Journal of Space Science and Technology

P-ISSN: 2008-4560
E-ISSN: 2423-4516

Vol. 18, Special Issue, pp. 26-33, 2025
https://doi.org/10.22034/jsst.2025.1520
Journal Homepage: https://www.jsstpub.com

Original Research Paper

Effectiveness of Multi-Layered Radiation Shields Constructed from Polyethylene and Metal Hydrides Using HZETRN and OLTARIS for Space Applications

VV Sreedevi and Kavita Lalwani*

Department of Physics, Malaviya National Institute of Technology Jaipur, India

ARTICLE INFO

Article History:

Received 15 January 2025
Revised 22 February 2025
Accepted 02 March 2025
Available Online 08 April 2025

Keywords:

Space radiation
Metal hydrides
Polyethylene
HZETRN
OLTARIS

ABSTRACT

A major challenge for extended human spaceflight in deep space is the hazardous exposure to space radiation, which consists of high-energy particles that pose significant risks to astronaut health. Effective radiation shielding is essential to mitigate these risks. This study optimizes the shielding performance of a multi-layered structure composed of polyethylene and metal hydrides for space applications. Using two simulation tools: HZETRN and OLTARIS, developed by NASA, we model these structures and evaluate dose equivalent in a Galactic Cosmic Ray (GCR) free-space radiation environment, which is the primary and major contributor to radiation exposure for long-duration space missions. Among the materials studied, lithium hydride exhibits the highest shielding effectiveness. The results on the dose equivalent are compared with aluminum, a conventional shielding material, revealing that the multi-layered structure constructed from polyethylene and lithium hydride provides a 54.9% improvement in shielding effectiveness while maintaining structural stability. Additionally, the dose equivalent contribution of different radiation particles (protons, alpha particles, and heavy ions) and their flux are analyzed for further validation across both tools. Our results highlight the effectiveness of multi-layered shielding in reducing dose equivalent while maintaining structural stability, making it a viable solution for deep-space missions.

* Corresponding Author's E-mail: kavita.phy@mnit.ac.in

How to Cite this Article:
VV. Sreedevi and Kavita Lalwani, "Effectiveness of multi-layered radiation shields constructed from polyethylene and metal hydrides using HZETRN and OLTARIS for space applications," *Journal of Space Science and Technology*, Vol. 18, Special Issue, pp. 26-33, 2025, https://doi.org/10.22034/jsst.2025.1520.

1. INTRODUCTION

One of the main challenges for prolonged human space expeditions is space radiation. Unlike on Earth, interplanetary space is constantly being bombarded with ionising radiation [1]. Exposure to such high radiation for a long duration can-do severe harm to the human body as well as electronic equipment. Space radiation cannot reach the Earth's surface because of the strong magnetic field and thick atmosphere of Earth. There are three main sources of space radiation: Galactic Cosmic Rays (GCRs), Solar Particle Events (SPEs), and Trapped particles such as electrons and protons. GCR is the primary and major contributor to radiation exposure for long-duration space missions. It consists of high-energy particles comprising 85% proton, 13% alpha particles, and heavy ions, with atomic numbers ranging from Z=1 to Z=28, that can penetrate spacecraft shielding and induce secondary radiation, making them crucial for shielding optimization. SEPs are sporadic and event-driven, whereas trapped radiation (Van Allen belts) is mainly relevant for LEO, not deep-space conditions considered in this study. Hence only GCR flux is considered for dose calculations in this study. Effective shielding against GCRs requires materials that not only stop primary particles but also minimize the production of secondary particles.

To minimize the radiation effects from different particles in the GCR space radiation environment, there are mainly two techniques for space radiation shielding: active and passive shielding methods [2]. Active shielding uses electromagnetic fields to divert harmful radiation. This advanced technique lowers direct exposure but necessitates energy input and intricate systems to sustain its effectiveness [3]. Active shielding remains largely theoretical and requires substantial advancements before it can be widely deployed. In this work, we focus on passive shielding techniques, where a physical material is employed, which can effectively attenuate the incoming radiation. Heavy charged particles lose their energy in shielding materials through electronic and nuclear fragmentation. Conventionally, aluminum is used as a passive shielding material due to its high density and tensile strength. However, studies have shown that liquid hydrogen offers significantly better dose reduction. Despite its effectiveness, liquid hydrogen is highly unstable, making it impractical for space radiation shielding. While previous studies have broadly explored the shielding effectiveness of various materials, we investigate the shielding effectiveness of hydrogen-rich materials, specifically metal hydrides. To further enhance structural strength, we propose multi-layered shields combining metal hydrides with polyethylene. This novel shielding design not only improves dose equivalent reduction but also enhances mechanical stability. Thus, the objective of this study is to evaluate the effectiveness of metal hydride-based shielding compared to conventional materials using HZETRN [4] and OLTARIS [5,6] simulations.

2. MATERIALS AND SIMULATION SETUP

In this section, the different shielding materials and their properties are discussed in detail. Further, the simulation tools HZETRN and OLTARIS are introduced.

2.1 Radiation Shielding Materials:

The selection of shielding materials for spacecraft must consider both high shielding effectiveness and additional essential properties such as high tensile strength and low reactivity. While high-density materials offer structural strength, they can also contribute to increased radiation exposure due to secondary radiation production. In contrast, low-density, hydrogen-rich materials are highly effective in reducing the dose equivalent but often require additional structural reinforcement. A promising approach to optimizing shielding performance is multi-layered shielding, which strategically combines materials of different densities to balance radiation protection and mechanical stability. Traditionally, aluminum has been widely used in spacecraft due to its lightweight nature and structural integrity. However, studies have shown that several other materials result in lower absorbed doses compared to aluminum. Among shielding materials, hydrogen is the most effective in reducing radiation exposure. However, its high instability presents significant challenges for practical application in spacecraft. As an alternative, hydrogen-containing compounds exhibit excellent shielding properties while offering better stability. Polyethylene, which has one of the highest hydrogen contents among polymers, is more effective than many other conventional materials, including aluminum. Additionally, as a polymer, its structural properties can be modified to enhance both mechanical strength and radiation shielding performance. UHMWPE (Ultra High Molecular Weight Polyethylene) [7] is a specialised form of polyethylene, characterised as a linear, semi-crystalline homopolymer with an exceptionally high molecular mass. UHMWPE fibres offer excellent radiation shielding, high tensile strength, low density, superior impact resistance, and durability in space environments, making them a promising material for future space structure applications. Metal hydrides are known for their hydrogen-storing capacity [8-10]. Following astrophysical conventions, all elements heavier than hydrogen are often referred to as metals. Therefore, in this study metal hydrides refer to compounds where hydrogen is chemically bonded to elements heavier than hydrogen. This paper explores the shielding effectiveness of various metal hydrides, as well as multi-layered shields combining polyethylene and metal hydrides. The materials such as Lithium Hydride, Lithium Borohydride, Beryllium Hydride, Beryllium Borohydride, Ammonia Borane, and Super Hydride are selected for their high hydrogen content and the presence of other low-Z elements, both of which are effective in attenuating high-energy heavy ions. Table 1 gives the list of all materials used in this study along with their chemical formula and density.

Table 1. List of optimised shielding materials.

S.No.	Material Name	Chemical Formula	Density in g/cm^3
1	Aluminum	Al	2.7
2	Polyethylene	C_2H_4	0.96
3	Beryllium Borohydride	$Be(BH_4)_2$	0.604
4	Ammonia Borane	NH_3BH_3	0.78
5	Super Hydride	$Li(C_2H_5)_3BH$	0.89
6	Beryllium Hydride	BeH_2	0.65
7	Lithium Borohydride	$LiBH_4$	0.68
8	Lithium Hydride	LiH	0.82

2.2 HZETRN

The HZETRN (High charge (Z) and Energy TRaNsport) code is a deterministic transport model designed by NASA specifically for simulating space radiation transport. The HZETRN code employs numerical solutions to the time-independent, linear Boltzmann equation, utilizing the continuous slowing-down approximation. In this approach, discrete atomic interactions are modeled through stopping power. HZETRN2015 is employed for all calculations in this study. The code supports transport calculations for Galactic Cosmic Rays (GCR), Solar Particle Events (SPE), Low Earth Orbit (LEO), and custom environmental boundary conditions. For SPE and LEO scenarios, it accounts for the transport of neutrons, protons, and light ions, while GCR boundary conditions extend to include heavy ions, pions, muons, electrons, positrons, and photons.

2.3 OLTARIS

In this work, OLTARIS simulation software is used to investigate the proposed materials for space radiation shielding. OLTARIS is a NASA-based software platform. A flowchart for data flow and execution is shown in Figure 1. Materials for space radiation shielding are characterized based on their density and chemical composition. The chemical composition of the materials is defined in terms of chemical formula, elemental mass percentage or molecular mass percentage. The geometry of the shields is specified as either a semi-infinite slab or a spherical configuration with any number of materials/layers in any order. In this study, spherical geometry is being used with radius varying from 1-15 g/cm^2. Also, for simulating multi-layered shields, semi-infinite slab geometry consisting of three layers is used.

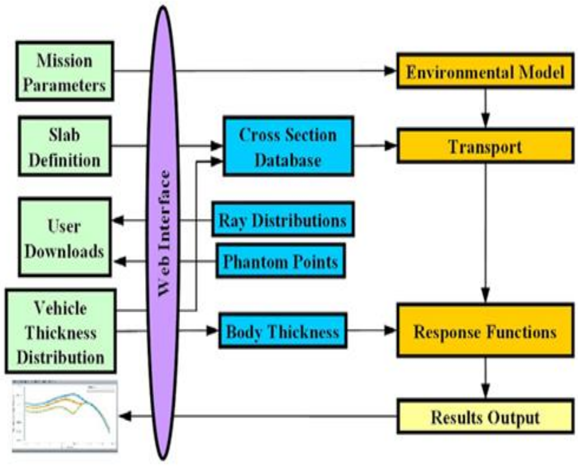

Fig. 1. OLTARIS data and execution flowchart [5].

OLTARIS has many benefits as it provides information on dose equivalent and flux contributions from different particle radiations such as protons, alpha particles, neutrons, and heavy ions. In addition, it also gives organ-wise dose equivalent, effective dose equivalent (for female or male anatomical model), and Linear Energy Transfer (LET) as response functions.

All simulations are carried out in a free-space Galactic Cosmic Ray (GCR) environment at 1 AU, using the Badhwar-O'Neill 2014 model [11]. The full GCR spectrum is included, incorporating all ions (proton and heavy ions) atomic numbers ranging from Z = 1 to Z = 28 in the boundary conditions. Since GCR flux is higher during solar minimum, a solar modulation parameter (φ) of 475 MV is selected to represent these conditions for a 1-day mission duration. The response is evaluated in tissue using the ICRP 60 quality factor [12]. These parameters remain consistent across both HZETRN and OLTARIS simulations.

3. RESULTS

In this section, the dose equivalent contribution of different radiation particles (protons, alpha particles, and heavy ions) and their flux are analyzed using both tools. As the absorbed dose quantifies the energy deposited per unit mass of a material, therefore in order to account for the varying biological impact of different types of radiation, the dose equivalent is calculated by multiplying the absorbed dose by a quality factor (Q), which adjusts for radiation-specific biological effectiveness.

3.1 Dose Equivalent for Variable Thickness of Shielding Materials

The dose equivalent of different materials is computed in the tissue by varying their thickness from 5 to 15 g/cm^2 in HZETRN. Spherical geometry is used to run the simulation. The results are shown in Fig. 2.

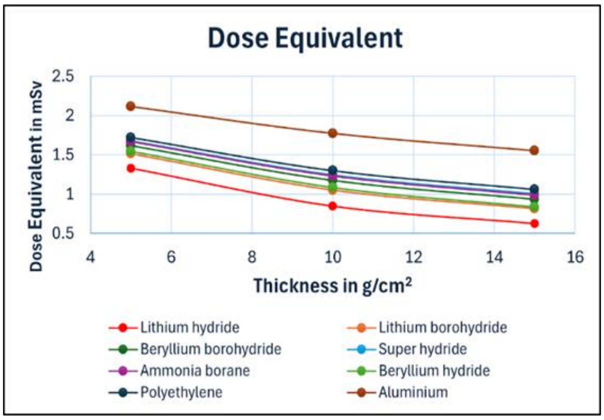

Fig. 2. Variation of dose equivalent with a thickness of metal hydrides, polyethylene, and aluminium using HZETRN.

It can be seen from the figure that, beyond 15 g/cm^2, there is no considerable reduction in dose. The dose equivalent of metal hydrides is less than polyethylene and aluminium. Lithium hydride offers a much lesser dose equivalent than other metal hydrides. Hence, it has greater potential for space radiation shielding as compared to other metal hydrides.

3.2 Dose Equivalent from Different Particles

The particle-wise dose equivalent is studied for different incoming particles such as proton, alpha particle, and heavy ion (iron) in the GCR spectrum. The thickness for all the materials is 15 g/cm^2. Proton and alpha particles are the particles with high relative abundance in the GCR spectrum and iron represents the HZE (High Charge and Energy) particle category. The results are shown in Fig. 3.

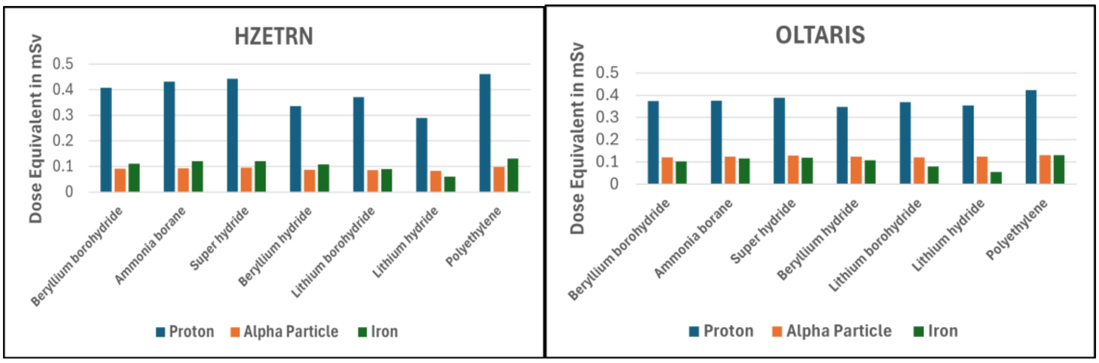

Fig. 3. Particle-wise dose equivalent of 15 g/cm^2 of metal hydrides and polyethylene using HZETRN (left) and OLTARIS (right).

The highest dose equivalent is due to the proton, which is clearly due to its abundance. The dose equivalent due to iron, despite its low abundance, is comparable to that of alpha particles. The comparison between the metal hydrides aligns with the previous trend (Section 3.1). Lithium hydride is effective in reducing proton as well as heavy ion doses. The results from both HZETRN and OLTARIS confirm the relative effectiveness between the different materials. The dose equivalent of proton in HZETRN is in general slightly higher than that in OLTARIS and the dose equivalent of alpha particle is higher in OLTARIS when compared to that in HZETRN. The difference in these results can be due to the difference in numerical approximations employed in HZETRN and OLTARIS that can introduce systematic biases in their radiation transport calculations. Because HZETRN uses semi-empirical nuclear fragmentation models, and OLTARIS incorporates updated NASA cross-section libraries.

3.3 Comparison of Dose Equivalent in HZETRN and OLTARIS

In this section, we compare the dose equivalent for variable thickness of LiH and polyethylene from HZETRN and OLTARIS. The results are shown in Fig. 4.

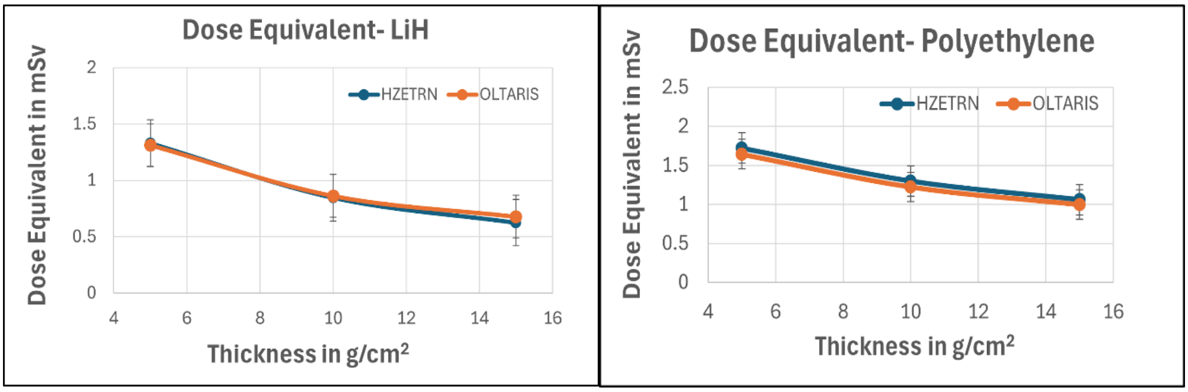

Fig. 4. Dose equivalent of lithium hydride (left) and polyethylene (right) - comparison between OLTARIS and HZETRN.

From section 3.1 it can be seen that out of all metal hydrides, LiH proves to be a better shielding material, as it produces the least dose equivalent. Polyethylene is also taken into consideration due to its high tensile strength. For LiH, dose equivalent values from both transport codes are in agreement. For polyethylene, the dose equivalent values from HZETRN are higher than that from OLTARIS by 0.0715 mSv on average.

3.4 Comparison of Radiation Flux in HZETRN and OLTARIS

Radiation flux after transport as a function of kinetic energy is studied for proton, alpha particle, and iron in LiH. The results are shown in Fig. 5.

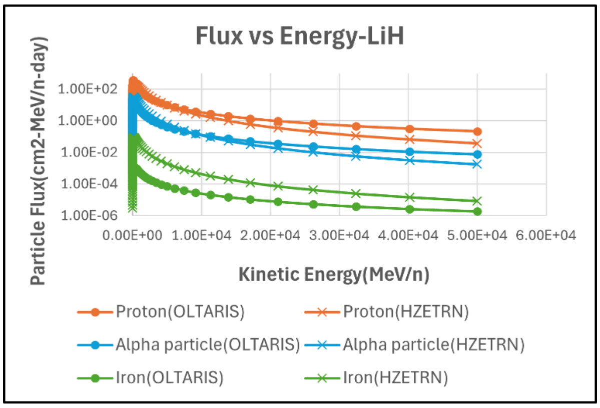

Fig. 5. Flux vs energy of 15 g/cm^2 lithium hydride using HZETRN and OLTARIS.

The relative values of particle flux for proton, alpha particle, and iron correspond to their abundance in the GCR spectrum. At higher energies, the particle flux for each particle reduces. Flux after transport obtained from OLTARIS is higher for proton and alpha particles and is lesser for iron when compared to the values from HZETRN.

3.5 Comparison of Dose Equivalent for Multi-layered Shields

A multi-layered semi-infinite slab of 15 g/cm^2, which consists of three layers of 5 g/cm^2 each is created using polyethylene and lithium hydride. The dose equivalent is calculated for all possible combinations of such a shield and is compared with that of 15 g/cm^2 LiH slab and 15 g/cm^2 polyethylene slab. The results of dose equivalent from OLTARIS and HZETRN are compared and shown in Fig. 6.

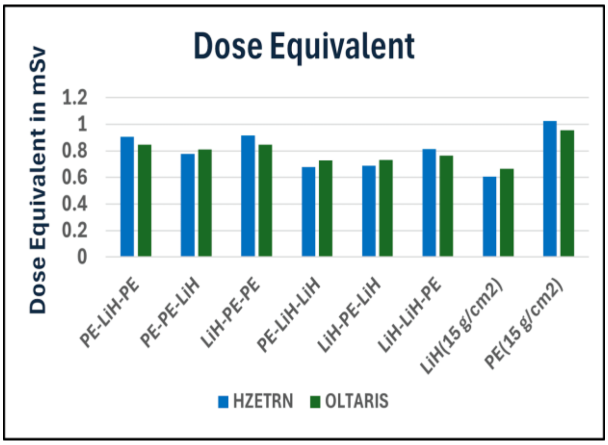

Fig. 6. Dose equivalent of different combinations of a multi-layered shield using polyethylene and lithium hydride.

The results show that the dose equivalent not only depends on the material composition of the shield but also the relative position of the materials. LiH seems to be more effective when placed in the innermost layer than when it is placed in the middle or outer layer. The dose equivalent values from HZETRN and OLTARIS are in agreement. The average difference between both sets of results is 0.0537mSv. It is noteworthy that there is only a little difference in dose equivalent between the 15 g/cm^2 LiH slab and PE-LiH-LiH combination. On comparing the results from multi-layered shields of this work with the previous work [13] where aluminium was used, we observed that a multi-layered shield with polyethylene gives a lesser dose equivalent and it is more feasible as it is lightweight shielding material for practical application in space.

3.6 Variation of Dose Equivalent with Depth Inside the Multi-layered Shields

From section 3.5, it is observed that the dose equivalent depends on the order of different shielding layers inside the radiation shield. Therefore, it is necessary to investigate the variation in dose equivalent with depth inside the shield. Let us take the cases of two shields with the same material composition: PE-LiH-LiH and LiH-LiH-PE (two LiH layers and one PE layer). The multi-layered shields consist of three layers of 5 g/cm^2 each, the total thickness of the shield being 15 g/cm^2. The variation of dose equivalent with depth of these two shields is computed and is shown in Fig. 7.

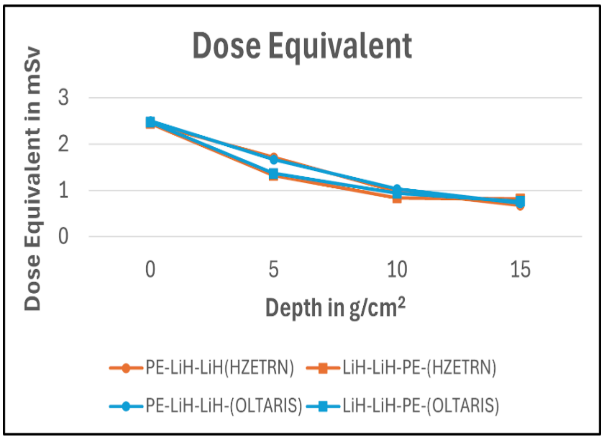

Fig. 7. Dose equivalent vs depth for PE-LiH-LiH and LiH-LiH-PE combinations using OLTARIS and HZETRN.

It can be seen that maximum dose reduction is achieved in the outermost layer. Polyethylene on the inner layer does not contribute to the dose reduction as when it is placed on the outer layer. The results from both sources align with this observation.

4. CONCLUSION

In this study, we investigated the shielding effectiveness of various metal hydrides based on their hydrogen storage capacity. The dose equivalent variation with shield thickness was analyzed, along with particle-wise dose contributions. All tested hydrides outperformed conventional materials like aluminum and polyethylene, with lithium hydride (LiH) emerging as the most effective. Further, a multi-layered shield combining LiH with polyethylene was evaluated, showing that an outer polyethylene layer improves the structural stability of the radiation shield without affecting the dose equivalent significantly. Particle flux after transport through 15 g/cm² of LiH was also examined. The variation of dose equivalent with depth inside the optimal combination of multi-layered structures was also studied. This novel study is important as it gives information on how the radiation from different particles interacts while passing through the shielding material and it was not done in the previous work [13]. The results from HZETRN and OLTARIS showed strong agreement, with a maximum discrepancy of 0.07 mSv. These findings highlight the potential of LiH-based shielding in space applications, offering an effective balance between radiation protection and structural stability.

5. FUTURE PERSPECTIVES

This study has demonstrated the radiation shielding effectiveness of multi-layered shields constructed from polyethylene and lithium hydride. The outcome of the simulation studies will be useful as an input for fabricating radiation shields for space applications. However, significant opportunities remain to enhance the shielding performance of polymer-based materials. One promising direction is the integration of various nanofillers into polymer matrices [14], which could improve material properties and enhance radiation attenuation. Additionally, further investigation into a broader range of hydride materials may lead to the discovery of novel compounds with superior dose-reduction capabilities.

Another emerging area of research is the development of hybrid methods [15] that integrate passive and active shielding techniques. These approaches aim to combine the material-based shielding of passive systems with the dynamic capabilities of active shielding technologies, such as magnetic or electric fields, to achieve more effective and versatile radiation protection. Together, these advancements could revolutionize shielding strategies, offering lightweight, efficient, and adaptable solutions for a variety of applications.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENTS

We thank MNIT Jaipur for supporting this research work. We are also thankful for the OLTARIS and HZETRN transport codes provided by NASA.

REFERENCES

[1] G. A. Nelson, “Space radiation and human exposures, A primer,” *Radiation Research*, vol. 185, no. 4, pp. 349–358, 2016, https://doi.org/10.1667/RR14311.1.

[2] P. Spillantini *et al.*, “Shielding from cosmic radiation for interplanetary missions: Active and passive methods,” *Radiation Measurements*, vol. 42, no. 1, pp. 14-23, 2007, https://doi.org/10.1016/j.radmeas.2006.04.028.

[3] L. W. Townsend, “Overview of active methods for shielding spacecraft from energetic space radiation,” *Physica Medica*, vol. 17, pp. 84-85, 2001.

[4] J. W. Wilson *et al.*, “HZETRN: description of a free-space ion and nucleon transport and shielding computer program,” NASA, Tech. Paper 349, 1995.

[5] NASA. “OLTARIS” (18/02/2025). [Online]. Available: https://oltaris.larc.nasa.gov/

[6] T. C. Slaba, A. M. McMullen, S. A. Thibeault, C. A. Sandridge, M. S. Clowdsley, and S. R. Blattnig, “OLTARIS: An efficient web-based tool for analyzing materials exposed to space radiation,” *Nanophotonics and Macrophotonics for Space Environments V*, vol. 8164, 2011, Art. No. 81640G, https://doi.org/10.1117/12.898960.

[7] J. H. Cha, S. K. Sarath Kumar, C. G. Kim, J. E. Noh, J. S. Choi, and Y. Kim, “Ultra-high-molecular-weight-polyethylene/hydrogen-rich benzoxazine composite with improved interlaminar shear strength for cosmic radiation shielding and space environment applications,” *Composite Structures*, vol. 300, 2022, Art. no. 116157, https://doi.org/10.1016/j.compstruct.2022.116157.

[8] B. Sakintuna, F. Lamari-Darkrim, and M. Hirscher, “Metal hydride materials for solid hydrogen storage: A review,” *International Journal of Hydrogen Energy*, vol. 32, no. 9, 2007, pp. 1121-1140, 3199, https://doi.org/10.1016/j.ijhydene.2006.11.022.

[9] W. Atwell, K. Rojdev, D. Liang, and M. Hill, “Metal hydrides, MOFs, and Carbon composites as space radiation shielding mitigators,” in *44th International Conference on Environmental Systems*, Tucson, Arizona, USA, 2014.

[10] A. M. Osman, “Analysis of radiation shielding effectiveness of hydride and borohydride metals for nuclear industry,” *International Journal of Advanced Nuclear Reactor Design and*

Technology, vol. 5, no. 1, pp. 30-43, 2023, https://doi.org/10.1016/j.jandt.2023.04.001.

[11] P. M. O'Neill, S. Golge, and T. C. Slaba, "Badhwar-O'Neill 2014 galactic cosmic ray flux model description," NASA, TP-2015-218569, 2015.

[12] A. V. Sannikov and E. N. Savitskaya, "Ambient dose equivalent conversion factors for high energy neutrons based on the icrp 60 recommendations," *Radiation Protection Dosimetry*, vol. 70, no. 1-4, pp. 383–386, 1997, https://doi.org/10.1093/oxfordjournals.rpd.a031982.

[13] A. Gohel and R. Makwana, "Multi-layered shielding materials for high energy space radiation," *Radiation Physics and Chemistry*, vol. 197, 2022, Art. no. 110131, https://doi.org/10.1016/j.radphyschem.2022.110131.

[14] E. Toto, L. Lambertini, S. Laurenzi, and M. Gabriella Santonicola, "Recent advances and challenges in polymer-based materials for space radiation shielding," *Polymers*, vol. 16, no. 3, 2024, Art. no. 382, https://doi.org/10.3390/polym16030382.

[15] R. P. Chowdhury, L. A. Stegeman, M. L. Lund, D. Fry, S. Madzunkov, and A. A. Bahadori, "Hybrid methods of radiation shielding against deep-space radiation," *Life Sciences in Space Research*, vol. 38, pp. 67-78, 2023, https://doi.org/10.1016/j.lssr.2023.04.004.