Radiation Study of Boron Containing Nanocomposites

CALISTA LUM
CHEOL PARK AND SANG-HYON CHU

JANUARY 13, 2022

Overview

- Challenge
  - Space Radiation
- Objective
  - Radiation Shielding
  - Literature Review
- Approach
  - Online tool for assessment of radiation in space
- Results
  - Lunar Surface Analysis
  - Sequencing of Materials
- 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).

<u>GCR</u>

High energy particles from outer space

<u>SPE</u>

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

<u>Van Allen Belts</u>

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.

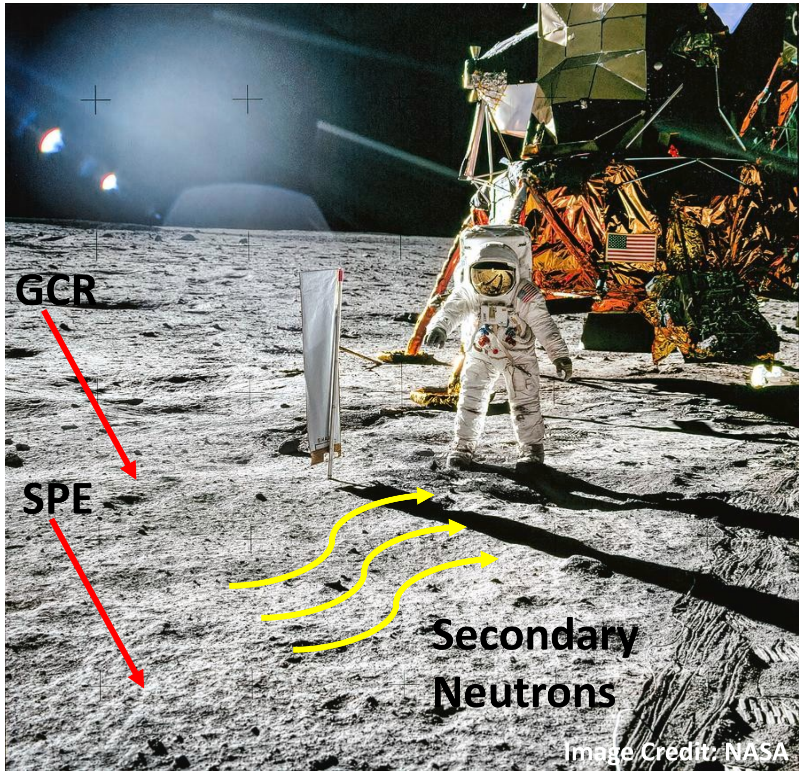


Figure 1. Image of galactic cosmic radiation and secondary particle event radiation interacting with surface to create secondary neutrons

Thibeault, Sheila A., et al. "Nanomaterials for Radiation Shielding." *MRS Bulletin*, vol. 40, no. 10, 2015, pp. 836–841., doi:10.1557/mrs.2015.225.

Objective

- Better understand shield effectiveness against secondary neutron radiation for future space trips to prevent excessive radiation exposure.
- Test boron containing nanocomposites and other materials to discover shielding properties and effectiveness.

APOLLO 50 NEXT GIANT LEAP

Figure 2. Image of potential lunar station habitat on moon Image Credit: NASA

Boron Nitride Nanotube (BNNT) for Radiation Shielding

<u>Nanomaterials for Shielding from Neutrons</u>

- 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
- Combining boron and hydrogen can actively and effectively shield against GCR, SPE, and secondary neutron

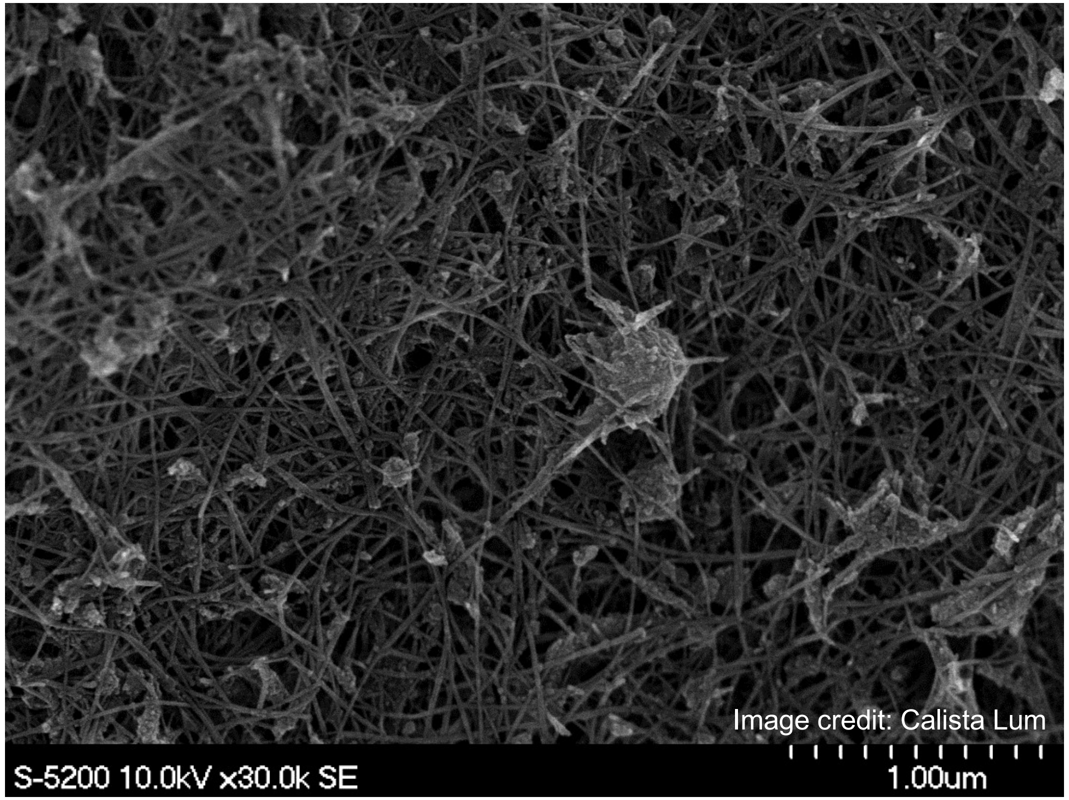


Figure 3. HRSEM image of Boron-10 boron nitride nanotube mat

Nanomaterials for Radiation Shielding

Nanomaterials for Shielding from Neutrons

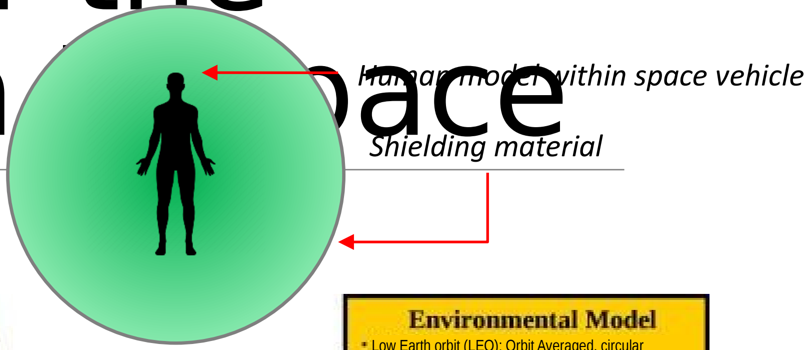
- High thermal neutron absorption: boron, lithium, and gadolinium
  - Can't use heavier elements because of fragmentation leading to secondary radiation
- Hydrogen is best shielding against GCR
  - Liquid hydrogen is not practical

Hydrogen Containing Nanostructures

- Nanotubes favored to store hydrogen over particles and sheets because the greater surface area and higher hydrogen bonding energies
- Carbon nanotubes (CNTs) and BNNTs theoretical capacity to store hydrogen and improve other materials properties
  - Ideal for radiation shielding
- Materials such as magnesium borohydride combine boron and high hydrogen content!

Thibeault, Sheila A., et al. "Nanomaterials for Radiation Shielding." *MRS Bulletin*, vol. 40, no. 10, 2015, pp. 836–841., doi:10.1557/mrs.2015.225.

OLTARIS: On-Line Tool for the Assessment of Radiation In Space



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.

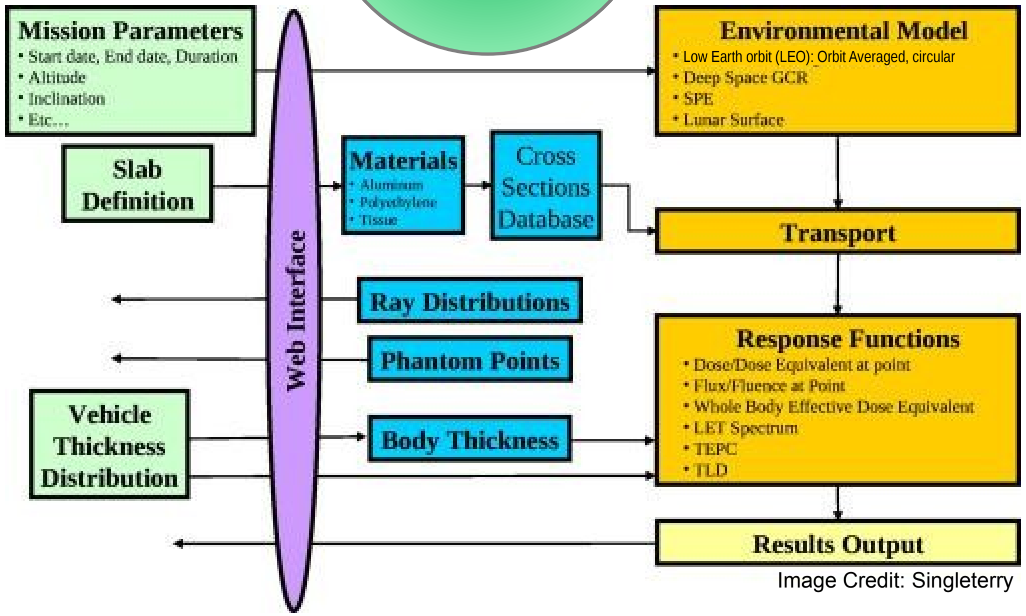
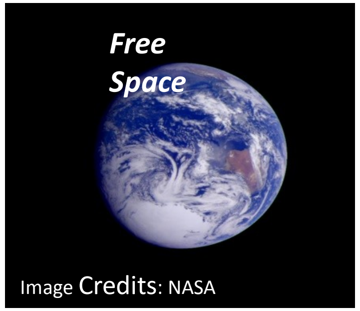
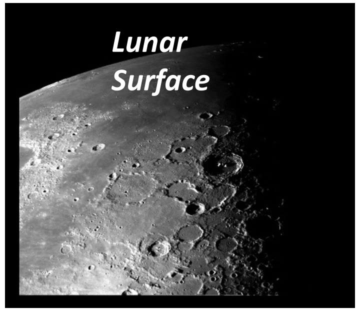
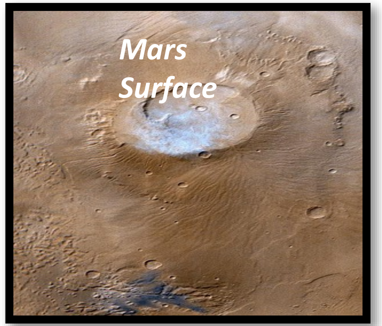


Image Credit: Singleterry

Figure 4. Graphic of OLTARIS interface functions based on user inputted data, web server data, and host computations







Singleterry, Robert. "OLTARIS: On-Line Tool for the Assessment of Radiation In Space." *AIAA SPACE 2009 Conference & Exposition*, 2009, doi:10.2514/6.2009-6645.

OLTARIS: Lunar Surface Radiation Analysis

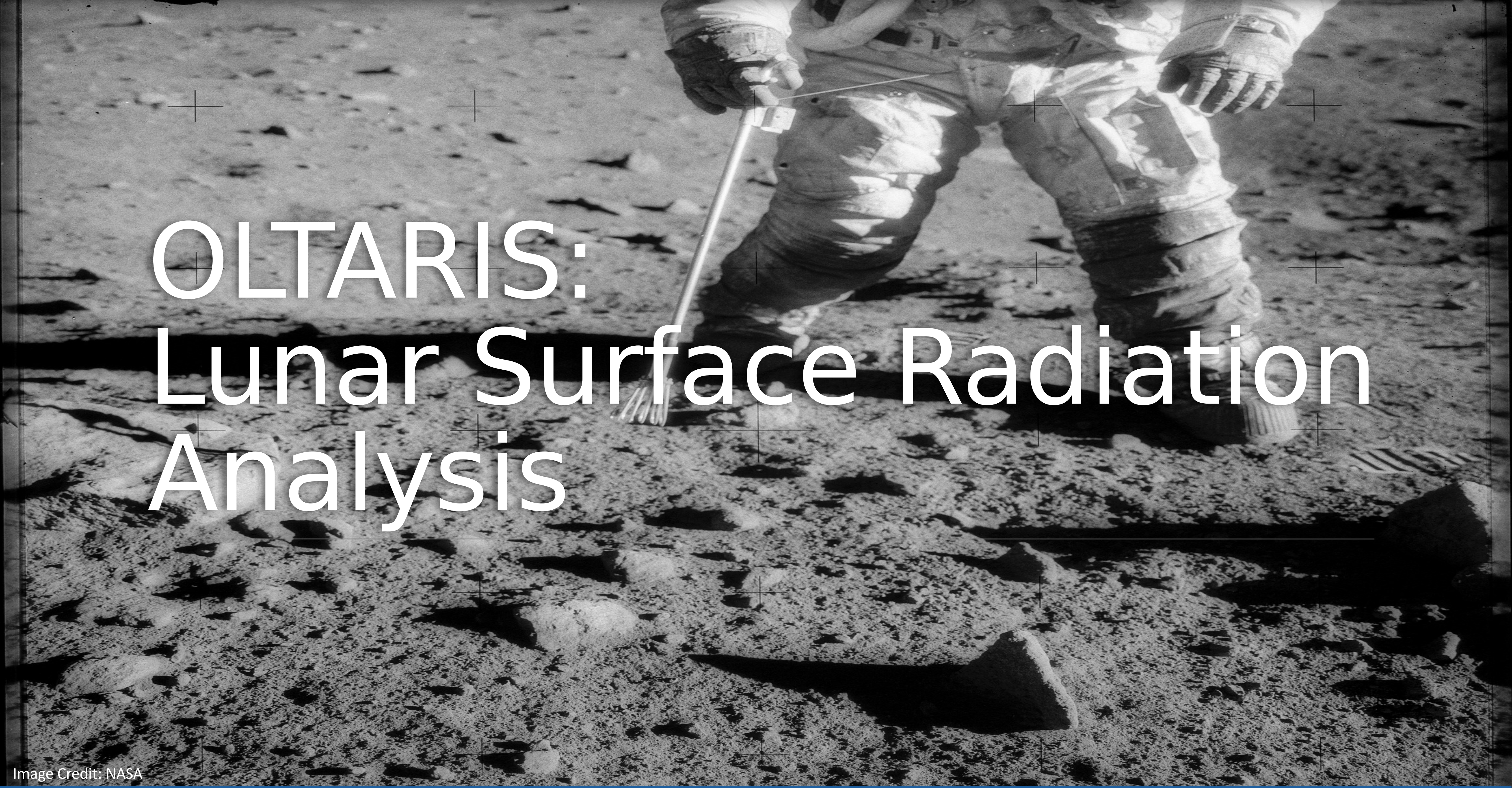


Image Credit: NASA

Table 1. List of all pure materials used and their description

Material	Description
Aluminum 6061	Pure Aluminum-6061
B_4C	Pure boron carbide
BNNT	Pure boron nitride nanotubes
BNNT-B10	Boron-10 enriched BNNT
Boron	Pure Natural Boron
Boron-10	Pure Boron-10
Boron-11	Pure Boron-11
Carbon	Pure Carbon
Lunar Regolith a-17	lunar regolith Apollo-17 sample from OLTARIS
MgBH	Pure Magnesium borohydride ($Mg(BH_4)_2$)
Polyethylene	Pure Polyethylene
Ti64	Pure Titanium-64

Table 2. List of all composite materials used

Titanium-64 with x wt % BNNT	Titanium-64 with x wt % boron-10 enriched BNNT	Titanium-64 with x wt % carbon	Aluminum-6061 with x wt % boron carbide	Aluminum-6061 with x wt % BNNT	Aluminum-6061 with x wt % boron-10 enriched BNNT	Aluminum-6061 with x wt % carbon	Magnesium borohydride with x wt % BNNT	Magnesium borohydride with x wt % carbon
Ti64-0.5BNNT	Ti64-0.5BNNT-B10	Ti64-2C	Al-5B4C	Al-2BNNT	Al-2BNNT-B10	Al-2C	MgBH-2BNNT	MgBH-2C
Ti64-1BNNT	Ti64-1BNNT-B10	Ti64-5C	Al-10B4C	Al-5BNNT	Al-5BNNT-B10	Al-5C	MgBH-5BNNT	MgBH-5C
Ti64-2BNNT	Ti64-2BNNT-B10	Ti64-10C	Al-20B4C	Al-10BNNT	Al-10BNNT-B10	Al-10C	MgBH-10BNNT	MgBH-10C
Ti64-5BNNT	Ti64-5BNNT-B10	Ti64-25C	Al-30B4C	Al-25BNNT	Al-25BNNT-B10	Al-25C	MgBH-25BNNT	MgBH-25C
Ti64-10BNNT	Ti64-10BNNT-B10	Ti64-50C	Al-50B4C	Al-50BNNT	Al-50BNNT-B10	Al-50C	MgBH-50BNNT	MgBH-50C
Ti64-25BNNT	Ti64-25BNNT-B10		Al-60B4C					
Ti64-50BNNT	Ti64-50BNNT-B10		Al-70B4C					
			Al-80B4C					
			Al-90B4C					

Total 65 Materials

unar Surface Zero Shield BON20: 1.25 mSv/day

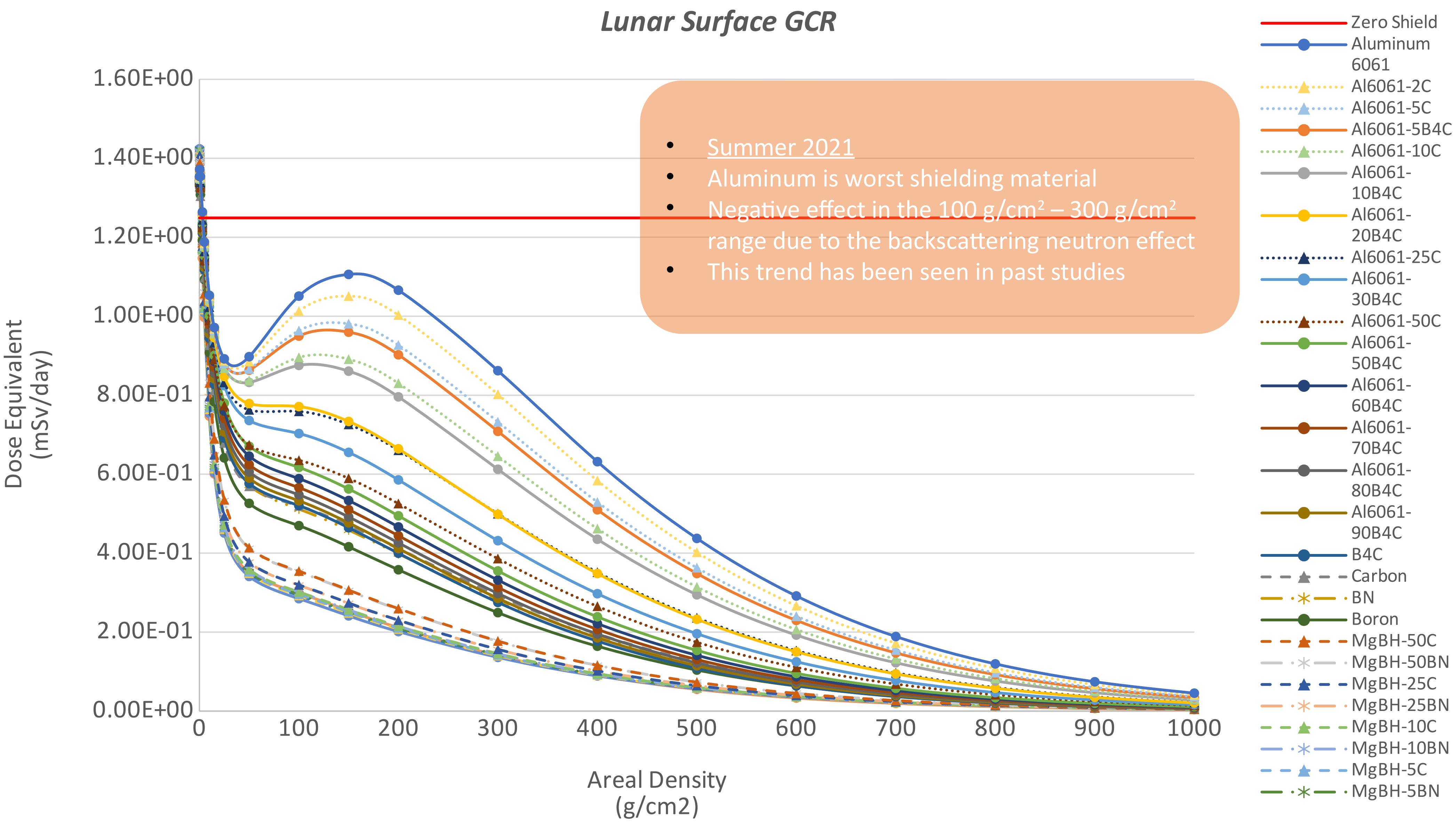
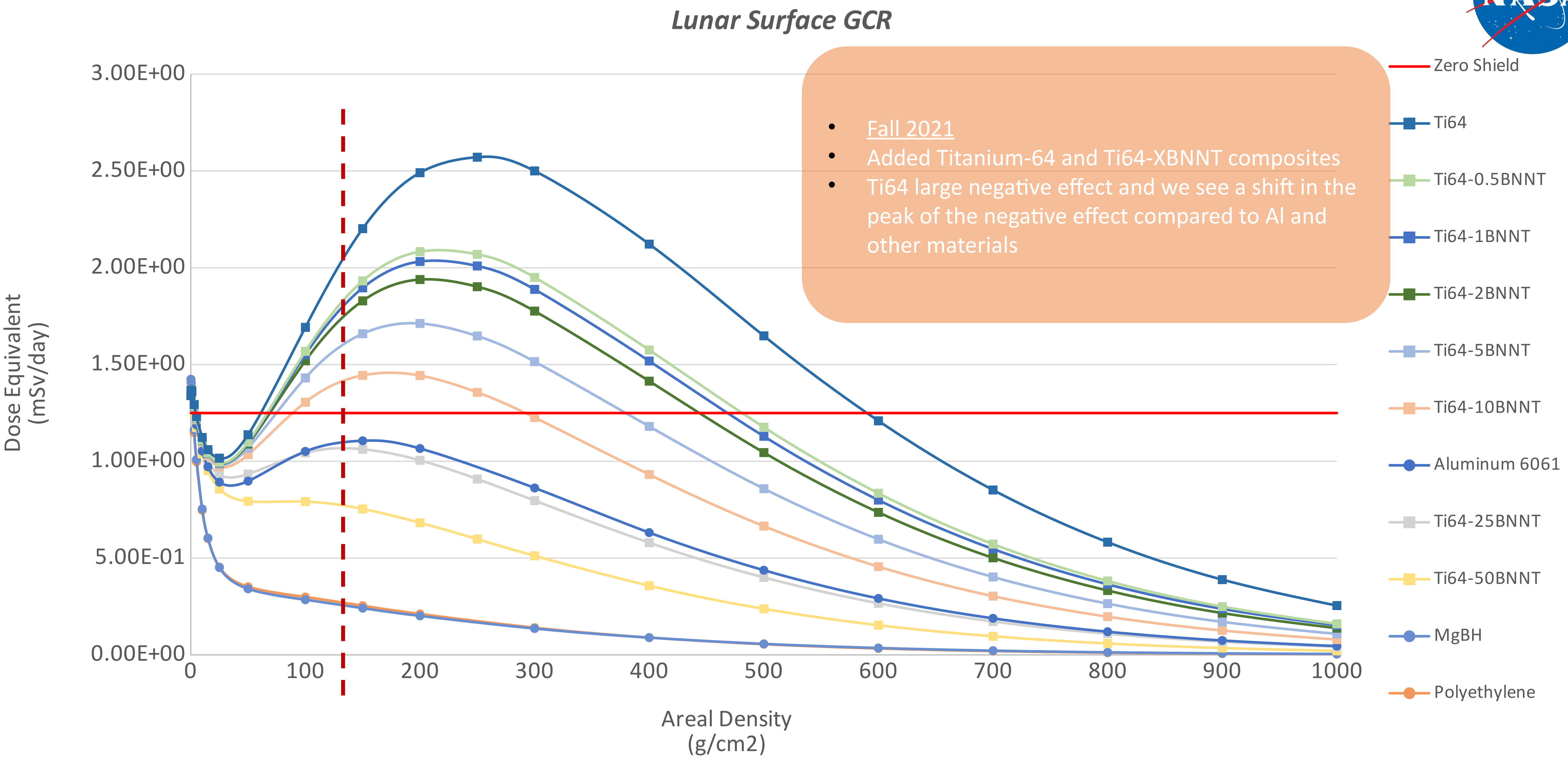


Figure 5. Graph of materials on lunar surface in galactic cosmic ray radiation environment. GCR parameter BON-20 and historical solar min/max 1977 (DSNE). 968-ray analysis of shielding material

unar Surface Zero Shield BON20: 1.25 mSv/day



- Fall 2021
- Added Titanium-64 and Ti64-XBNNT composites
- Ti64 large negative effect and we see a shift in the peak of the negative effect compared to Al and other materials

Figure 6. Graph of materials on lunar surface in galactic cosmic ray radiation environment. GCR parameter BON-20 and historical solar min/max 1977 (DSNE). 968-ray analysis of shielding material

Material	Density (g/cm³)	Real Thickness (cm)	Areal Density (g/cm²)
Al6061	2.70	9.3	25
B4C	2.52	9.9	25
MgBH	0.99	25.3	25

- MgBH shields 3x more than Ti64 and 2x more than Al6061
- The MgBH composites also perform similarly, meaning that reinforcing materials BNNT and carbon can be added without reducing overall shielding effectiveness

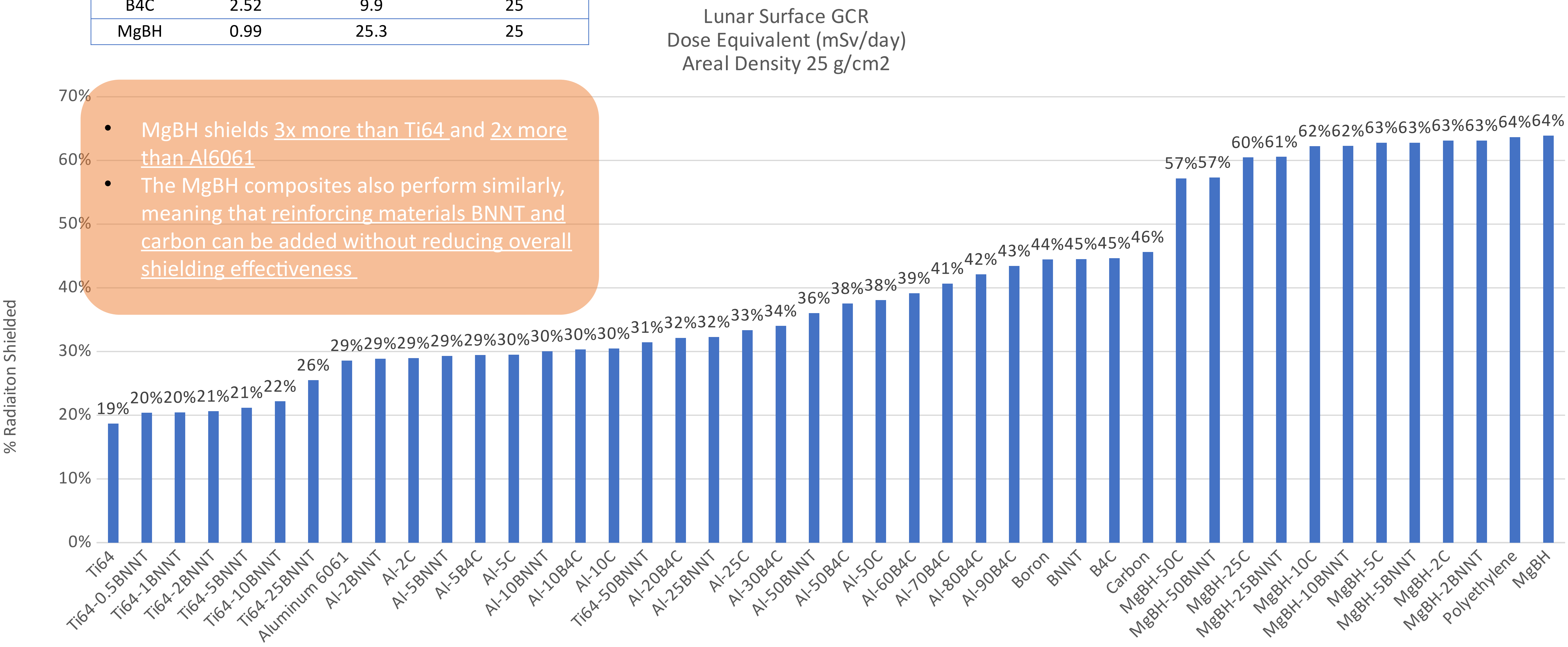
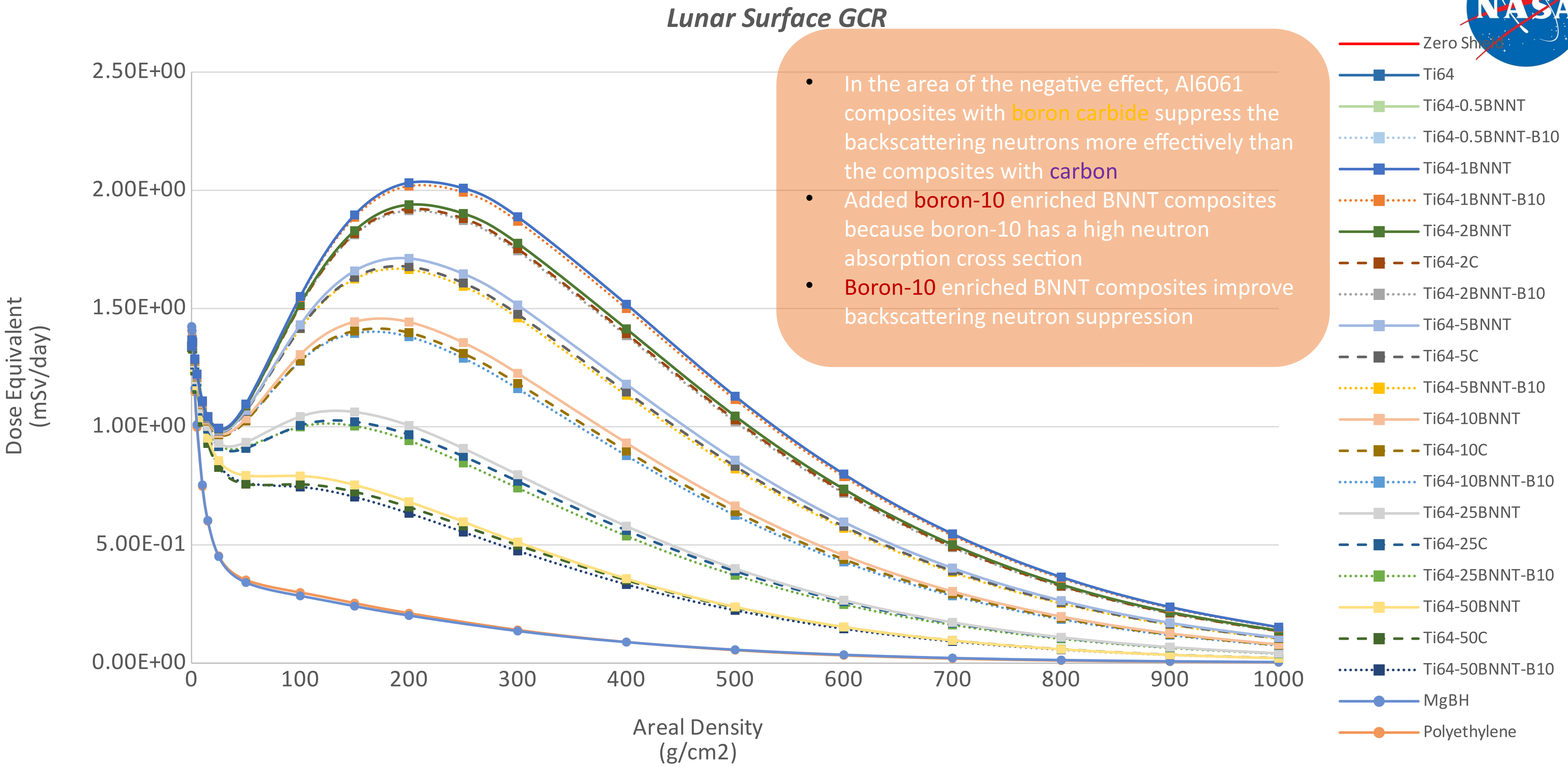


Figure 7. Materials plotted as the percent of total radiation shielded in the lunar surface GCR environment with BON-20 and 968 ray parameters

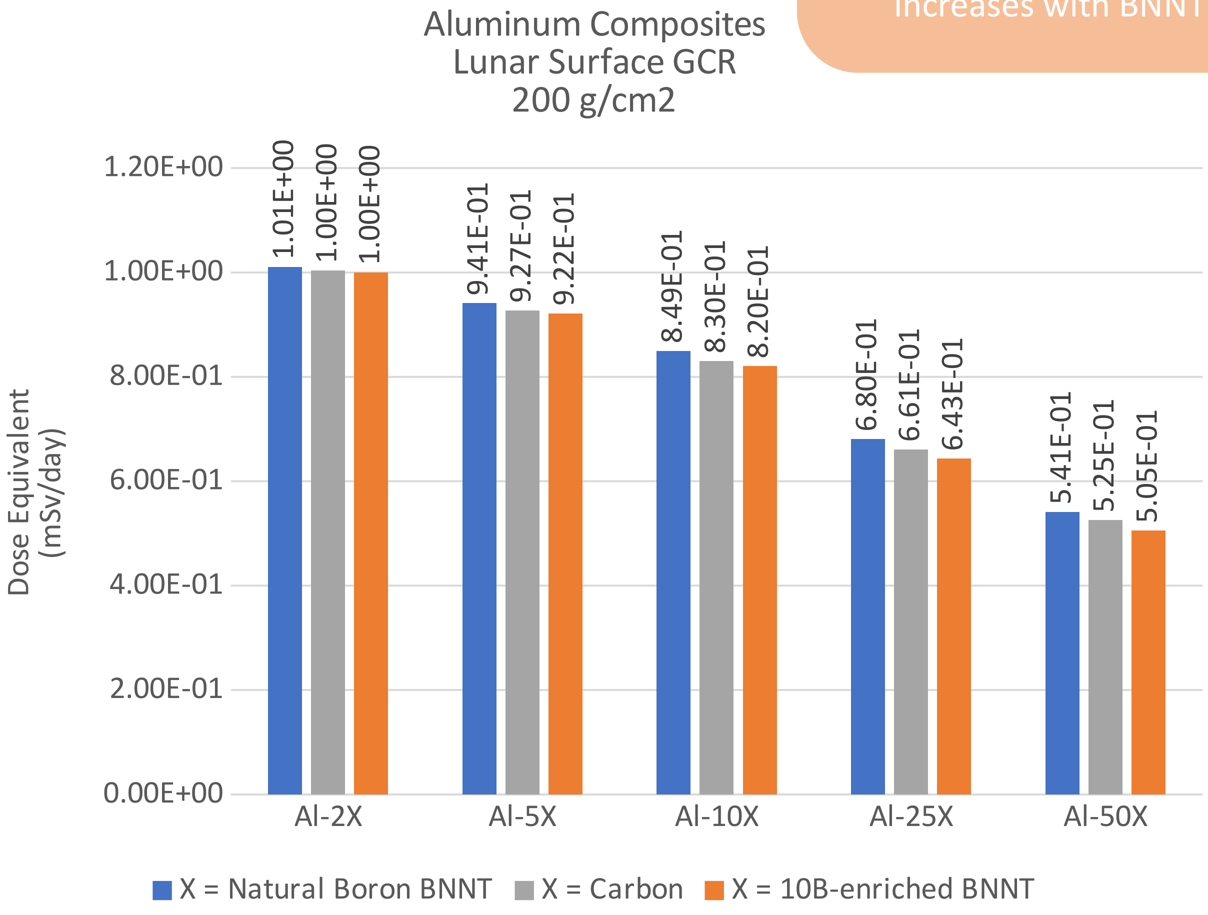


- In the area of the negative effect, Al6061 composites with boron carbide suppress the backscattering neutrons more effectively than the composites with carbon
- Added boron-10 enriched BNNT composites because boron-10 has a high neutron absorption cross section
- Boron-10 enriched BNNT composites improve backscattering neutron suppression

Figure 8. Graph of Ti64 composite materials on lunar surface in galactic cosmic ray radiation environment. GCR parameter BON-20 and historical solar min/max 1977 (DSNE). 968-ray analysis of shielding material

Material	Density (g/cm³)	Real Thickness (cm)	Areal Density (g/cm²)
Al6061	2.70	74.1	200
Ti64	4.41	45.4	200

- 200 g/cm² is the peak of the negative effect from the backscattering neutrons
- Boron-10 decreases the dose equivalent more effectively than natural boron
- Effectiveness of boron-10 enriched BNNT increases with BNNT content



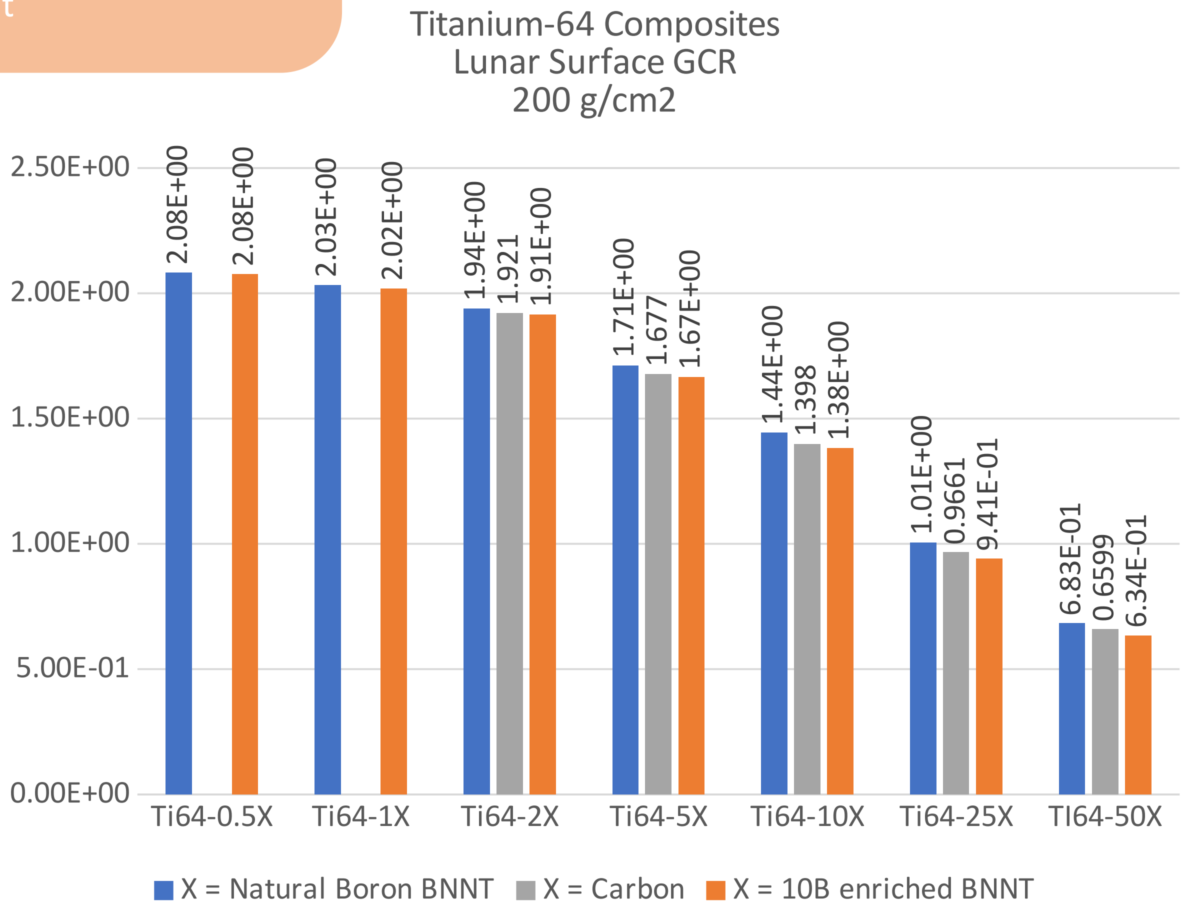
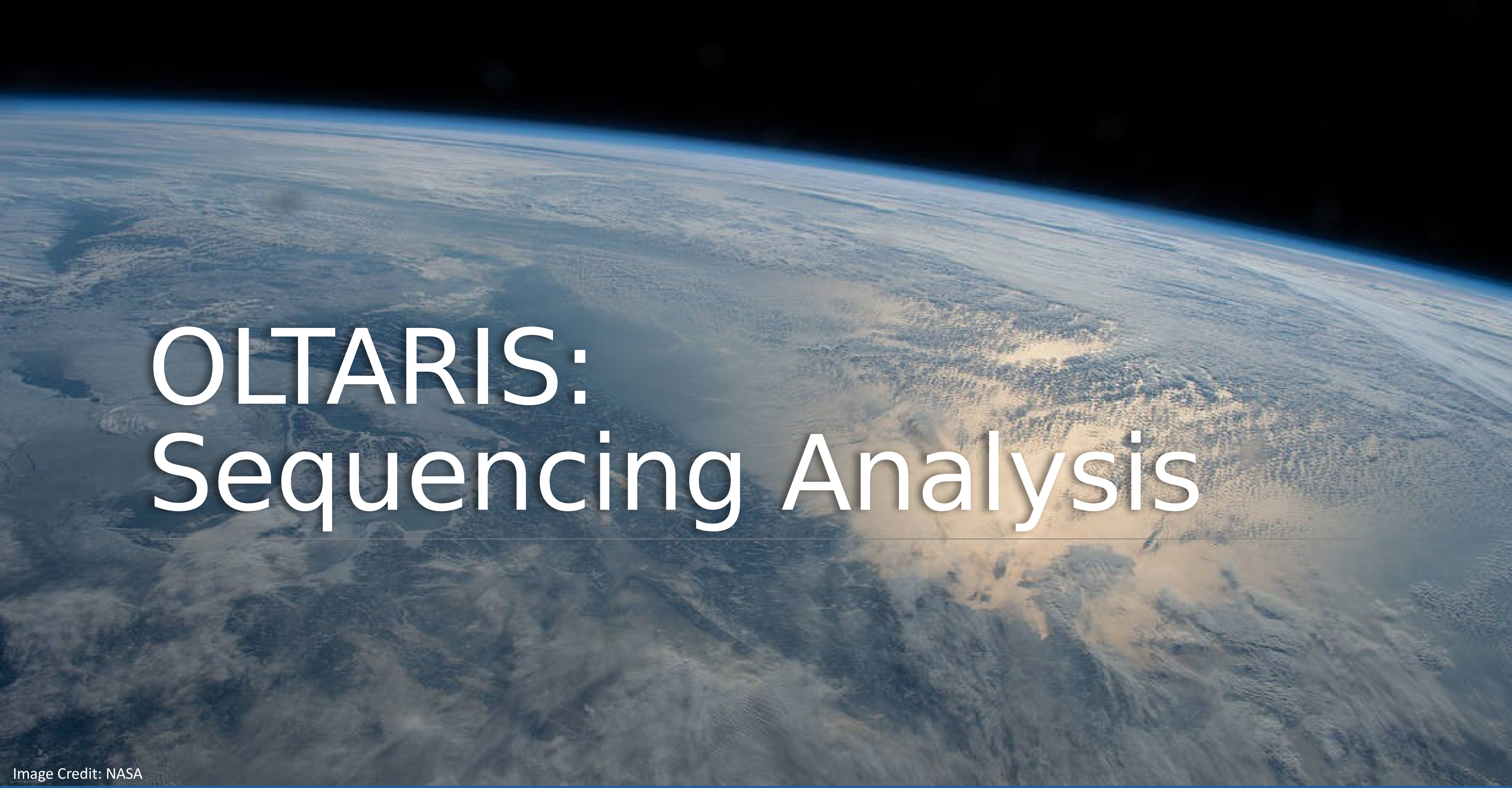


Figure 9. Graphs show the added effectiveness of boron-10 enriched BNNT materials in comparison to natural boron. Lunar surface GCR environment at 200 g/cm².



OLTARIS: Sequencing Analysis

Image Credit: NASA

OLTARIS Parameters

Free Space GCR

- Slab
- Environment: GCR, Free Space 1 AU
  - GCR model: Badhwar-O'Neill 2020
  - Mission definition: Select Historical Solar Min/Max
  - Historical min/max: 1977 (DSNE)
  - Mission duration days: 1
- Geometry: Slab
- Response Functions: Dose Equivalent, ICRP 60
- Note: Slab accounts for bi-directional, or backscattered neutrons

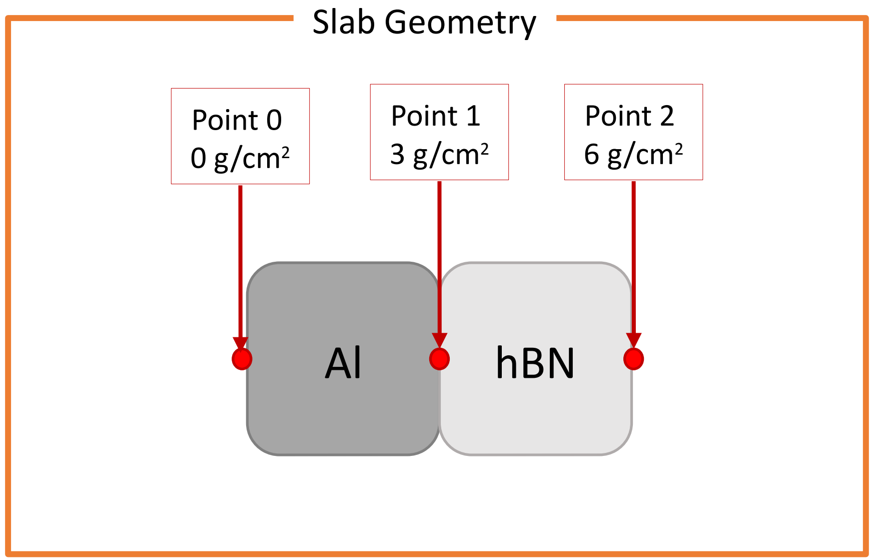
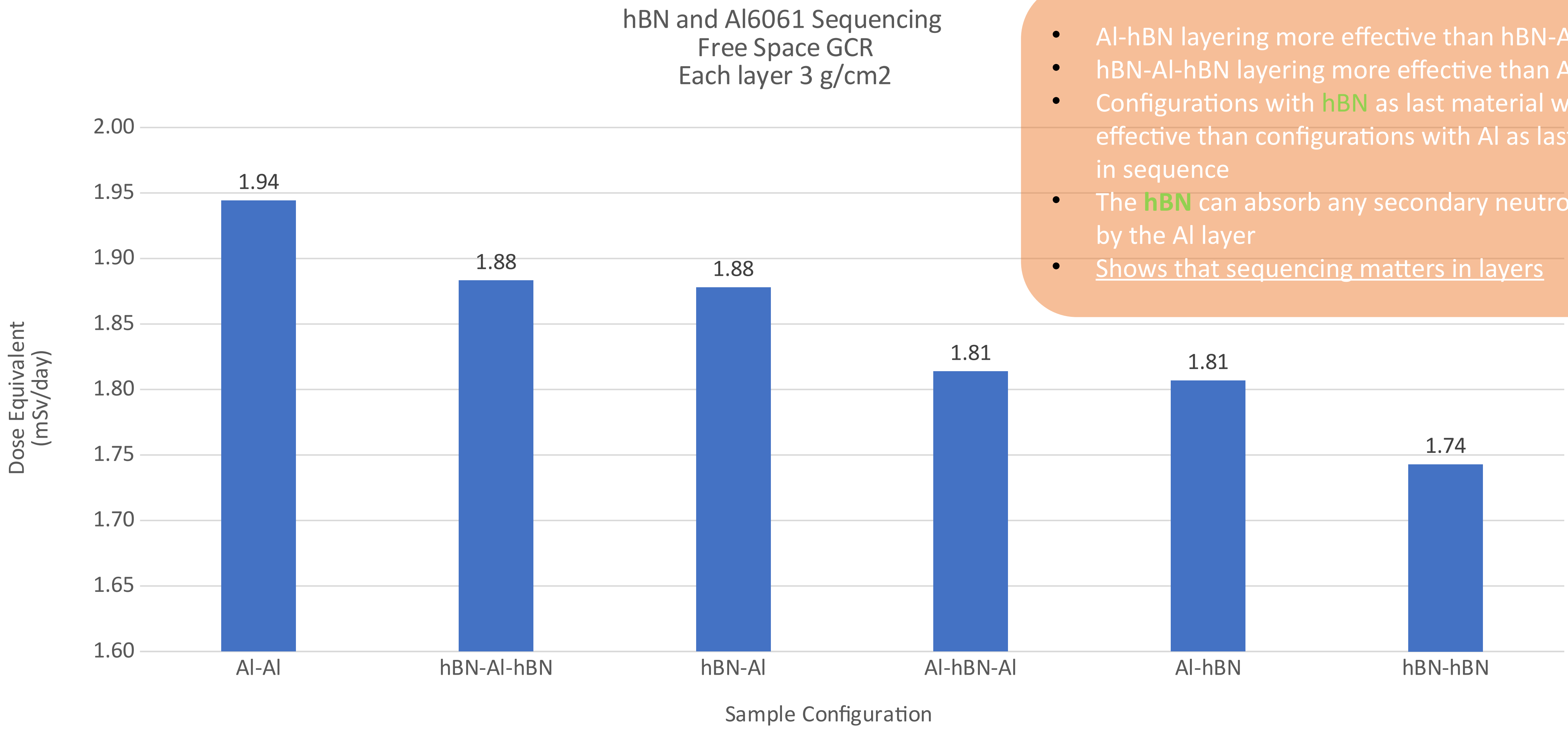


Figure 10. Slab geometry allows for the easy layering of multiple materials and gives the dose through each point in layer with added backscattering neutron effect

Parameters apply to all graphs shown after this slide



- Al-hBN layering more effective than hBN-Al
- hBN-Al-hBN layering more effective than Al-hBN-Al
- Configurations with hBN as last material were more effective than configurations with Al as last material in sequence
- The **hBN** can absorb any secondary neutrons created by the Al layer
- Shows that sequencing matters in layers

Figure 11. Various configurations of hBN and Al6061 in Free Space GCR environment. Each layer is of 3 g/cm² areal density. Dose equivalent is through entire sequence

Neutron Experiments

IN PERSON

Neutron Source

- Americium Beryllium fast neutron source
- Source is a mixture of Am-241 and Be-9
- Emits ~1300 mrem/hr directly at source

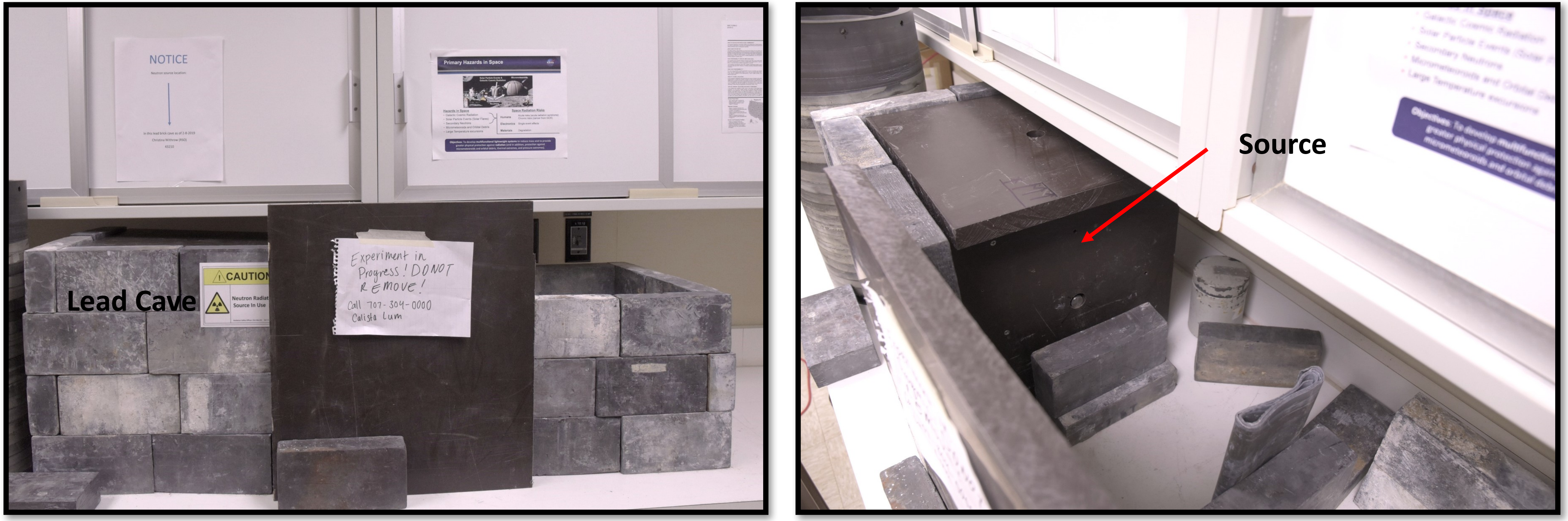


Figure 12. Image of lead cave set up surrounding LaRC radiation source

Sample Configurations

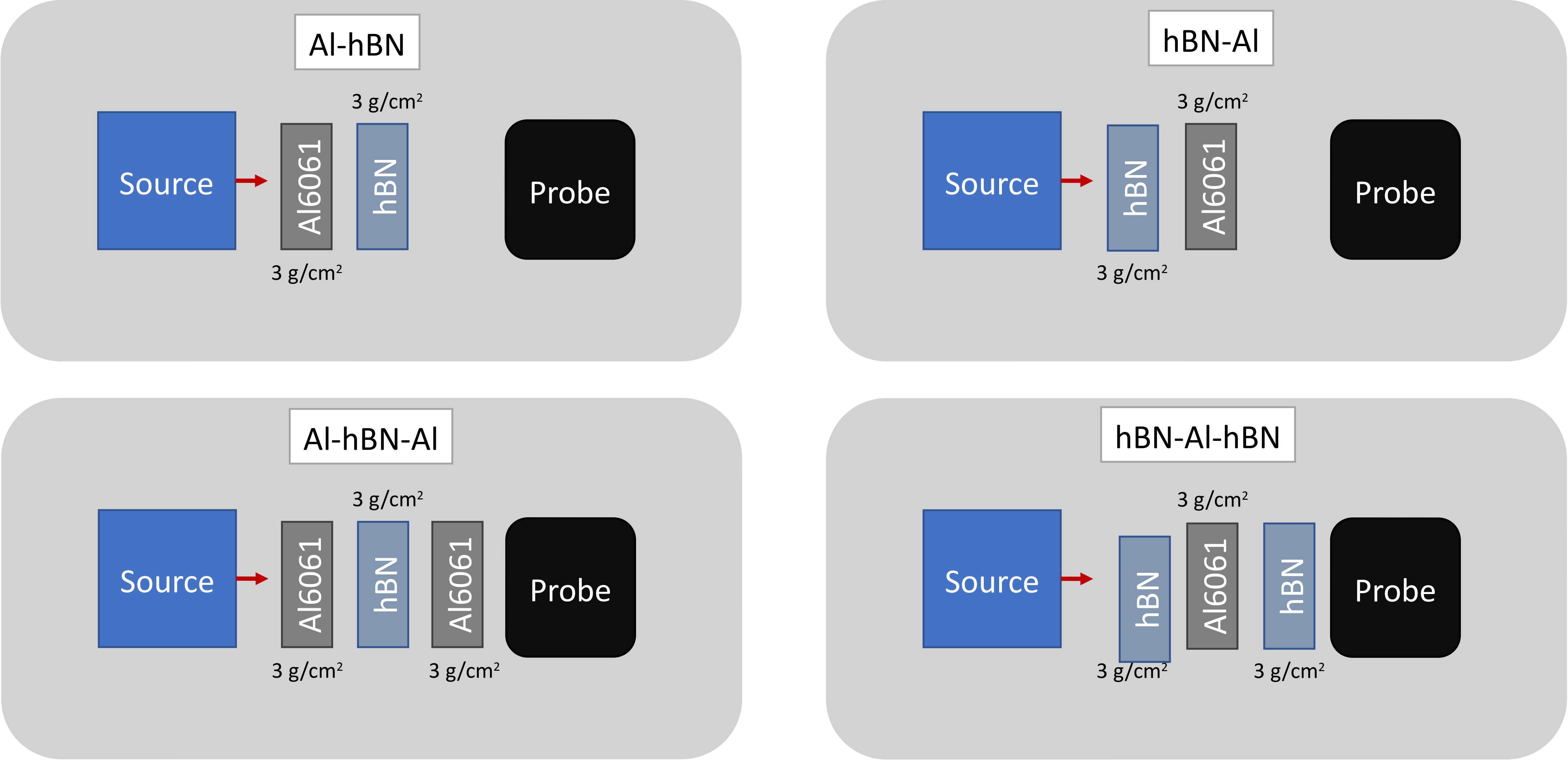


Figure 13. hBN and Aluminum configurations with various sequencing. Each layer is 3 g/cm^2 areal density. Dose equivalent measured with Geiger probe

Sample Configurations

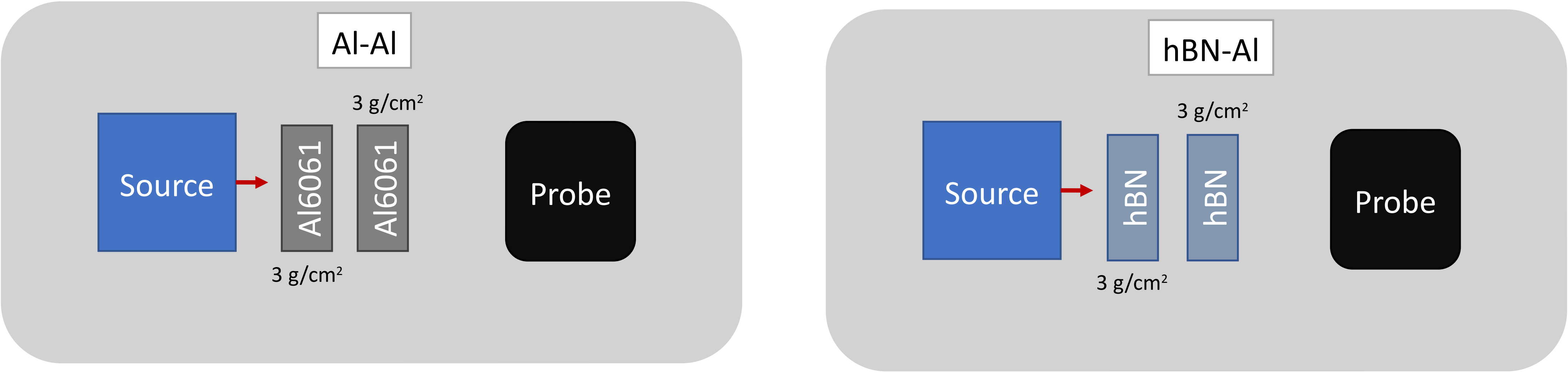
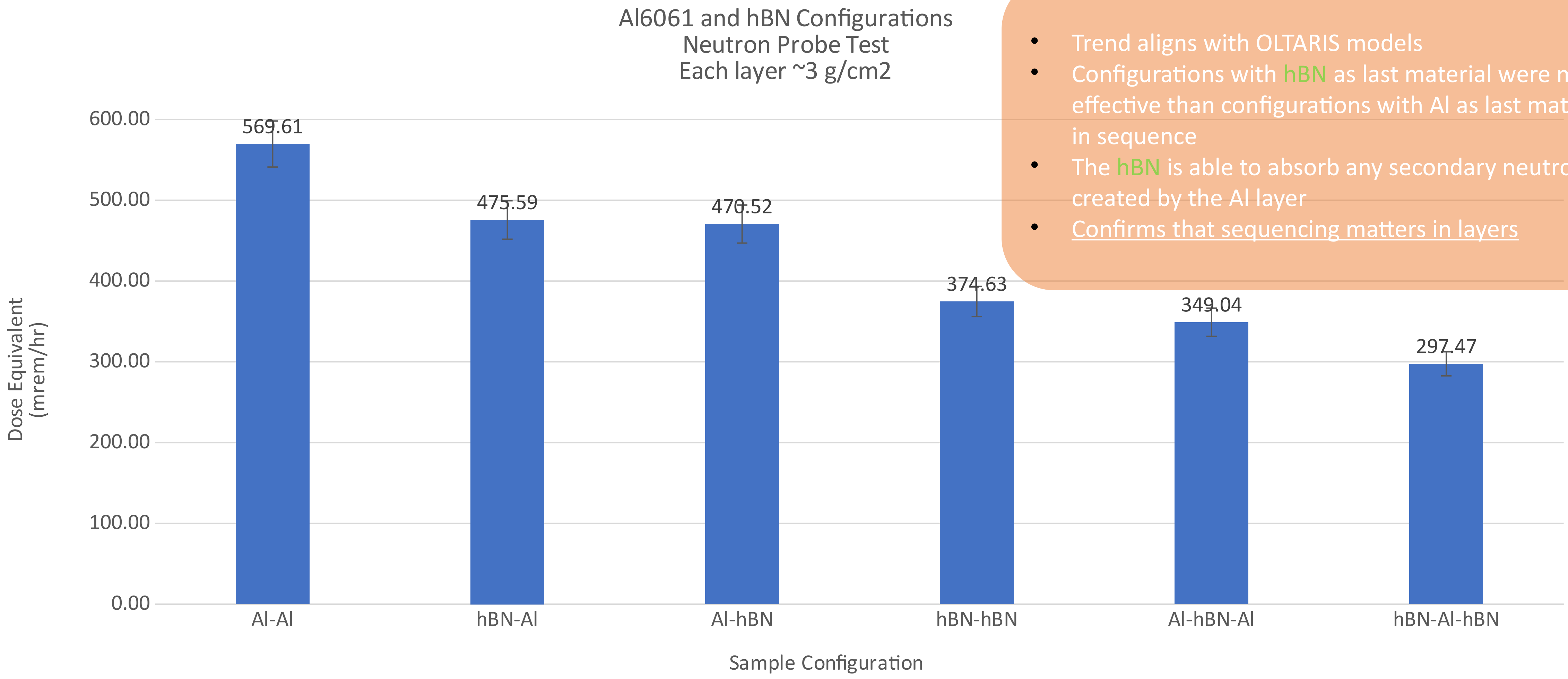


Figure 14. hBN and Aluminum configurations with various sequencing. Each layer is 3 g/cm² areal density. Dose equivalent measured with Geiger probe



- Trend aligns with OLTARIS models
- Configurations with hBN as last material were more effective than configurations with Al as last material in sequence
- The hBN is able to absorb any secondary neutrons created by the Al layer
- Confirms that sequencing matters in layers

Figure 15. hBN and Aluminum configurations with various sequencing. Each layer is 3 g/cm[2] areal density. Dose equivalent measured with Geiger probe

Conclusions and Future Remarks

My time at NASA Langley Research Center has been key in my development as a student and individual. I have had the opportunity to learn new skills and further my competency as a researcher.

Conclusions:

- We found that the presence of boron is imperative to effectively suppress the back scattering neutron.
- We also found that boron-10 enriched BNNT materials can increase the suppression of secondary neutrons.
- Furthermore, if reinforcing materials such as BNNT or boron-10 enriched BNNT are added to effective shielding materials such as MgBH, mechanical properties can be improved while the shielding effectiveness is maintained.
- Lastly, sequencing of configurations matters. Placing effective shielding materials such as hBN after less effective materials such as aluminum allows for any negative effect to be suppressed.

Next Steps:

- Investigation of how to best optimize shielding material sequencing
- Further analysis of the secondary neutron effect and potential of BNNTs as a shielding material

Acknowledgements

Thank you to the following for their support and the opportunity to gain such valuable experience:

Dr. Cheol Park and Dr. Sang-Hyon Chu

Professors Sayantani Ghosh and Jennifer Lu

NIFS Coordinators

Minority University Research and Education Project

AMPB Branch

Group members: Jenna Frey, Joshua Crawford, and Scott Phan

Special thanks to Dr. Catharine Fay, Christine Dillard, Jalisa Thomas, Jessica Gangitano, and all of those who helped in allowing me to be in-person and on center!