Studying the Effects of Multi-Layer Shielding in Reducing Space Radiations Exposure of Human and Electrical Components in Space Missions

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ABSTRACT

Protection of astronauts and electronic components in satellites and spacecraft against space rays is one of the most important primary requirements in space missions. In this work, the effect of three materials, aluminum, as the most common material, polyethylene and a graded-z structure, in the protection of space radiations has been evaluated. The calculations of the dose caused by these radiations on the human body and a silicon piece have been carried out by MCNPX Monte Carlo code. The dose caused by cosmic rays has been calculated after applying shields of aluminum, graded-z structure and polyethylene. The results showed that by using polyethylene and about 4.4% increase in weight compared to the aluminum shield, it is possible to reduce the dose caused by photons by more than 50% in the human body and 30% in silicon parts, and the dose caused by protons by about 30%. It cut both for astronauts and electronic components. Graded-z shielding performed very well in the dose attenuation caused by photons, but appeared ineffective in the dose attenuation caused by protons.

Keywords: Biological damage, Space radiation, MCNPX, Multi-Layer shield, Graded-Z structure

1. Introduction

The orbits of satellites are divided into five categories based on their altitude: (1) Low Earth Orbit (LEO), (2) Medium Earth Orbit (MEO), (3) Geosynchronous Equatorial Orbit (GEO), (4) High Earth Orbit (HEO) and (5) the Polar Orbit [1].

Current space programs are shifting toward planetary exploration, and especially human missions to the Moon and Mars. Astronauts are exposed to energetic protons and particles, as well as secondary radiation including neutrons and recoiled nuclei caused by nuclear interactions in the spacecraft or tissue. Radiation mitigation methods include: (1) increasing the distance from the radiation source, (2) reducing the radiation time and (3) shielding. Since space radiation is spread in all directions, the distance factor is not applicable in the space environment. The time of space missions is increasing day by day. The only accepted solution is to use shielding, although it is very expensive considering the current mass limits [2].

The multi-layer shielding method works well in both proton and electron environments. The design of such shielding usually includes three layers. The first layer is a low-z material to minimize induced X-ray. The second layer is a material with a higher atomic number to maximize the attenuation of the X-rays produced in the first layer. In the third layer, a material with a low atomic number is used to weaken the secondary electrons produced by secondary X-rays [3].

In this work, the effect of using shielding of polyethylene and a graded-z structure on the deposited dose due to space radiation in the body of astronauts and silicon electronic components is investigated.

2. Methodology

The energy and flux of space radiation on Voskhod 1 spacecraft, which belonged to Russia and had a crew, for a 5-year mission duration was calculated by the Space Environment Information System (SPENVIS) [4] in order to investigate the effect of space radiation on the body of astronauts and electronic components.

The energy and fluence of the mission defined by the SPENVIS code are calculated and shown in Figure 1. The calculation results of OMERE software is also given in this figure to compare and validate the considered space radiation source. As can be seen, these data are almost identical and have a maximum relative difference of 3.6%.

Figure 1. Energy and fluence of the mission’s radiation source
Simulations of the human body, silicon component and radiation shielding are performed by MCNPX code [5] and is shown in Figure 2. According to the data, the maximum energy of the charged particles is 500 MeV, which is related to solar protons. According to SRIM calculations, the range of protons with such energy in aluminum, the common material used in the structure of satellites and spacecraft, is about 55 cm. Using this thickness of aluminum is an impossible affair from the weight budget point of view.

The wall thickness of satellites and spacecrafts in Leo orbit is usually around 7.5 mm of aluminum. Therefore, in this work, a suitable shielding equivalent to 7.5 mm aluminum has been introduced and examined.

3. Results and Discussion

In Figure 3, the effect of a graded-z shield, the outermost layer of which is 5 mm polyethylene, the middle layer is 2.5 mm carbon and the innermost layer is 2 mm aluminum, and the polyethylene shield, as the relative dose in the human body, is compared to the aluminum shield. As can be seen, both structures reduce the contribution of electron dose factor to the absorbed dose by completely weakening the trapped electrons. The polyethylene shielding reduces both proton and photon doses of trapped protons to about 75% and 45%, respectively, and also reduces the dose caused by protons and photons of solar protons to 70% and zero in comparison to aluminum shielding. The graded-z shielding is also more successful than aluminum in shielding the photon and electron parts by reducing the dose caused by photons of solar protons and trapped protons by about 5% and 45%, respectively. However, regarding the dose caused by the protons related to the trapped proton sources and solar protons, with the increasing the deposited dose to the astronaut's body by a factor of 110% compared to the aluminum shield, one can say it does not perform well.

The relative absorbed dose in a silicon component is also investigated for both polyethylene and graded-z shielding and is compared to aluminum shield in Figure 4. As can be seen, the dose caused by electrons can be reduced to zero and the dose caused by photons and protons can be reduced to about 70% by using polyethylene shielding. Using the graded-z shielding, the dose caused by photons is reduced by about 30% for trapped protons and 5% for solar protons compared to aluminum shielding, which will improve the total ionizing dose, but for protons, the dose increases about 110%, which can have adverse effects due to relatively high LET of protons in silicon.

4. Conclusions

The results of this work showed that with almost the same weight, about 4.4% increase in weight compared to the Al shield, by using the polyethylene shield, the dose caused by photons can be decreased by more than 50% in the human body and 30% in silicon components, and the dose caused by protons is reduced by about 30% for both astronauts and electronic components. If it is necessary to use an aluminum box, the introduced multi-layer shielding can reduce the dose caused by photons by more than 50% in the astronaut's body and by more than 70% in the silicon part compared to the case of Al shielding. But the graded-z shield will increase the dose caused by protons by about 110% in the astronaut's body and the silicon component compared to the Al shield.

5. References