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Radiation Protection Using Martian Surface Materials in Human Exploration of Mars

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Abstract

To develop materials for shielding astronauts from the hazards of GCR, natural Martian surface materials are considered for their potential as radiation shielding for manned Mars missions. The modified radiation fluences behind various kinds of Martian rocks and regolith are determined by solving the Boltzmann equation using NASA Langley's HZETRN code along with the 1977 Solar Minimum galactic cosmic ray environmental model. To develop structural shielding composite materials for Martian surface habitats, theoretical predictions of the shielding properties of Martian regolith/polyimide composites has been computed to assess their shielding effectiveness. Adding high-performance polymer binders to Martian regolith to enhance structural properties also enhances the shielding properties of these composites because of the added hydrogenous constituents. Heavy ion beam testing of regolith simulant/polyimide composites is planned to validate this prediction. Characterization and proton beam tests are performed to measure structural properties and to compare the shielding effects on microelectronic devices, respectively.

KEYWORDS: Human exploration, galactic cosmic radiation, Martian regolith, polyimides.

1. Introduction

A surface habitat is critical for providing a safe haven for human explorers of Mars from galactic cosmic rays (GCR), solar particle events (SPE), and global dust storms [1]. In order to maximize the safety of the explorers and minimize the payload weight from Earth to Mars, the use of Martian surface materials has been studied for the issues associated with shielding humans from the hazards of space radiation [2]. The radiation attenuation characteristics of GCR behind each material are assessed theoretically by using HZETRN [3]. Because the energy requirement for utilizing rock is high compared with that for regolith [4] and hydrogenous material is known to be a good shielding material [5], model structural shielding composites of Martian regolith with a polyimide, which has hydrogen atoms, were fabricated on Earth for processing development and laboratory testing. These targets are tested for radiation protection efficiency of microelectronics from proton beams, and will be tested in ground-based facilities for the validation of theoretical protection predictions for GCR. Preliminary characterization is also made for the composites.

2. Shield effectiveness of Martian surface materials from GCR exposure

Martian regolith, which is merely gathered on surface, was considered to be a less expensive alternative to other Martian surface materials [2]. Because employing a polymeric binder can enhance the shielding effectiveness of regolith, a Langley-developed polyimide was selected which can be manufactured from the methane fuel plant to be placed on the Martian surface [2]. Although the absolute human risk within the habitat material is not known, the theoretical results of two risk models shown in the Figure 1 do provide some indication of the response of living tissue behind the materials. It illustrates that increasing the concentration of lighter atoms is effective for developing shield materials against GCR.

3. Fabrication of Targets and Laboratory Testing

Two composite targets with randomly dispersed simulated regolith in a polyimide (LaRC-SI, Imitec, Inc.) were fabricated by compression molding as described elsewhere [2]. Specimen 101 of 1.89 g/cm^2 thick is a composite of regolith with 40 wt% LaRC-SI. For specimen 102 of 2.01 g/cm^2 thick, the amount of LaRC-SI is decreased to 20 wt% at which the final composite ingot is still well-consolidated with no voids. These targets were irradiated to the monoenergetic 55 MeV proton beams produced at Texas A&M University Cyclotron facility to test the shielding property.

The single event upset in a 4 MB MCM6246-5V SRAM was studied for the two specimens with

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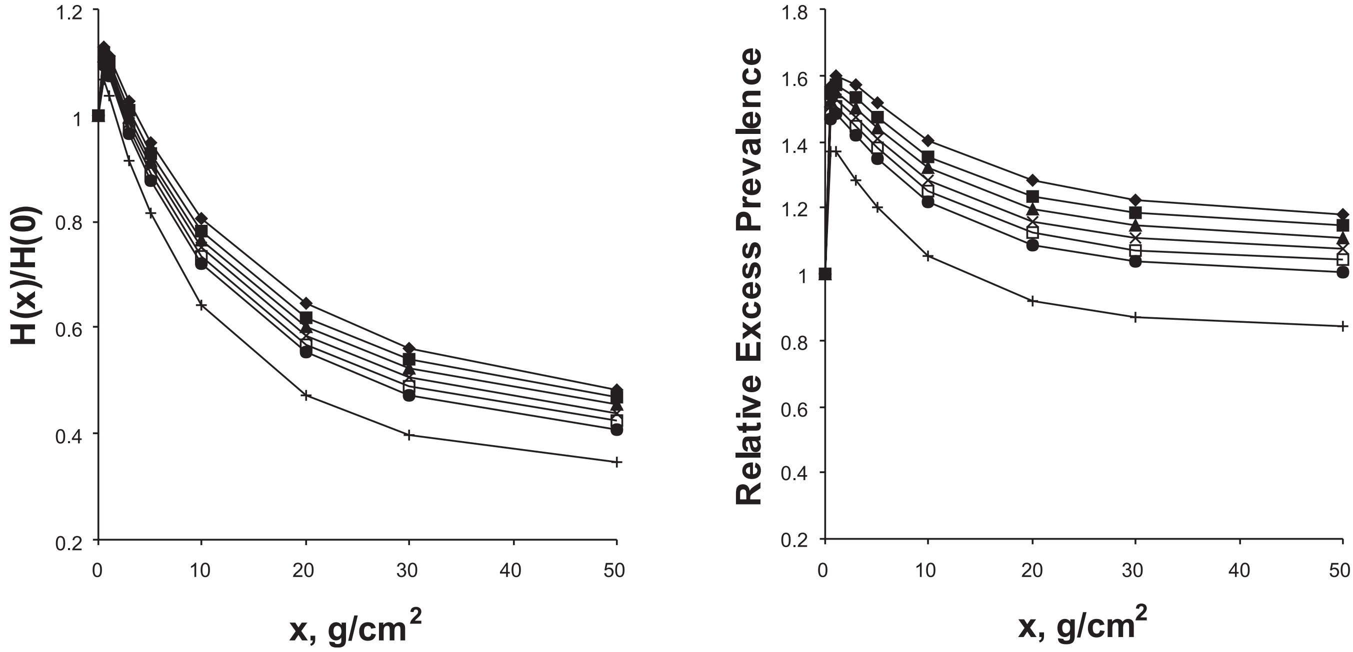

(a) Relative dose equivalent

(b) Relative excess prevalence

Fig. 1 – Attenuation of biological response behind various materials after one year GCR exposure (♦, aluminum; ■, Martian regolith; ▲, Martian regolith/LaRC-SI composite of 90/10 wt%; ×, 80/20 wt% composite; □, 70/30 wt% composite; ●, 60/40 wt% composite; and †, LaRC-SI.)

55MeV proton beams at several fluence levels between 1×10^7 p/cm^2 to 4×10^9 p/cm^2 as shown in Figure 2. As the fluences are increased to 5×10^7 p/cm^2, measurable errors are observed. The results show clearly that specimen 101 with more LaRC-SI is much better than specimen 102 for shielding as the fluence of the beam reaches to 4×10^9/cm^2. It is reasoned that each linear energy transfer (LET) component of a given particle behind specimen 101, which represents radiation quality, is attenuated faster than that behind specimen 102. Therefore, specimen 101 is more effective to shield the SRAM from 55 MeV proton beams. The thick composites with 40 wt% LaRC-SI are also expected to be more effective than those with 20 wt% LaRC-SI to shield other heavier particles and will be investigated further in heavy ion beam experiments.

For the characterization of composites, thermomechanical analysis (TMA) and thermogravimetric analysis (TGA) were used to measure the glass transition temperature (T_g) and mass loss, respectively. The glass transition temperatures measured by TMA are shown in Figure 3 and they indicate that these composites should contain good mechanical properties up to at least 223 °C. The temperatures at 5% mass loss and 10% mass loss measured by TGA in this figure show that mass loss temperatures are increased as the amount of LaRC-SI decreases due to the smaller erosion rate of the polymer in the composites. These data indicate that the composites are reasonably stable at high temperature.

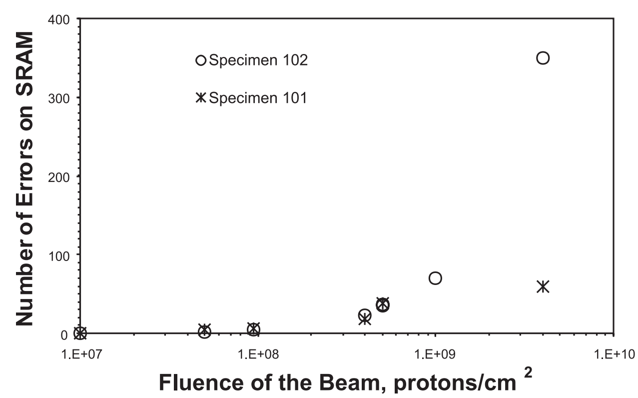

Fig. 2 – Single event upsets on Motorola MCM6246-5V SRAM from 55-MeV proton beams behind regolith/LaRC-SI microcomposite shields.

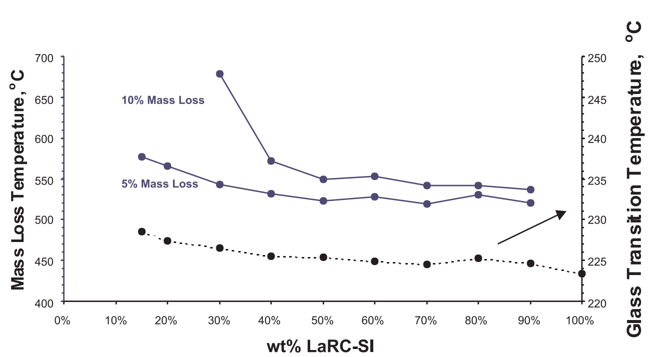

Fig. 3 – TGA mass loss and TMA glass transition temperature for regolith/LaRC-SI microcomposite shields.

4. Discussion and Concluding Remarks

The selected key issue is relating to the protection of humans from the hazards of ionizing radiation from GCR while on the Martian surface. It is clear that Martian regolith, although abundantly available on the Martian surface, is not an ideal shielding material. To develop structural shielding materials, regolith simulant/polyimide composite targets are being fabricated, which will be employed by astronauts on Martian surface when necessary processing equipment and adequate source power are available from propellant manufacture.

From the proton beam irradiation, the regolith composite with 40 wt% LaRC-SI is effective to shield the SRAM and is also expected effective to shield other heavier particles. The current radiation protection predictions will be validated by measuring the transport properties from high-energy heavy ion beam tests. The physical and mechanical properties will also be characterized because it is desirable to utilize these materials not only for radiation shielding but also as structural components. The preliminary characterization shows that the composites are reasonably stable at reasonable temperature range.

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