

Analyses of Several Space Radiation-Mitigating Materials: Computational and Experimental Results

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ABSTRACT

Long-term exposure to the space radiation environment poses deleterious effects to both humans and space systems. The major sources of the radiation effects come from high energy galactic cosmic radiation and solar proton events. In this paper we investigate the radiation-mitigation properties of several shielding materials for possible use in spacecraft design, surface habitats, surface rovers, spacesuits, and temporary shelters. A discussion of the space radiation environment is presented in detail. Parametric radiation shielding analyses are presented using the NASA HZETRN 2005 code and are compared with ground-based experimental test results using the Loma Linda University Proton Therapy facility.

INTRODUCTION

The application of light weight, cost effective, radiation-mitigating materials for use in crew cabins and lunar surface habitats is an on-going research effort. In this paper we present the preliminary results of three materials that might be considered for such use that were tested at the Loma Linda University Medical Center using a high energy proton beam. In addition, we also present some computational results for these three materials using an extremely large solar proton event as the source term coupled with the NASA Langley (LaRC) HZETRN 2005 code.

THE SPACE RADIATION ENVIRONMENT

GALACTIC COSMIC RADIATION (GCR) – The GCR environment consists of high energy stripped nuclei ranging from hydrogen (proton) to uranium.

These very energetic particles are prevalent throughout the solar system and are thought to be produced during super novae. Although their fluences are low and they vary with the so-called 11 year solar cycle, these energetic particles have the capability to penetrate very large mass thicknesses. The radiation biology community is concerned with these types of particles due to their ability to produce single- and double-strand breaks in the DNA and the induction of cancer.

Figure 1 /1/ shows the differential spectra for the GCR environment exhibiting several nuclei species. Typically, one considers solar minimum (MIN) and solar maximum (MAX) conditions when assessing the radiation exposure and effects from the GCR environment. During solar minimum it is found that the GCR fluxes are highest due to the fact that the solar magnetic field is “relaxed” or weakened and has less of an effect on the GCR environment. During solar maximum (MAX) just the opposite is true.

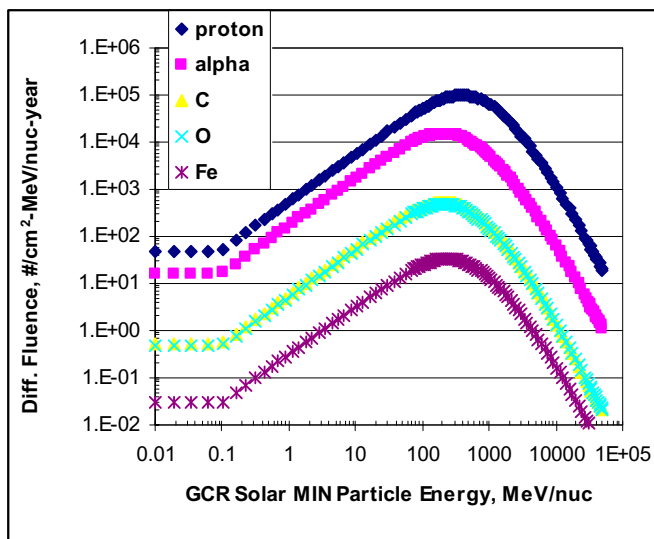


Figure 1: The differential spectra for the GCR environment for several nuclei species.

SOLAR PROTON EVENT (SPE) – As mentioned above, the sun goes through what is known as a solar cycle and is typically 11 years in length. Sunspots are the prominent visible features on the observable solar disk. During solar minimum few if any sunspots are present. It has only been within ~70 years that it was determined /2/ the sun was the source of sporadic, but sometimes very intense solar

particle emission. These events are called SPEs (solar proton events) and are usually associated with CMEs (coronal mass ejections). Some of these events are energetic enough to penetrate the earth’s magnetic field, interact via nuclear reactions with the earth’s atmosphere, and produce secondary particles (neutrons, for one) that can be measured at the surface, especially at high latitudes.

MATERIALS TESTING AT LOMA LINDA UNIVERSITY MEDICAL CENTER (LLUMC)

Principal investigator, Dr. Richard Wilkins and co-PI, Dr. Brad Gersey, completed a proton radiation shielding study for three commercial materials. Two of the materials were polyethylene composites, one doped with 5.5% boron and the other with 7.5% lithium. Both of these were manufactured by Shieldwerx Inc., Rio Rancho, NM. The third material is a 60% beryllium – 40% aluminum alloy manufactured by Brush Wellman, Inc., Warren, MI. Three sets of material sample coupons, Figures 2-4, were acquired for the shielding experiments; each set was made to allow stacks of the materials with density thicknesses of approximately 1, 5, 10, 15, and 20 g/cm², typical values for spacecraft structures. A tissue equivalent proportional counter (TEPC) was used to measure adsorbed dose and dose equivalent from a 190 MeV proton beam impinging on the shield samples, an energy representative of solar protons.

During three visits to the Loma Linda University Medical Center (LLUMC) proton synchrotron, experiments using the five thicknesses of the commercial shield samples, as well as equivalent thicknesses of neat polyethylene and aluminum (for comparison to common spacecraft materials), were performed. Preliminary data on thin samples of the boron- and lithium-doped polyethylene composites show shielding performance similar to comparable thicknesses of neat polyethylene and aluminum, which is an expected result. Any significant differences that may exist are expected to be manifested in the data from experiments with thicker samples. A complete analysis of the data for all samples tested will be included in a final report.



Figure 2: Sample coupons of lithium doped polyethylene (92.5% polyethylene, 7.5% lithium). The samples had dimensions of 15.24 cm x 15.24 cm (6" x 6") and the blocks were of various thicknesses. There are a total of ten coupons for this type of material. Combinations of the various thicknesses of this and the other samples described in Figs. 3 and 4 were used to achieve the desired density thickness for a particular shielding experimental run.

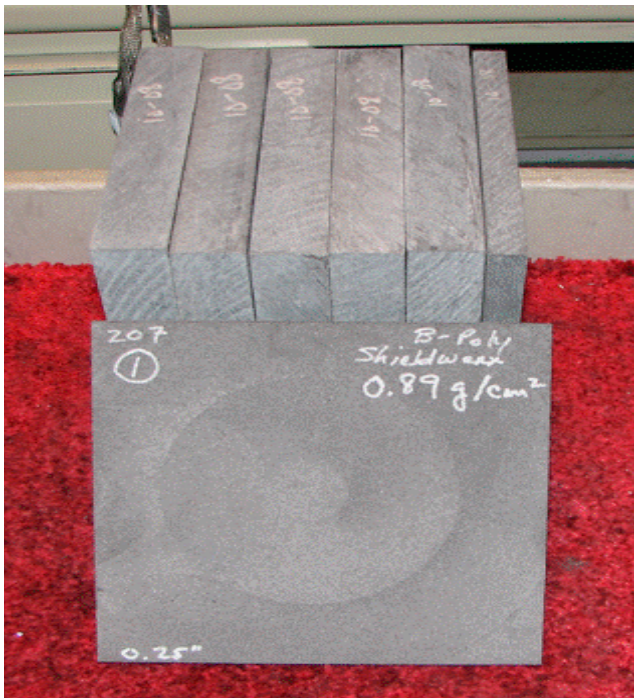


Figure 3: Sample coupons of boron doped polyethylene (94.5% polyethylene, 5.5% boron).

These samples are also 6" x 6". There are a total of seven coupons.

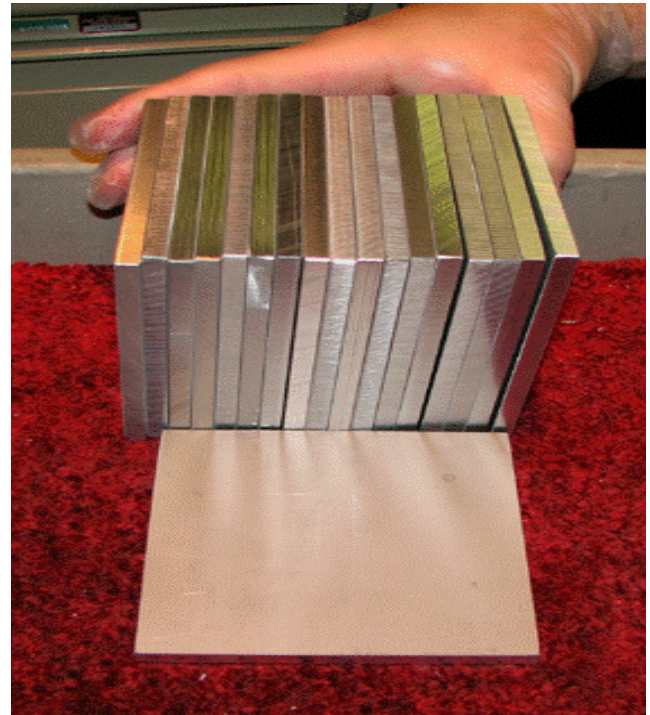


Figure 4: Sample coupons of the Be-Al alloy (60% Be, 40% Al). The sample coupons had the dimensions of 10.16 cm x 10.16 cm x 0.635 cm (4" x 4" x 0.25"). There are a total of 18 coupons.

Figs.2-4 show the three test materials: PE (7.5% Li), PE (5.5% B), and the Be-Al alloy, respectively.

Figure 5 shows a test being set up in the LLUMC laboratory.