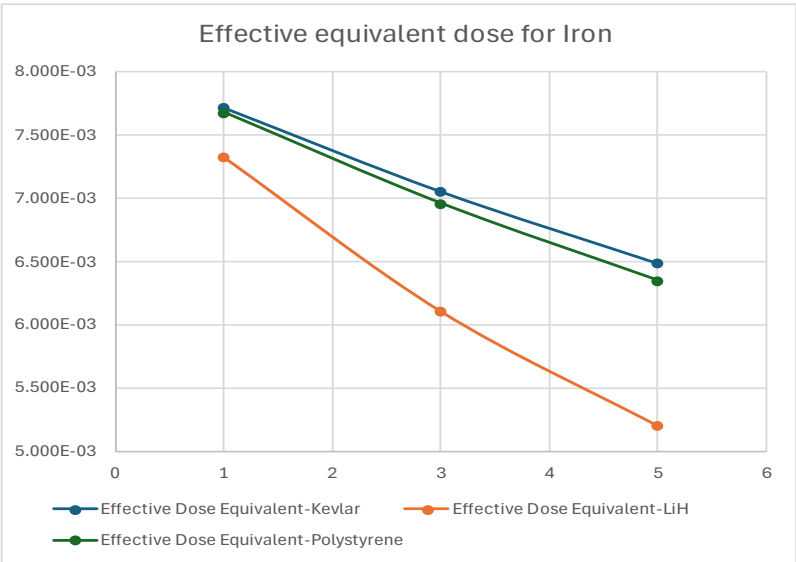


Figure 6: Effective dose equivalent for GCR iron for different shielding materials.

It can be seen from Figure 6 that LiH performs better as a shielding material due to the less effective dose equivalent compared to Kevlar and polystyrene for GCR iron.

3.3 Linear Energy Transfer (LET) Spectra

Linear energy transfer (LET) is the average (radiation) energy deposited per unit path length along the track of an ionizing particle. Its units are keV/μm. Figure 7 shows the integral flux as a function of LET.

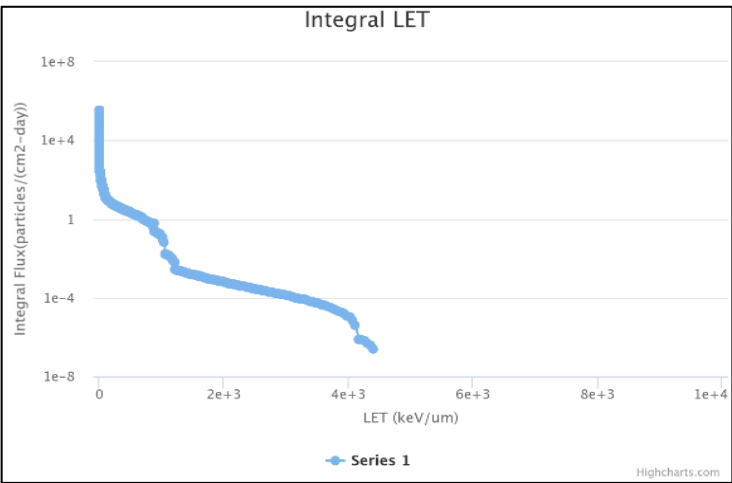


Figure 7: Integral flux as a function of LET and (left) differential flux as a function of LET (right).

Figure 8 shows the radiation flux as a function of energy. We can see from the figure that, as expected, GCR contains a higher contribution from proton than from alpha and iron.

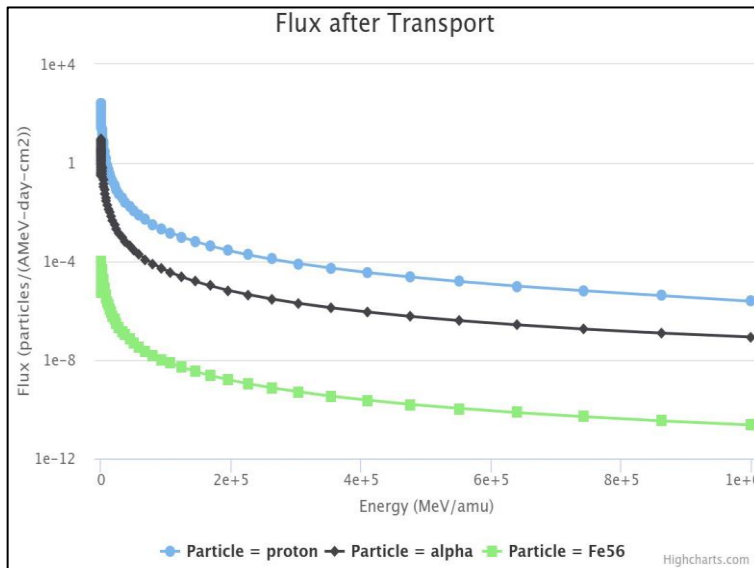


Figure 8: Radiation flux as a function of energy

4. Summary and Conclusions

This work uses three shielding materials, Kevlar, Polystyrene, and LiH, for the Mars surface. The LiH is one of the best shielding materials with less absorbed dose than Kevlar and polystyrene. Further, the effective dose equivalent is simulated for different components of the human female phantom (FAX) using Oltaris simulation. In addition, LET spectra are also simulated in the FAX for all shielding materials. The radiation flux as a function of the energy of incoming radiation/particles, namely proton, alpha, and iron, is simulated, and it is observed that proton radiation flux is higher than alpha and iron, which is expected for the GCR environment.

Acknowledgements

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