Final Report

Radiation Modeling and Testing in Support of Space Radiation Shielding of Nanocomposites

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To

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INTRODUCTION

This project investigates the shielding effectiveness of novel boron-injected, nano-particle shielding material, which was developed by the Material Science program at the University of Kentucky. This material utilizes polyethylene injected with up to ten weight percent microparticle and nanoparticle boron compounds. The radiation shielding effectiveness of polyethylene, in addition to polyethylene-based boron carbide, boron nitride, and nano-boron nitride was compared to aluminum, which is the typical material employed against galactic cosmic radiation. This material was tested at both the Los Alamos Neutron Science Center (LANSCE) Weapons Neutron Research (WNR), and at the Fermi National Accelerator Laboratory (Fermilab). The WNR beam line (FP30L) provided high-energy neutrons up to 600 MeV, and Fermilab's (M02) beam line provided high-energy protons at an energy of 120 GeV.

DESCRIPTION OF THE ACTUAL WORK

Using a 30 cm x 30 cm x 30 cm tank of water as a phantom, absorbed dose measurements were made with and without several thicknesses of each shielding material in the beam. Since the incident spectrum on the tank changes due to the attenuation of the beam by the shielding material, absorbed dose measurements were performed at several depths in the water phantom using a tissue-equivalent ion chamber. The ion chamber is specifically constructed of A150 plastic and has a 1 cm^3 measurement volume. The ion chamber location was adjusted using an x-y positioning table.

The FP30L neutron spectrum in the ICE house at the LANSCE/WNR facility is similar to the cosmic-ray induced neutron spectrum in the earth's upper atmosphere. At the WNR, due to the potential for the neutron beam intensity to fluctuate, two detectors were used as monitors of the total neutron fluence rate during the irradiation period. The first detector was the U-238 fission chamber used at WNR to perform time-of-flight measurements of the neutron spectrum.[1]. The second detector affectionately called the "Banjo" detector due to its shape was also used as a neutron intensity monitor. This detector utilized a 30.48 cm x 30.48 cm piece of BC-408 plastic scintillator attached to a fishtail light pipe. These detectors are shown in Fig 1.

At Fermilab, the 120-GeV proton beam impinged upon shielding samples in the beam line. Samples at both Fermilab and WNR were measured in multiple cells of three sheets per unit cell. Fermilab data were acquired at a single position in the beam line, located directly at the center of the water phantom box. Conversely, WNR data were taken at incremental distances from the beam line, at varying x-y positions.

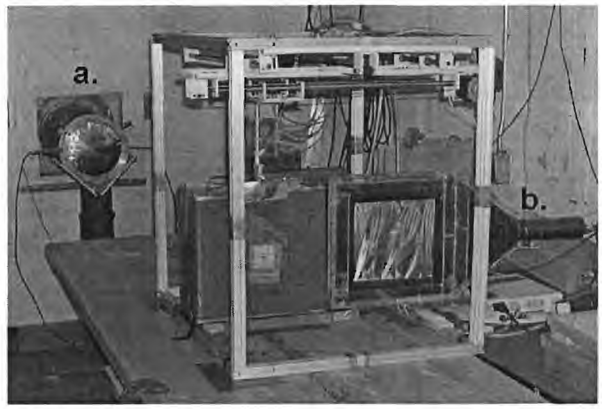

Fig 1. Neutron Detectors (a. WNR Fission Chamber, b. "Banjo" Detector) Used in Experiment.

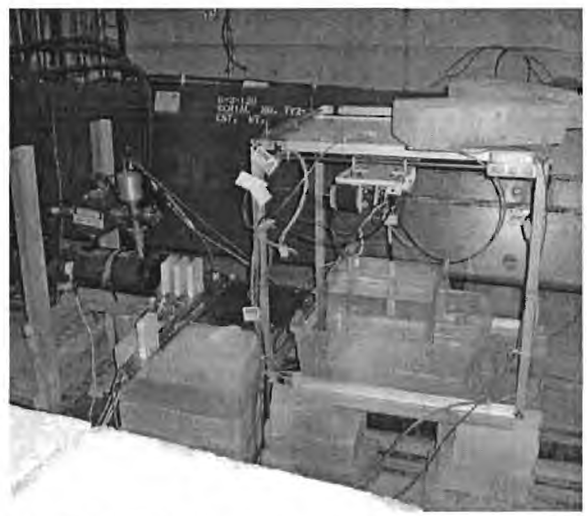

Fig 2. Fermilab Shielding Experiment Setup with Ion Chamber Submerged in Water Phantom.

The charge collected in the tissue-equivalent ion chamber is proportional to the absorbed dose in of tissue. For absolute absorbed dose measurements, correction factors have to be made for temperature and pressure. However, since we are looking at a shielding effectiveness, this correction was not made and the attenuation factor for each shielding thickness was reported. Aluminum plates were used as a reference shielding material since it is a typical material used in spacecraft. The shielding attenuation factor calculated at the WNR is the ratio of the charge collected in the TE ion chamber with and without the shielding in place, properly normalized for fission counts. The shielding effectiveness at Fermilab is calculated as a ratio of the charge accumulated by the ion chamber to the charge detected by the transmission chamber, located anterior to the ion chamber and water phantom.

RESULTS

The graphs from Fermilab and WNR depict the fraction of radiation transmitted through the attenuation sheets. A greater shielding capability is indicated by a lower transmission factor. The overall transmission factor from the WNR is shown in Fig. 3. At the neutron energies composing the beam, all the polyethylene-based materials have similar attenuation properties. This is expected as boron offers no advantage in attenuating neutrons except at lower energies. Like the WNR data, polyethylene-based materials have similar attenuation properties is also reflected for high-energy protons, as seen in the Fermilab data tabulated in Fig. 4. The shielding material with the lower transmission factor is the most effective shield. It is believe that the transmission factor increases in the Fermilab beam because spallation in the shielding materials produced higher LET radiations that then enter the phantom.

Results from both the WNR and Fermilab concluded that aluminum, the material conventionally used for space shielding, exhibited the most effective shielding against high-energy protons and the worst shielding properties for neutrons, of the five materials tested. Although the polyethylene-based materials did exhibit similar shielding behavior, pure polyethylene was the least effective shielding material for protons. Boron nitride and nano-boron nitride displayed equivalent shielding properties as polyethylene for high-energy neutrons. Boron nitride, nano-boron nitride, and boron carbide displayed approximately equivalent shielding properties for high energy protons. Boron carbide proved to be the most effective shielding material for high energy neutrons. Overall, boron carbide was the best overall shielding material for high energy protons and neutrons.

Based on the accumulated data, it is recommended that mechanical properties of boron nitride, nano-boron nitride, and boron carbide be further tested to determine which will be most effective as a structural material for spacecraft.

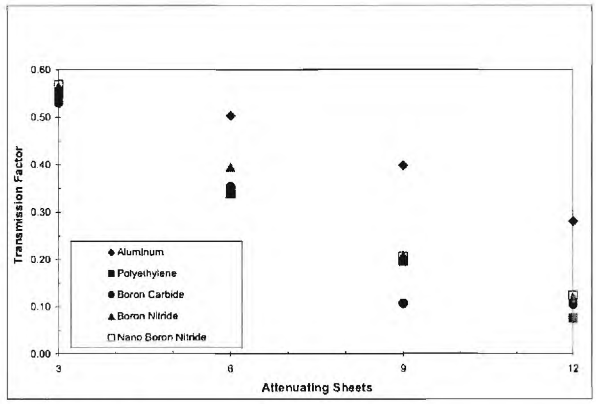

Fig 3. WNR Attenuation Comparison.

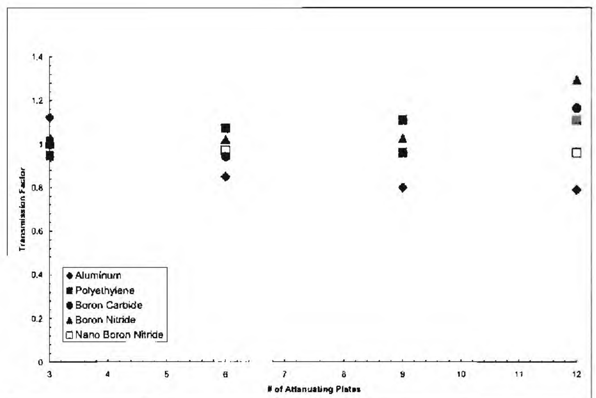

Fig 4. Fermilab In-Beam Comparison of Transmission.

REFERENCES

1. S. A. Wender, et al, A Fission Ionization Detector for Neutron Flux Measurements at a Spallation Source, *Nuclear Instruments in Physics Research A*, **336**, 226 (1993)