Radiation Study of Boron Nitride Nanotube (BNNT) and BNNT Composites

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Overview

• Challenge
  • Space Radiation

• Objective
  • Radiation Shielding
  • Literature Review

• Approach
  • Indium Foil experiments
  • Online tool for assessment of radiation in space

• Results

• Analysis

• Next Steps

• Acknowledgements
Challenge

There are 3 main sources of radiation in space: galactic cosmic radiation (GCR), solar particle events (SPE), and trapped radiation belt particles (Van Allen Belts).

GCR
High energy particles from outer space

SPE
Events containing a high number of high energy charged particles from sun

Van Allen Belts
Outer belt: High energy particles from Sun trapped in Earth’s magnetic field
Inner Belt: interactions of GCR with Earth’s atmosphere

When radiation interacts with matter it causes secondary neutrons.

Radiation presents risk to not only humans but also electronics and materials.

Image Credit: NASA
Objective

- Understanding shield effectiveness against secondary neutron radiation is an important factor regarding future space trips to prevent excessive radiation exposure.
- Testing BNNTs, BNNT composites, and other materials to discover shielding properties and effectiveness.
BNNT for Radiation Shielding

Nanomaterials for Shielding from Neutrons

• High thermal neutron absorption: boron, lithium, and gadolinium
  • Can’t use heavier elements because of fragmentation leading to secondary radiation

• Hydrogen is best shielding against GCR
  • Liquid hydrogen is not practical

Hydrogen Containing Nanostructures

• Nanotubes favored to store hydrogen over particles and sheets because the greater surface area and higher hydrogen bonding energies

• CNTs and BNNTs theoretical capacity to store hydrogen and improve other materials properties
  • Ideal for radiation shielding

Approach: Neutron Source

- Americium Beryllium fast neutron source
- Source is a mixture of Am-241 and Be-9
- Emits ~800 mrem/hr directly at source
Approach: Experimental Setup

Polyethylene block 25mm < Shielding Sample (opt) < Indium Foil < Kapton Film

- Using the source’s current orientation within the lead cave
- Indium foils placed in front of source become activated
  - $^{115}\text{In}(n, \gamma)^{116}\text{In}$
- Analysis method with Geiger Mueller counters used
### Results: Indium Foil B4C Al6061

<table>
<thead>
<tr>
<th>Description</th>
<th>Average A₀</th>
<th>Trial 1 A</th>
<th>Trial 2 A</th>
<th>Average A</th>
<th>Areal Density (g/cm²)</th>
<th>Linear Absorption (cm⁻¹)</th>
<th>Linear Absorption (mm⁻¹)</th>
<th>% shielded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Foil</td>
<td>2486.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Al 6061</td>
<td>-</td>
<td>2455.8</td>
<td>2462.5</td>
<td>2459.2</td>
<td>0.4256</td>
<td>0.07</td>
<td>0.01</td>
<td>1.1</td>
</tr>
<tr>
<td>NIA B4C 5% vol</td>
<td>-</td>
<td>1788.0</td>
<td>1696.1</td>
<td>1742.1</td>
<td>0.4741</td>
<td>2.01</td>
<td>0.20</td>
<td>29.9</td>
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<tr>
<td>NIA B4C 10% vol</td>
<td>-</td>
<td>1384.3</td>
<td>1309.8</td>
<td>1347.1</td>
<td>0.4750</td>
<td>3.42</td>
<td>0.34</td>
<td>45.8</td>
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<tr>
<td>NIA B4C 20% vol</td>
<td>-</td>
<td>947.8</td>
<td>964.6</td>
<td>956.2</td>
<td>0.4773</td>
<td>5.18</td>
<td>0.52</td>
<td>61.5</td>
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<tr>
<td>NIA B4C 30% vol</td>
<td>-</td>
<td>755.1</td>
<td>776.5</td>
<td>765.8</td>
<td>0.4300</td>
<td>6.94</td>
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<td>NIA B4C 50% vol</td>
<td>-</td>
<td>600.1</td>
<td>620.3</td>
<td>610.2</td>
<td>0.4269</td>
<td>8.18</td>
<td>0.82</td>
<td>75.5</td>
</tr>
</tbody>
</table>

**Parameters**

- Indium Foil AA Detector 1, 960V
- 300 mrem setup

**Graph**: Time (min) vs. Count

- Foil AA Bare Foil
- Al 6061
- 5% vol
- 10% vol
- 20% vol
- 30% vol
- 50% vol

**Images**: Images of Indium Foil and B4C Al6061 samples.
OLTARIS is an online system used for the analysis of in space radiation. Transport based on HZETRN (High charge (Z) and Energy TRaNsport) code and the input nuclear physics model NUCFRG2 (NUClear FRaGmentation).

For this project, the tool was used primarily to model different shielding materials under varying GCR and SPE scenarios.

OLTARIS: GCR Free Space Environment

BON-14 GCR Model in Free Space with 1977 Solar Min. Incident on vehicles with varying thickness

Dose Equivalent (mSv/day)

Areal Density (g/cm²)

Zero Shield (mSv/day)

Al6061

5% vol B4C

10% vol B4C

20% vol B4C

30% vol B4C

50% vol B4C

60% vol B4C

70% vol B4C

80% vol B4C

90% vol B4C

B4C

Pure Boron

Mg(BH₄)₂

Polyethylene
OLTARIS: SPE Free Space Environment

SPE Model Free Space with 1972 (King) historic Solar Particle Event Incident on vehicles with varying thickness

Areal Density (g/cm²) vs. Dose Equivalent (mSv)

- Al6061
- 5% vol B4C
- 10% vol B4C
- 20% vol B4C
- 30% vol B4C
- 40% vol B4C
- 50% vol B4C
- 60% vol B4C
- 70% vol B4C
- 80% vol B4C
- 90% vol B4C
- B4C
- Pure Boron
- Mg(BH4)2
- Polyethylene

Parameters:
- Environment Selection: SPE, Free Space 1 AU
- Historical SPE: August 1972 (King)
OLTARIS Mission to Mars: Past Mission Totals

- Earth and Mars’s orbits meet ideal alignment every 26 months.
- The outgoing trip to Mars would take 9 months, once at Mars there would need to be a wait of either a few weeks or a year before alignment is correct for return.
- Return flight would take an additional 9 months.
- Total of ~630 mission days

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>25</th>
<th>35</th>
<th>45</th>
<th>55</th>
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<tbody>
<tr>
<td>Male</td>
<td>1,500 mSv</td>
<td>2,500 mSv</td>
<td>3,250 mSv</td>
<td>4,000 mSv</td>
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<tr>
<td>Female</td>
<td>1,000 mSv</td>
<td>1,750 mSv</td>
<td>2,500 mSv</td>
<td>3,000 mSv</td>
</tr>
</tbody>
</table>
OLTARIS Mission to Mars: 5 g/cm² Dose Totals

Mars Mission Totals (mSv) at Areal Density 5 g/cm²
630 day mission

- Al6061
- 5% vol B₄C
- 10% vol B₄C
- 20% vol B₄C
- 30% vol B₄C
- 40% vol B₄C
- 50% vol B₄C
- 60% vol B₄C
- 70% vol B₄C
- 80% vol B₄C
- 90% vol B₄C
- B₄C
- Pure Boron
- Mg(BH₄)₂
- Polyethylene

Areal Density = density * thickness

5 g/cm² thickness
2 cm (Al6061, B₄C, B)
5 cm (MgBH₄, PE)

SPE Mars Surface (1972) King
GCR Mars Surface 90 days
SPE Free Space (1972) King
GCR Free Space 540 Days
Lifetime Limit
OLTARIS Mission to Mars: 25 g/cm² Dose Totals

Mars Mission Totals (mSv) at Areal Density 25 g/cm²
630 day mission

- **Increase in GCR on Mars surface for Al based composites most likely due to secondary radiation**
- 25 g/cm² thickness
  - 10 cm (Al6061, B4C, B)
  - 25 cm (MgBH₄, PE)

Areal Density = density * thickness

- SPE Mars Surface (1972) King
- GCR Mars Surface 90 days
- SPE Free Space (1972) King
- GCR Free Space 540 days
- Lifetime Limit
Conclusions and Future Remarks

My time at NASA Langley Research Center has been key in my development as a student and individual. Through my work over the past year we have been better able to understand the relationship between different materials and radiation. The indium foil results show B4C to be an effective shielding material which could be further investigated. Also, modeling shows the negative effect some materials may have and shows the importance of areal density.

Next Steps:

➢ Further analysis of B4C samples potentially using B10 enriched material
➢ Further use of OLTARIS modelling
➢ Attempt to understand the effect of secondary neutron
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