Spacecraft Shielding Design and Protection Methods

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Abstract

Deep space missions need spacecraft shields to protect sophisticated instruments and humans from contrary impacts caused by the space radiation environment, predominantly Galactic Cosmic Rays (GCR), Solar Particle Events (SPE) and trapped radiation. The poster presents a comprehensive analysis of the radiation hazards to humans in the space due to these radiations. Several ways to shield the spaceship from these radiations are introduced, and the most effective method of shielding is chosen based on the various parameters. Each shielding method is selected after thoroughly studying the other candidates in order to make a safe journey to Mars. Space radiation can cause acute radiation syndromes; therefore, it is essential to not only prepare for the physical shielding but also to prepare for the optimal shielding in terms of medical countermeasure. Various parameters have been taken into consideration in order to find best medical countermeasures such as ground-based in vitro pre-flight screening of the candidates, use of Vitamin C to reduce the exposure effect and to cover the essential parts of the body for least radiation exposure

Introduction

The radiation environment of space consists of electromagnetic radiation and charged particles that have been accelerated to high velocities. The charged particles come from three primary sources, Solar Particle Events (SPE), Galactic Cosmic Rays (GCR) and Trapped Radiation. GCR is a constant source of high charge and energy (HZE). It has been reported that long-term exposure to high levels of space radiation can irremediably damage to deoxyribonucleic acid (DNA) and significantly increase the risk of cancer in astronauts [1]. Moreover, degenerative tissue effects, damages in the central nervous system (CNS) and acute radiation syndrome (ARS) are among the other possible space radiation risks. In order to complete a successful mission in space, exposure of radiation must be less than 3% lifetime risk of exposure-induced death (REID) for cancer [5]. Passive shielding is effective at stopping lower-energy particles. It can help protect against high energy particles, but to do so completely is costly due to enormous mass requirements. Thus, active shielding is also taken into account to provide a required shielding while maintaining the payload of the spacecraft.

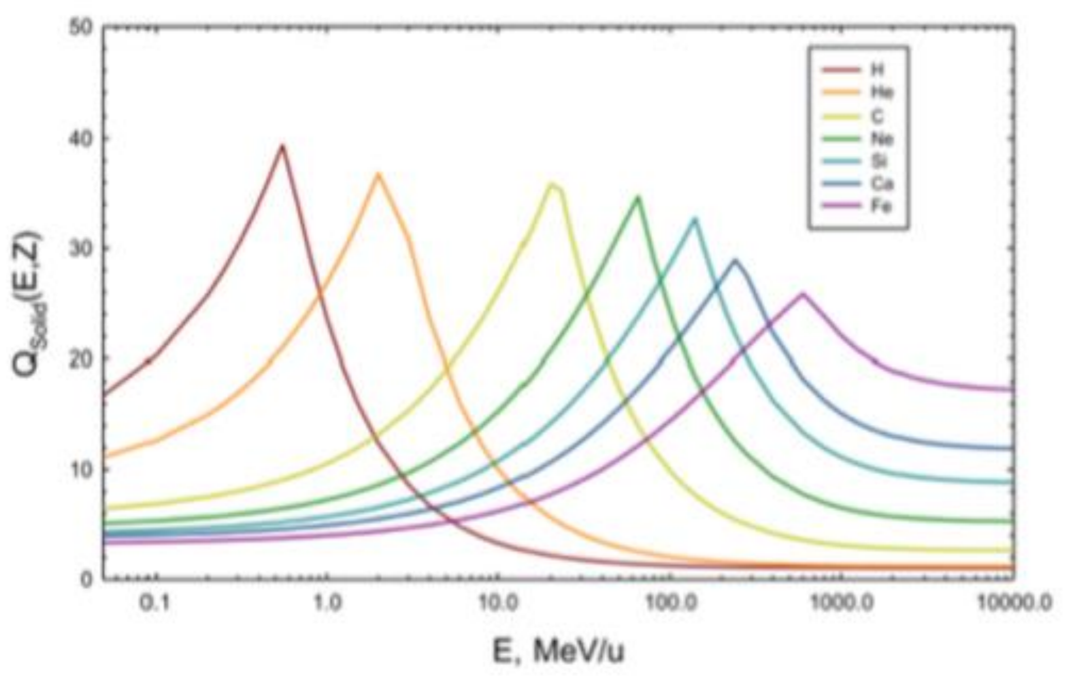

Figure 1. Taken from [2], This graph shows the relative harmfulness of each GCR particle by type and energy. Q_{solid} refers to a quality factor corresponding to the increased cancer risk of the associated particle energy.

Methods of Shielding

1. **Passive Shielding:**
Engineering analyses have been done to determine which material would work best for passive radiation shielding, and some in-flight measurements have been taken behind various shielding materials.

2. Active Shielding:
Active radiation shields actively generated magnetic fields or sustained electromagnetic fields. Magnetic and electric fields can affect the trajectory of charged particles govern with Lorentz force,.

$$F = qE + q(V \times B)$$

3. Biological Protection:
In addition to shielding from the radiation, some biological protection is very much required for a safe journey to outer space. Among the main concerns which should be addressed before any long-term manned deep space mission, are exposed to high levels of space radiation and microgravity.

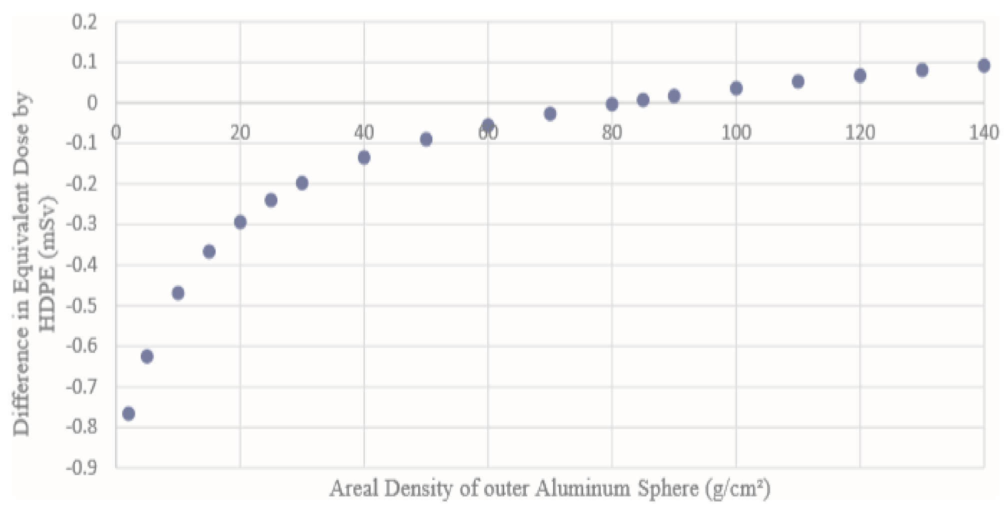

Fig. 2 The difference in effective dose caused by the addition of 5 g/cm^2 HDPE with an Aluminium sphere of varying thickness. Radiation incident on the spherical segment of Aluminium of varying thickness before 5g/ cm^2 HDPE. The HDPE layer increases an effective dose with 85 g/cm^2. (Adapted from [4])

Table 1. Extra weight spacecraft has to carry of each type of shielding

Shielding	Total weight
Active Shielding	147 tons
Passive Shielding	519.3 tons
Active + Passive Shielding	334.26 tons

Results

The extra weight spacecraft has to carry for shielding the 1000 cubic meters of habitable volume from radiation is about 334.26 tons or 303235.571 Kg. Shape of the probe is taken to be cylindrical to support the toroid, in addition to that curved shape reduces the radiation exposure to some extend.

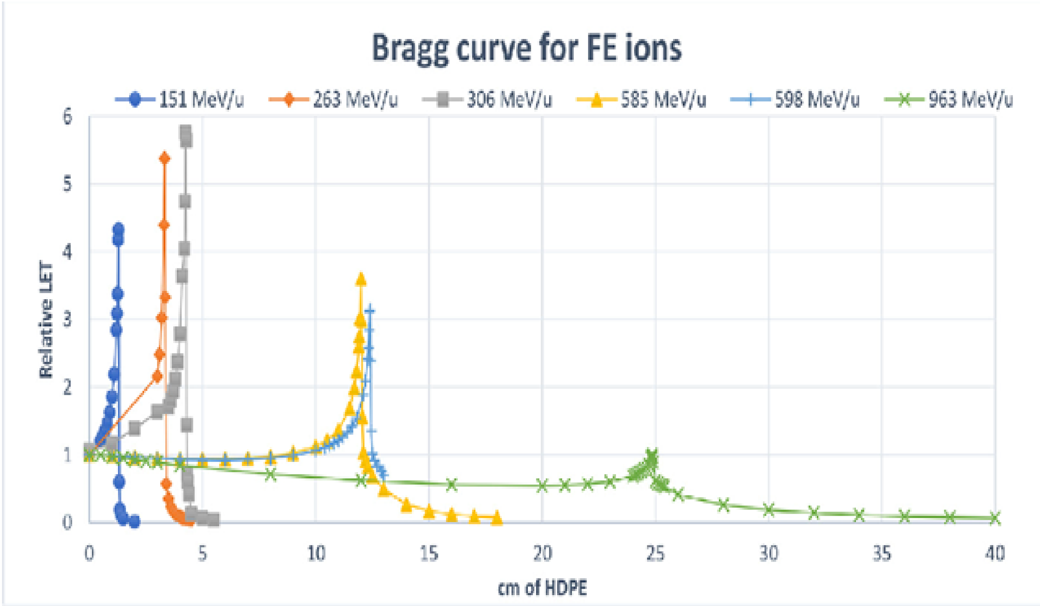

Fig. 2. The relative linear energy transfer of a beam of iron ions travelling in HDPE. The energy loss rate declines due to the creation of secondary, lighter ions caused by interactions of the iron ion beam with the target material's nuclei. (Experimental Data From) https://www.bnl.gov/nsrl/userguide/bragg-curves-and-peaks.php retrieved on Oct 21, 2016).

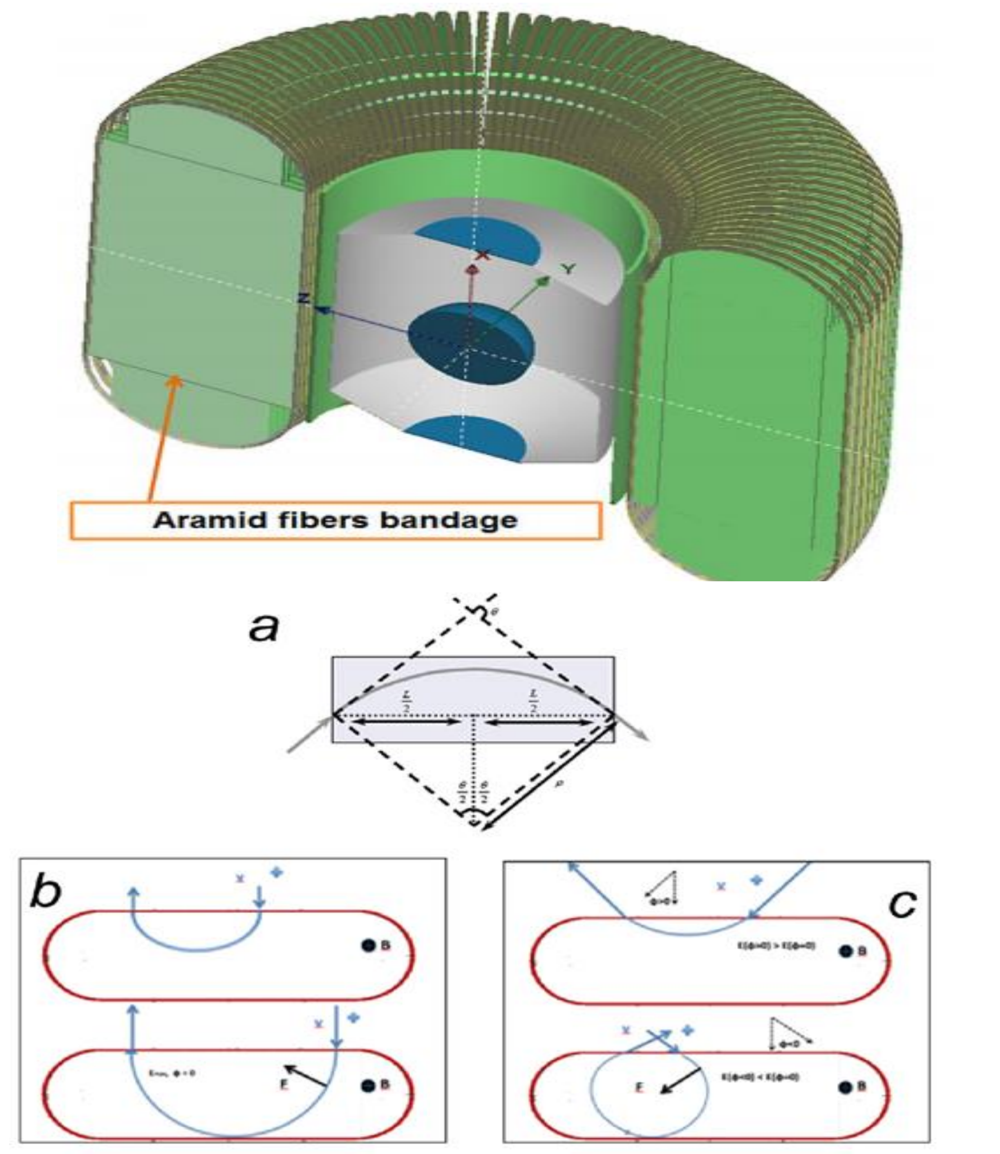

Fig. 9. Taken from [2]. The geometrical shape of the Toroid around the Spacecraft

Discussion

Various computations and experiments were performed in order to select the materials of each segment of Magnetic Toroid [3], and the best result was obtained by the materials shown in Table 2.

Table 2. Configuration of the materials used in active shielding

Parameters	Result
Winding Cable Material	57% Al, 9% Mg , 23% Ti, 11%
Length	10 m
Former	Aluminium
Toroid internal radius	2.80 m
Toroid external radius	8.75 m
Bending Power	11.9 Tm
Structure Cylinder Material	B_4C/Al
Total Mass	147 tons

Conclusions

Thorough analysis done in this poster suggests that best shielding can be provided with the combination of active shielding (By Toroidal magnetic fields) and passive shielding (multi-layering radiation shielding) from Fig. 2 we have concluded that best protection will be by adding 5g/cm^2 layer of HDPE inside a large spherical aluminium spacecraft with aluminium walls that are 80g/cm^2 would cause an overall increase in equivalent shielding. Accounting both the shielding which will be used the spacecraft has to carry extra 334.26 ton of weight in order to protect 1000 cubic meters of the habitable volume. In addition to physical protection, different medical countermeasures are required. Effective methods of biological protection, such as ground-based in vitro pre-flight screening of candidates for evaluation of the extent of their adaptive response can reduce the risk of exposure to relatively high levels of radiation in a human-crewed deep space mission. Rather than covering the whole body with the suit, covering the pelvic area with a suitable radiation shielding suit (ex. Water) will reduce the threat of radiation exposure.

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