RADIATION TRANSPORT PROPERTIES OF POTENTIAL IN SITU-DEVELOPED REGOLITH-EPOXY MATERIALS FOR MARTIAN HABITATS

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Abstract

Mission crews in space outside the Earth's magnetic field will be exposed to high energy heavy charged particles in the galactic cosmic radiation (GCR). These highly ionizing particles will be a source of radiation risk to crews on extended missions to the Moon and Mars, and the biological effects of and countermeasures to the GCR have to be investigated as part of the planning of exploration-class missions. While it is impractical to shield spacecraft and planetary habitats against the entire GCR spectrum, biological and physical studies indicate that relatively modest amounts of shielding are effective at reducing the radiation dose. However, nuclear fragmentation in the shielding materials produces highly penetrating secondary particles, which complicates the problem: in some cases, some shielding is worse than none at all. Therefore the radiation transport properties of potential shielding materials need to be carefully investigated. One intriguing option for a Mars mission is the use of material from the Martian surface, in combination with chemicals carried from Earth and/or fabricated from elements found in the Martian atmosphere, to construct crew habitats. We have measured the transmission properties of epoxy-Martian regolith composites with respect to heavy charged particles characteristic of the GCR ions which bombard the Martian surface. The composites were prepared at NASA Langley Research Center using simulated Martian regolith, in the process also evaluating fabrication methods which could lead to technologies for *in situ* fabrication on Mars. Initial evaluation of the radiation shielding properties is made using radiation transport models developed at NASA-LaRC, and the results of these calculations are used to select the composites with the most favorable radiation transmission properties. These candidates are then evaluated at particle accelerators which produce beams of heavy charged particles representative in energy and charge of the radiation at the surface of Mars. The ultimate objective is to develop the models into a design tool for use by mission planners, flight surgeons and radiation health specialists.

Introduction

Possible adverse effects on astronaut health from extended exposure to the space radiation environment are a critical issue for the human exploration and development of space. Crews on long-duration missions outside the protective effects of the Earth's magnetic field will be exposed to relatively high numbers of high energy ions (HZE) in the galactic cosmic rays (GCR) (Fig. 1). These ions (Z>1), while small in number compared to the total GCR charged particle flux, can contribute substantially to radiation risk by virtue of their high energy deposition: a single particle traversal can kill, or what can be worse, severely damage a cell, which can lead to cancer (Fig. 2) [1]. Long term effects of GCR HZE particles have been identified by the National Research Council [2] as the principal radiation risk to astronauts on extended stays outside low Earth orbit.

Keywords: radiation protection, GCR, heavy ions, ISRU, Martian regolith

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Future astronauts will spend many months in habitats on the Martian surface. As a material for habitat construction, Martian regolith-epoxy composites offer favorable radiation transmission properties and structural advantages [3,4], and can potentially be fabricated using primarily *in situ* resources from the Martian soil and atmosphere, thus reducing the weight which will have to be carried on the Mars transit vehicle. These potential benefits must be considered in the context of a full mission scenario, including the challenges of transporting the necessary precursor chemicals and equipment to the Martian surface and safely processing the *in situ* resources into usable materials. It is therefore important to establish the radiation transport properties of candidate materials early on, so that if they are sufficiently promising, the necessary trade studies can be carried out. Model calculations and selected experiments at particle accelerators are being used to evaluate the radiation transmission properties of regolith-epoxy composites. The accelerator-based measurements produce detailed data on radiation transport properties of selected materials with respect to significant components of the GCR HZE. These data will be used both to quantify the radiation shielding effectiveness of the candidate materials and to improve the accuracy of the models. Ultimately the models, in combination with data from radiobiological experiments now in progress, will comprise a design tool for use by mission planners, flight surgeons and radiation health specialists.

Methods

The experimental setup is shown in Fig. 3. (For a more detailed description of the experimental methods, see Refs. [5,6]). All detectors were silicon solid state. Particle identification was by energy loss in the silicon. The detectors before the target were used to identify primary beam ions. The detectors after the target recorded charge and energy of surviving primary ions and produced fragments. The downstream detectors subtended small angles around the beam axis, and thus for most events recorded a single primary ion or a small number of fragments at or near the beam velocity. The fragment ΔE spectrum can be converted to a charge distribution by making use of the fact that when all particles are at or near the same velocity, the energy loss of charged particles in this energy range is approximately linear in Z^2. Targets were fabricated at NASA-Langley Research Center by mixing polymer with simulated Martian regolith and de-aerating the mixed powder under vacuum at 71° - 77°C. Measurements are being carried out with heavy ions at the Brookhaven National Laboratory Alternating Gradient Synchrotron (BNL AGS) and the Heavy Ion Medical Accelerator at Chiba, National Institute of Radiological Sciences, Japan (NIRS HIMAC). Data have thus far been taken with the following ions/energies: 1087 MeV/u ^{56}Fe; 600 MeV/u ^{28}Si; 400 MeV/u ^{14}N; 290 and 400 MeV/u ^{12}C.

Results and Discussion

Figures 4 and 5 show some representative results of the nuclear fragmentation measurements for 400 MeV/u carbon ions and 1087 MeV/u iron ions. (Iron is the heaviest ion present in significant numbers in the GCR.) These plots show numbers of recorded fragments as a function of energy deposited in a pair of 3 mm silicon detectors. The abscissa is number of ADC channels, which is readily converted to energy in MeV. Since energy loss is a function of fragment charge and velocity, and since most fragments near the beam axis are at roughly the same velocity, each peak represents a discrete charge state, a single charge in most cases, but some multi-fragment states, as well. These data illustrate the degree to which relatively modest amounts of shielding materials fragment high energy GCR nuclei. Measurements such as these are being used to quantify the effects of various materials and to benchmark and improve the models [7-10].

It is not sufficient, however, to make physical measurements: the biological effects of the entire produced particle spectrum must be taken into account. For example, the produced fragments, while less ionizing and therefore lower dose, are also more penetrating. Systematic accelerator studies of effectiveness of regolith composites as a function of incident particle charge and energy, and material composition and thickness need to be coupled to transport model development and eventually to biological data and models of biological effects, in order to have a tool for selection of composites with the most promising combinations of structural and radiation shielding properties.

Summary and Conclusions

Model calculations and measurements at particle accelerators are being used to evaluate the radiation transmission properties of Martian regolith composites. The accelerator measurements produce detailed data on radiation transport properties of selected materials with respect to significant components of the GCR HZE. Several regolith composites fabricated at NASA-LaRC have been modeled using two different benchmarks of biological effectiveness and then exposed to HZE beams at the BNL AGS and NIRS HIMAC. Nuclear fragmentation spectra have been recorded for charged projectile fragments produced in the forward direction. These data will be used both to quantify the radiation shielding effectiveness of the candidate materials and to improve the accuracy of the models. Ultimately the models, in combination with data from radiobiological experiments now in progress, will comprise a design tool for use by mission planners, flight surgeons and radiation health specialists.

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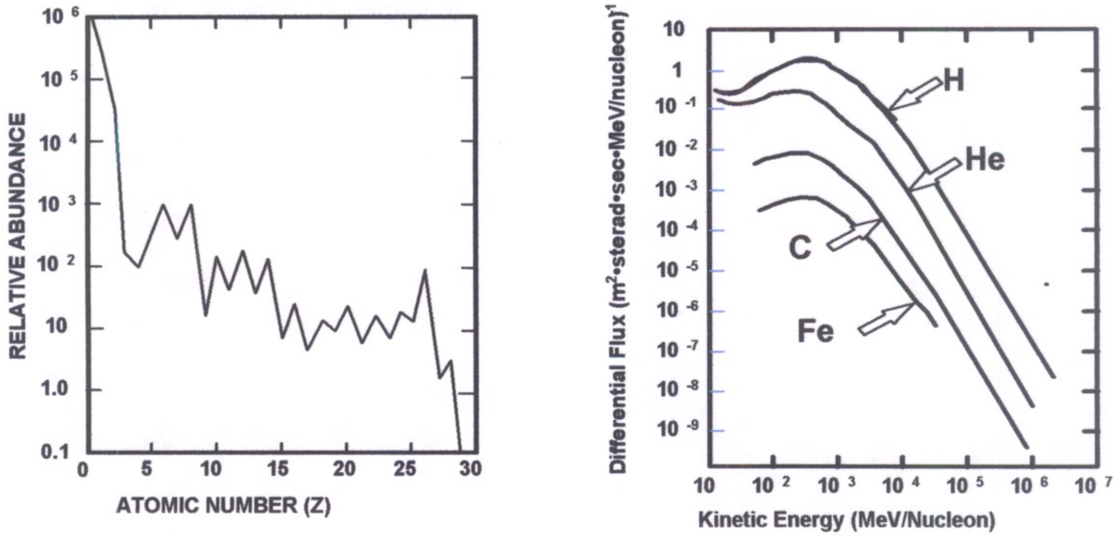

Figure 1. Distribution of GCR particles in atomic number, Z, and energy. The HZE particles relevant for space radiation risk range up to iron (Z = 26) and have energies up to several thousand MeV/nucleon.

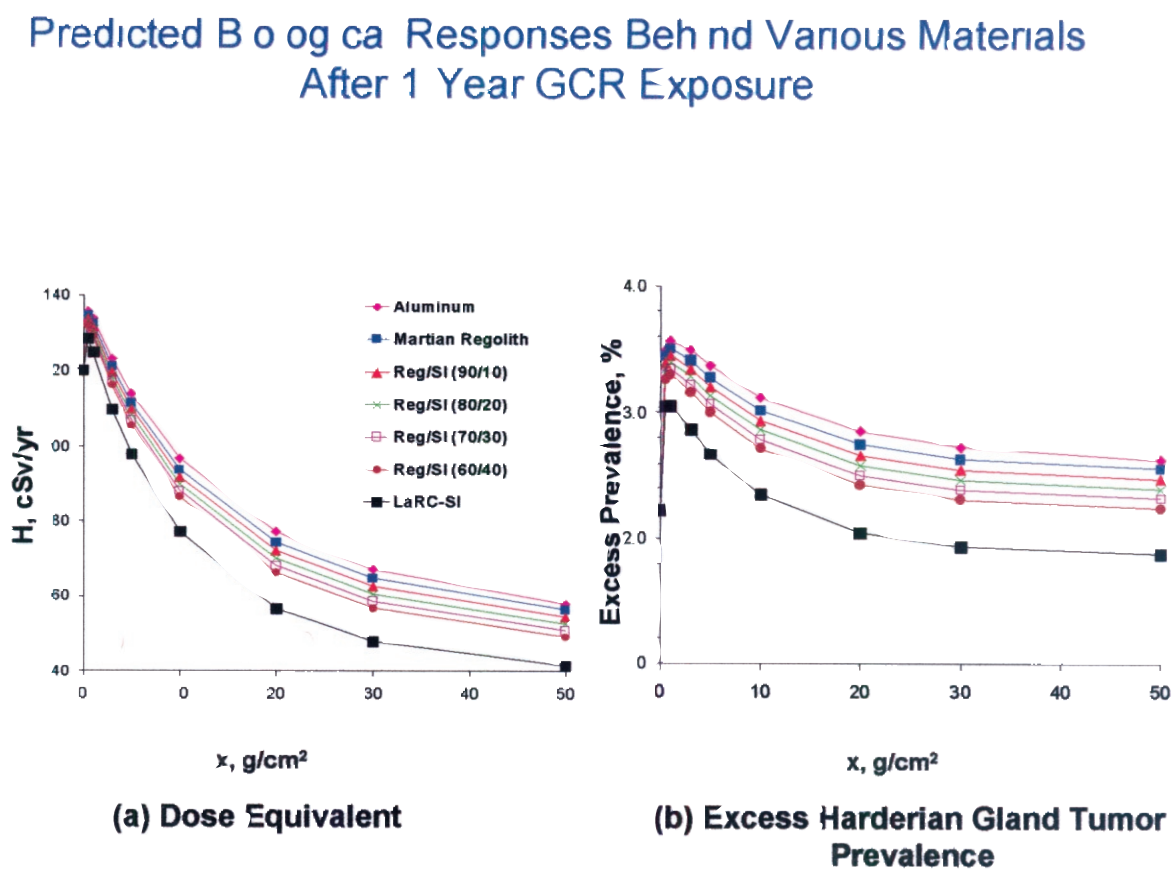

Figure 2. Calculated biological responses to space radiation, using two measures of biological effect: standard dose equivalent and excess tumor prevalence in the mouse Harderian gland.

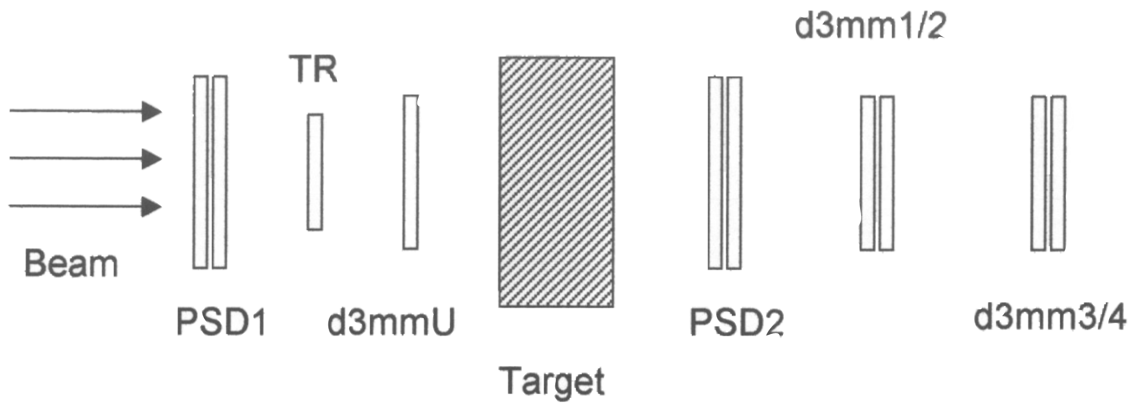

Figure 3. Typical detector setup. All detectors are lithium-drifted silicon. “PSD” denotes position-sensitive detectors.

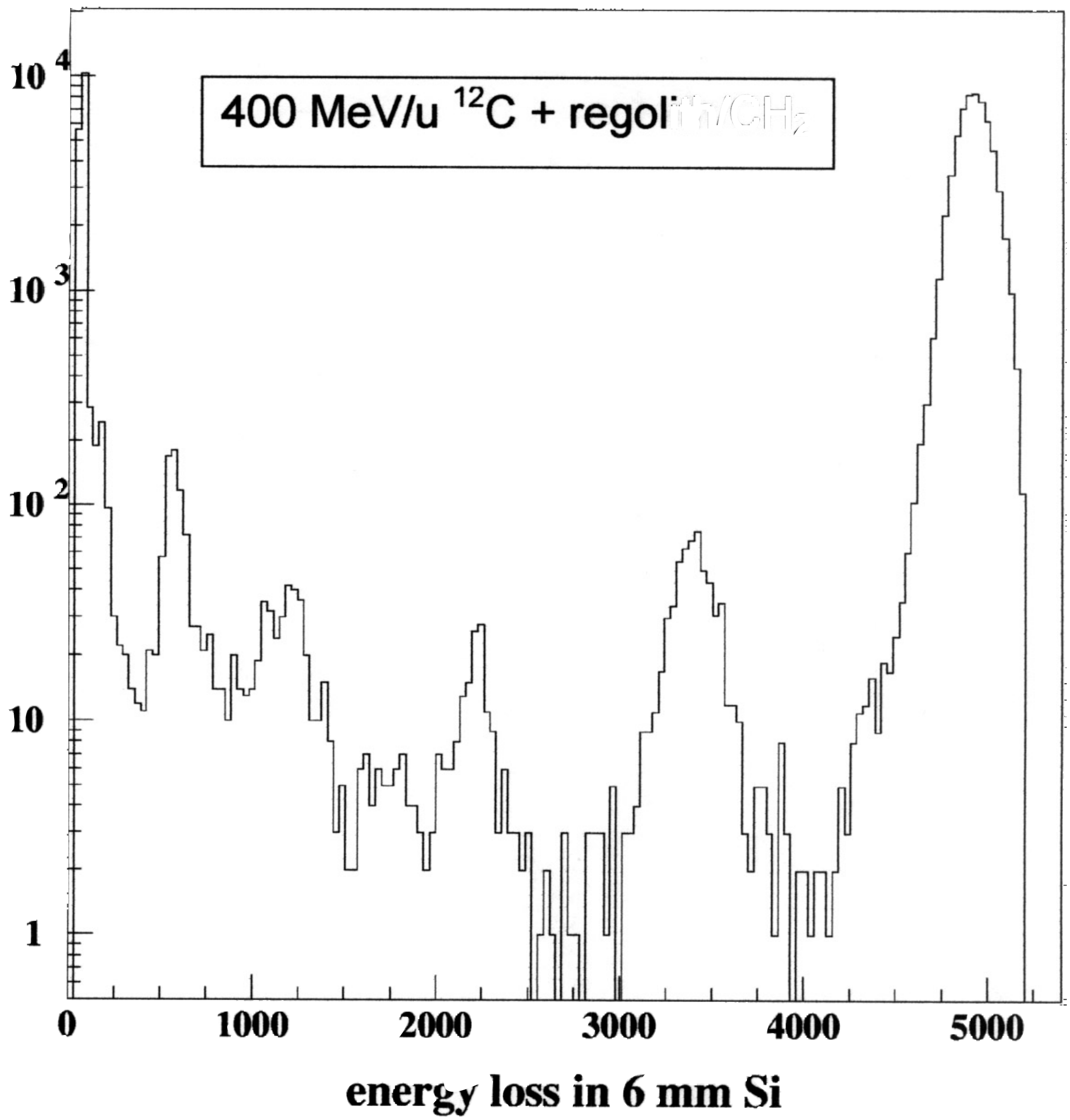

Figure 4. Number of fragments produced in 5 gm/ cm^2 Martian regolith composite (85% regolith / 15% CH_2) as a function of energy loss in by a 400 MeV/u ^{12}C beam.

Main Menu

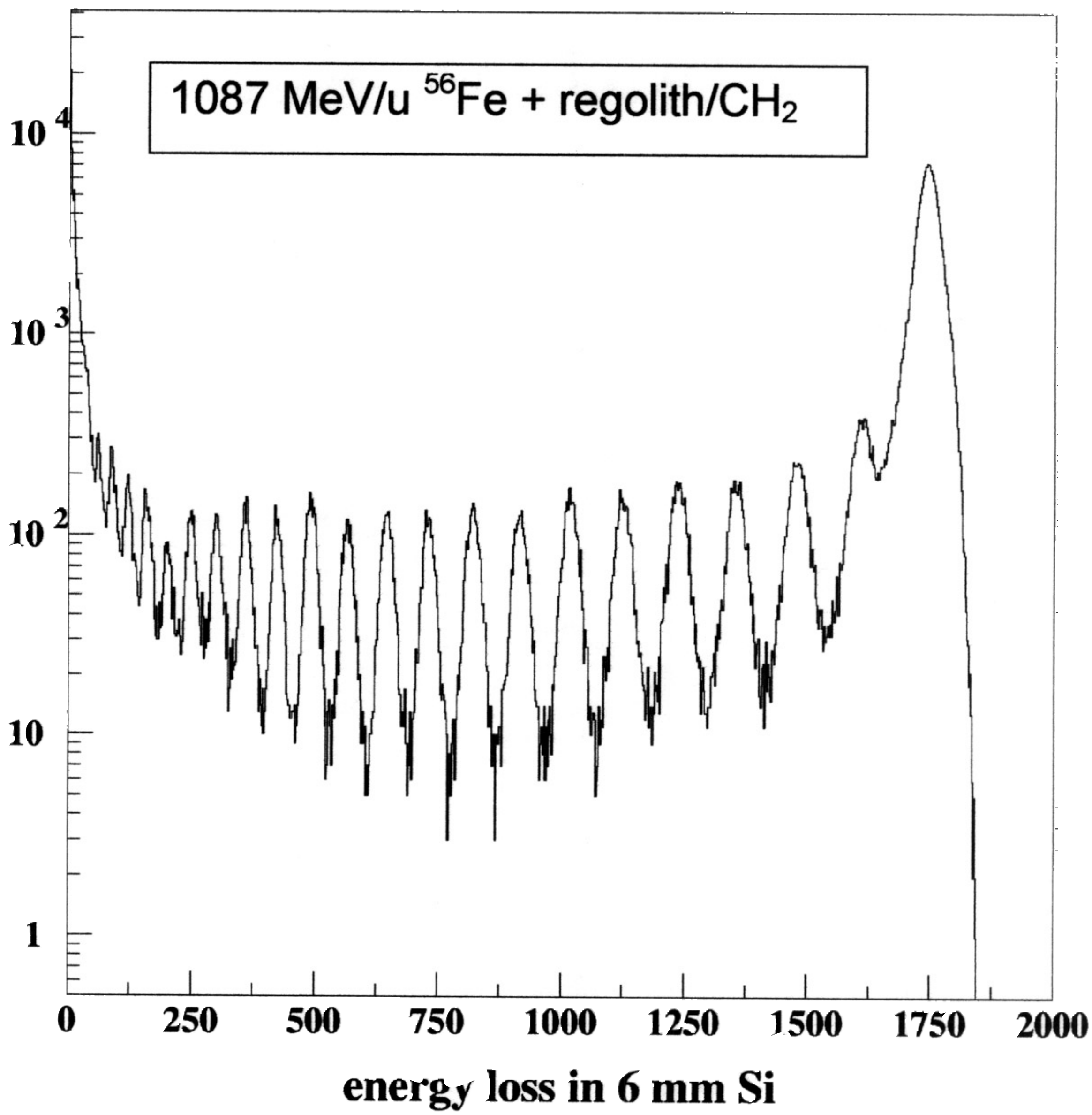

Figure 5. Same as Fig. 4 for a 1087 MeV/u ^{56}Fe beam.