Shielding Materials against Galactic Cosmic Rays: A Deterministic Simulation Approach

Bhargav K. Soni[1],* Surendra Singh Barala[2]
[1]The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat-390002, India
[2]Defence Laboratory Jodhpur, Rajasthan - 342011, INDIA
. * email: sonibhargav15@gmail.com

Introduction

During space missions, the hazardous space radiation environment is one of the major concerns. Recently, space missions outside the Low Earth Orbit (LEO) have been more focused. Where protection from the earth's magnetic field no longer exists. Moreover, exposure to space radiation lasts a long time during deep space missions. As a consequence of payload limitations, simply raising the density of shielding materials is not adequate. As a result, the only viable solution is to use lightweight and effective shielding materials.

The Galactic Cosmic Rays (GCR) and the Solar Particle Events (SPEs) are prime radiation sources in deep space. Compared to SPEs, the GCR is more arduous to shield.

The radiation from GCR travels at near relativistic speeds, having an energy of more than 1 Gev/nucleon. During the interaction of high-energy GCR radiation with spacecraft, a large amount of secondary generation is produced along with the primary. GCR and secondary radiation interact with body organs, causing severe damage to humans.Hence, the National Council on Radiation Protection and Measurements (the NCRP) has defined the dose limits for crew [1]. Hence, improved shielding materials allow deeper space exploration for longer time intervals.

Shielding from space radiation hazards has been a notable topic for a few decades. From the literature survey, it was found that elements with a higher charge-to-mass ratio provide better shielding against HZE [2].

Recently, aluminium has been extensively used for spacecraft shielding. Although aluminium is not as beneficial as materials with higher hydrogen content, Several materials that have high hydrogen content could be good alternatives for shielding against GCR.

Apart from that, multilayered shielding is another potential solution to deal with the space radiation issue, where each layer has a different characteristic for the incoming radiation. Previously, NASA had adopted this technique on the ISS. They used aluminum and polyethylene for shielding. [3]. This dual-layer structure shows a magnificent improvement in shielding over a solitary aluminum layer [4].

Effective shielding materials could be the most feasible solution for the GCR radiation concern. To identify potential candidates for feasible GCR shielding, several compounds and multilayered materials were studied using the most recent HZETRN (High Zand Energy TRaNsport): A Heavy Ion/Nucleon Transport Code for Space Radiations [5].

The focus of the present work is to evaluate the radiation dosimetric quantities from solar modulation parameter 475 in the GCR event using the HZETRN radiation transport code that is mainly used in space radiation estimation. In particular, this paper collates the dose and dose equivalent as a function of depth in water.

Radiation transport codes

The interactions of the incident primary radiation with the materials create downstream secondary radiation. A detailed and accurate characterization of the radiation field in terms of absorbed dose and dose equivalent is crucial in assessing the long-term radiation exposure to biological systems. Various transport codes have been developed which derive the solution of the transport equation using deterministic methods.

HZETRN is the deterministic transport code developed by NASA Langley Research Center [1]. The code uses the Boltzmann transport equation to solve the transport equation, employing the straight-ahead and continuous slowing down approximations. The code is specifically constructed for the execution of various types of space radiation environments (like GCR, SPE, etc.) with evaluation of the dose, dose equivalent, and other response quantities. The code uses the geometries to be specified as slabs, spheres, or complicated spacecraft, habitats, and crew suits.

Simulation methods

The simulation was performed to estimate dose and dose equivalent inside a slab containing 30g/cm2 of shielding materials (average material thicknesses used in the literature for crew modules) followed by 0 to 100g/cm2 of water (reference of a typical human investigation). Dose rates were measured using a tissue equivalent detector. There are minor variances in stopping power measurement. The target materials as listed in Table 1 were chosen for shielding analysis.

Table. 1. The density, stopping power, and hydrogen mass fraction of selected materials [6].

Material	Density (g/cm^2)	Stopping power	H fraction (wt %)
Aluminium	2.70	1.30	0.00
Polyethylene	0.94	0.54	14.40
LiH	0.78	0.39	12.70
$LiBH_4$	0.67	0.37	18.51
CFRP	1.17	0.67	8.87

Results and discussion

In the present work, the dose and dose equivalent quantities have been adopted for the estimation of radiation analysis.

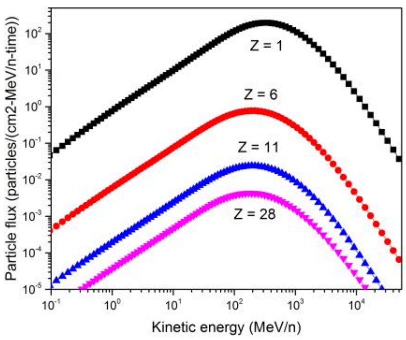

Fig. 1. GCR input particle flux spectra with selected particles.

The differential fluence spectra of the O'Neill 2020 GCR model (see Fig. 1.) were used for the analysis of primary and secondary particles, and results were compared behind the various shielding materials (see Table 1) in the water target using a tissue equivalent detector.

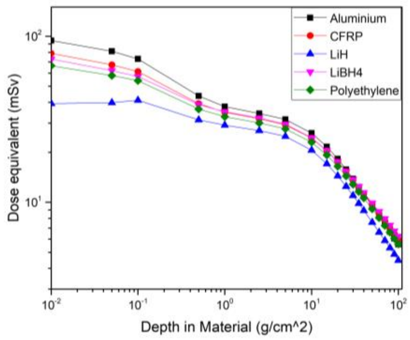

Fig. 2. Dose equivalent values at various depths inside water after 30 g/cm2 shielding materials for GCR environment.

The outcome of dose equivalent for shielding materials has does-depth curves and relative dose addition from created secondary particles in the absolute dose (see Fig. 2). Figure 2 shows the dose equivalent from primary and secondary reaching the detector volume. where the nonlinear variation is observed in measurement as a function of depth. It is worth noting that the dose equivalent from the LiH material is the lowest of all. Due to its lower atomic number, it produces less secondary generation and is more effective compared to others. Apart from the shielding, limitations on the payloads and quality are also taken into account.

References

[1] Townsend LW, et al., Radiat Meas. 1999.
[2] Aghara SK, et al., Life sciences in space research, **4,** 79-91, 2015.
[3] El-Jaby S, et al., Life Sci Space Res (Amst). 2020.
[4] Singletterry Jr, et al., Acta Astronautica, 68, 2011.
[5] Wilson JW, et al., Advances in NASA radiation transport research: 3DHZETRN. Life Sci. Space Res 2, 6–22.
[6] Naito, M et al., Life sciences in space research, 26, 69-76, 2020.