1st International Workshop on Space Radiation Research and
11th Annual NASA Space Radiation Health Investigators' Workshop
Arona (Italy), May 27-31, 2000

Physica Medica - Vol. XVII, Supplement 1, 2001

Shielded Heavy-Ion Environment Linear Detector (SHIELD): An Experiment for the Radiation and Technology Demonstration (RTD) Mission

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Abstract

Radiological assessment of the many cosmic ion species of widely distributed energies requires the use of theoretical transport models to accurately describe diverse physical processes related to nuclear reactions in spacecraft structures, planetary atmospheres and surfaces, and tissues. Heavy-ion transport models that were designed to characterize shielded radiation fields have been validated through comparison with data from thick-target irradiation experiments at particle accelerators. With the RTD Mission comes a unique opportunity to validate existing radiation transport models and guide the development of tools for shield design. For the first time, transport properties will be measured in free-space to characterize the shielding effectiveness of materials that are likely to be aboard interplanetary space missions. Target materials composed of aluminum, advanced composite spacecraft structure and other shielding materials, helium (a propellant) and tissue equivalent matrices will be evaluated. Large solid state detectors will provide kinetic energy and charge identification for incident heavy-ions and for secondary ions created in the target material. Transport calculations using the HZETRN model suggest that 8 g cm^{-2} thick targets would be adequate to evaluate the shielding effectiveness during solar minimum activity conditions for a period of 30 days or more.

KEYWORDS: Radiation shielding, cosmic radiation, heavy ion fragmentation.

1. Introduction

The transport properties of shield materials and tissue have been investigated through programs of ground-based experiments at particle accelerators [1, 2] and the coincident development of models of galactic cosmic radiation (GCR) and laboratory beam transport [3]. The presence of a large number of ion types, energies, materials and material configurations of interest require the use of theoretical transport models that accurately describe diverse physical processes related to nuclear reactions in spacecraft structures, planetary atmospheres and surfaces, and tissues. Heavy-ion transport codes that were designed to characterize shielded radiation fields have been validated through comparison with thick-target irradiation experiments at particle accelerators [4, 5, 6]. With the Radiation Technology and Demonstration (RTD) Mission comes a unique opportunity to validate existing radiation transport models and guide the development of tools for shield design.

The RTD vehicle is an unmanned spacecraft that will be launched ca. 2004 to demonstrate technologies in electric magneto-plasma propulsion for interplanetary space travel and to provide a platform for investigating radiological risks to crews on such missions. The RTD project was initially conceived to demonstrate a new rocket thruster technology – the Variable Specific Impulse Magneto-plasma Rocket (VASIMR) – and a scaled-up engine – the Hall thruster. Although several mission profiles are being considered, it is most likely that RTD will be launched from the Space Shuttle and the ion rockets will then thrust continuously to raise RTD to a maximum altitude of 30,000 km. The SHIELD experiments will be aboard as a Human Exploration and Development of Space Enterprise (HEDS) inspired project to reduce uncertainties associated with radiological risk to humans on exploratory missions.

More specifically, the SHIELD experiments were proposed in order to measure the shielded GCR heavy-ion environment outside the Earth's magnetic field. For the first time, transport properties will be measured in free-space or near-free space to characterize the shielding effectiveness of materials that are likely to be aboard interplanetary space missions. Separate target materials composed of aluminum, advanced composite spacecraft structure and shielding materials, helium (a propellant) and tissue and bone equivalent matrices will be evaluated.

2. Methodology

In the main experiment, shown in a schematic diagram in Figure 1, each test material will be mounted on a target wheel that will rotate between the detector arrays on a pre-programmed schedule. Large solid

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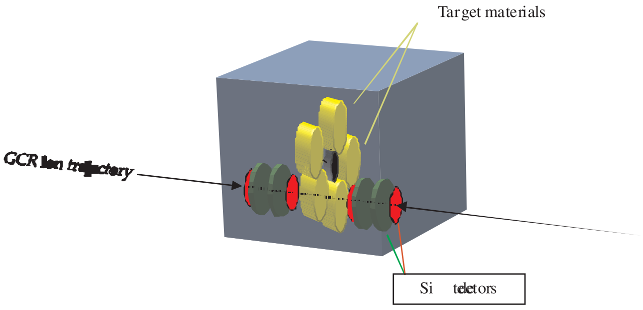

Fig. 1 – Schematic diagram of Shielded Heavy-Ion Environment Linear Detector Experiment

state detectors will provide kinetic energy and charge identification for heavy-ions that are incident on the target material. A co-linear stack of silicon detectors on the opposite side of a target will operate in coincidence with upstream detectors to determine the emitted reaction species. The detector arrays can be triggered by uncollided ions traveling from either side of the target. The spectrometers' solid state detectors have a great deal of heritage in ground-based experiments at particle accelerators and have been used successfully for GCR detection on previous long-duration space missions (e.g. Advanced Composition Explorer/Cosmic Ray Isotope Spectrometer [7]).

3. Results and Conclusions

Transport calculations using the HZETRN model suggest that 8 g cm^{-2} thick targets would be adequate to evaluate the shielding effectiveness during solar minimum activity conditions for a period of 30 days or more. The anticipated data collection phase for the SHIELD experiment is approximately 6 months. Calibrations and other pre-flight testing with particle accelerator beams are necessary. In separate experiments, a particle-identification spectrometer will evaluate the shielding effectiveness of helium in the VASIMR propellant tank.

Simulations using the HZETRN transport model (Fig. 2) predict similar H and He flux densities behind ≈ 8 g cm^{-2} water or aluminum shields. Compared with aluminum, water is a more effective shield against iron ions. Light and heavy ions that are not abundant in GCR are produced through fragmentation in water more efficiently than in aluminum. More comprehensive characterization of hydrogenous shields requires consideration of additional fragmentation species.

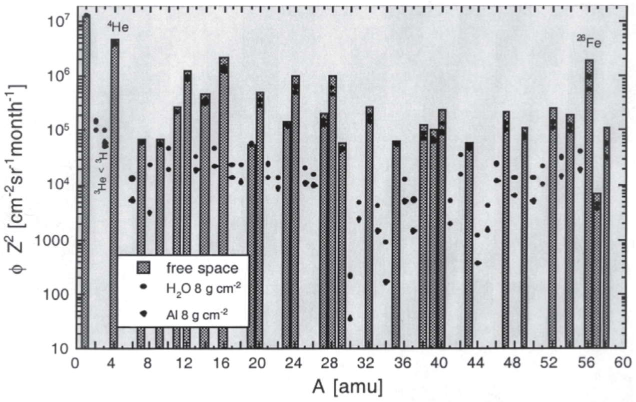

Fig. 2 – Shielded GCR flux density simulated by HZETRN for 1965 Solar Minimum in free space. Low energy cutoff at 20 MeV A^{-1}.

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