Online Training cum Summer Internship Program
On
Space Radiation Shielding & Spacecraft Protection

by MNIT, Jaipur

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PROJECT TITLE: Comparative Simulation of Boron Nitride and Aluminum Shielding Effectiveness against Galactic Cosmic Rays in Different Space Environments using OLTARIS

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O B J E C T I V E

The project aims to study how well ***Boron Nitride (BN)*** and ***Aluminum(Al)*** can block harmful space radiation, specifically ***Galactic Cosmic Rays (GCRs)***, using NASA's *OLTARIS* simulation tool.

It compares their shielding performance in three different ***space environments***:

1. Free Space
2. Lunar Surface
3. Martian Surface

In this project, we will study the

1. Dose Equivalent as a function of Areal Density
2. Flux of particles as a function of Kinetic Energy after transport

INTRODUCTION

With increasing interest in deep space exploration, protecting astronauts from high-energy ***Galactic Cosmic Rays (GCR)*** has become a critical challenge.

This project explores the effectiveness of ***Boron Nitride (BN)***, a promising alternative to conventional ***Aluminum (Al)***, as a radiation shielding material.

Using the *OLTARIS* simulation platform, we analyze how both materials perform in different ***extraterrestrial environments*** —

- Free Space
- Lunar Surface
- Martian Surface

MATERIALS

PARAMETER	ALUMINIUM	BORON NITRIDE
Radiation Attenuation	Moderate	High, especially for GCR heavy ions
Atomic Number	Higher(3) Undergo nuclear fragmentation when hit by high energy particles	Lower(B = 5, N = 7) Produces less harmful secondary particles
Secondary Radiation	More neutron and gamma production	Less secondary particle generation
Thermal Stability	Good	Excellent, stable at high temperatures
Spaceflight usage	Extensive	Emerging
Weight vs. Effectiveness	Higher mass for same shielding	Effective at lower mass
Mechanical Strength	Ductile	Brittle but strong in composite forms

OLTARIS

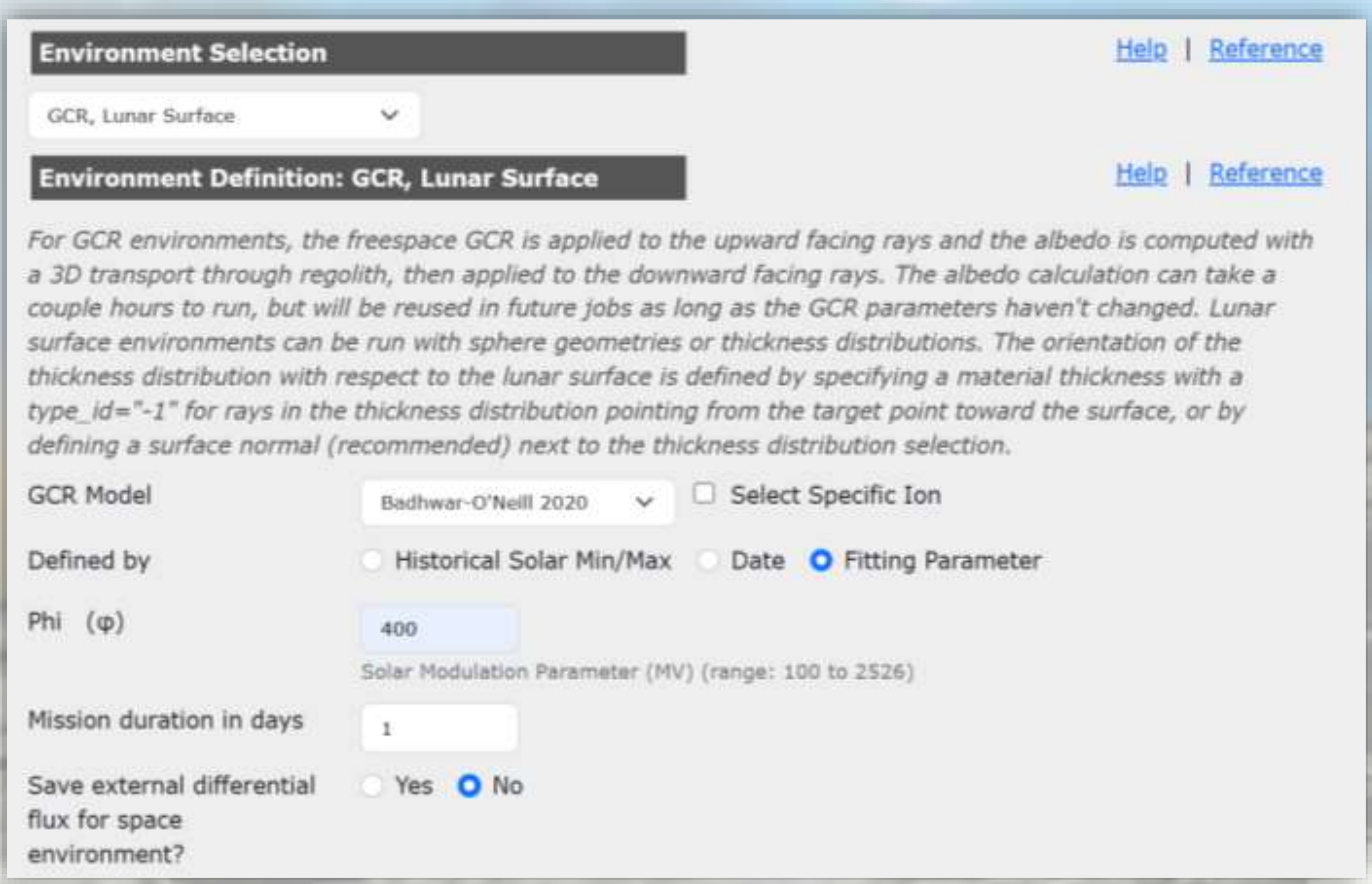
OLTARIS is an **O**n-**L**ine **T**ool for the **A**ssessment of **R**adiation in **S**pace.

- Developed by **NASA** as a web-based simulation platform to assess space radiation effects.
- Used to evaluate radiation impact on **spacecraft, habitats, space suits, and electronics**.
- Simulates exposure to **Galactic Cosmic Rays (GCR)** and **Solar Particle Events (SPE).**
- Powered by the **HZETRN** (High Charge and Energy Transport) code for accurate radiation transport modeling.
- Allows users to define **mission profiles**, **shielding materials**, and **geometry configurations**.
- Supports realistic simulations for **Free Space, Lunar, and Martian** environments.
- Designed with modern software practices and user-driven requirements for flexibility and accuracy.

SIMULATION SETUP

OLTARIS allows users to simulate space radiation exposure by configuring mission conditions and environment-specific parameters.

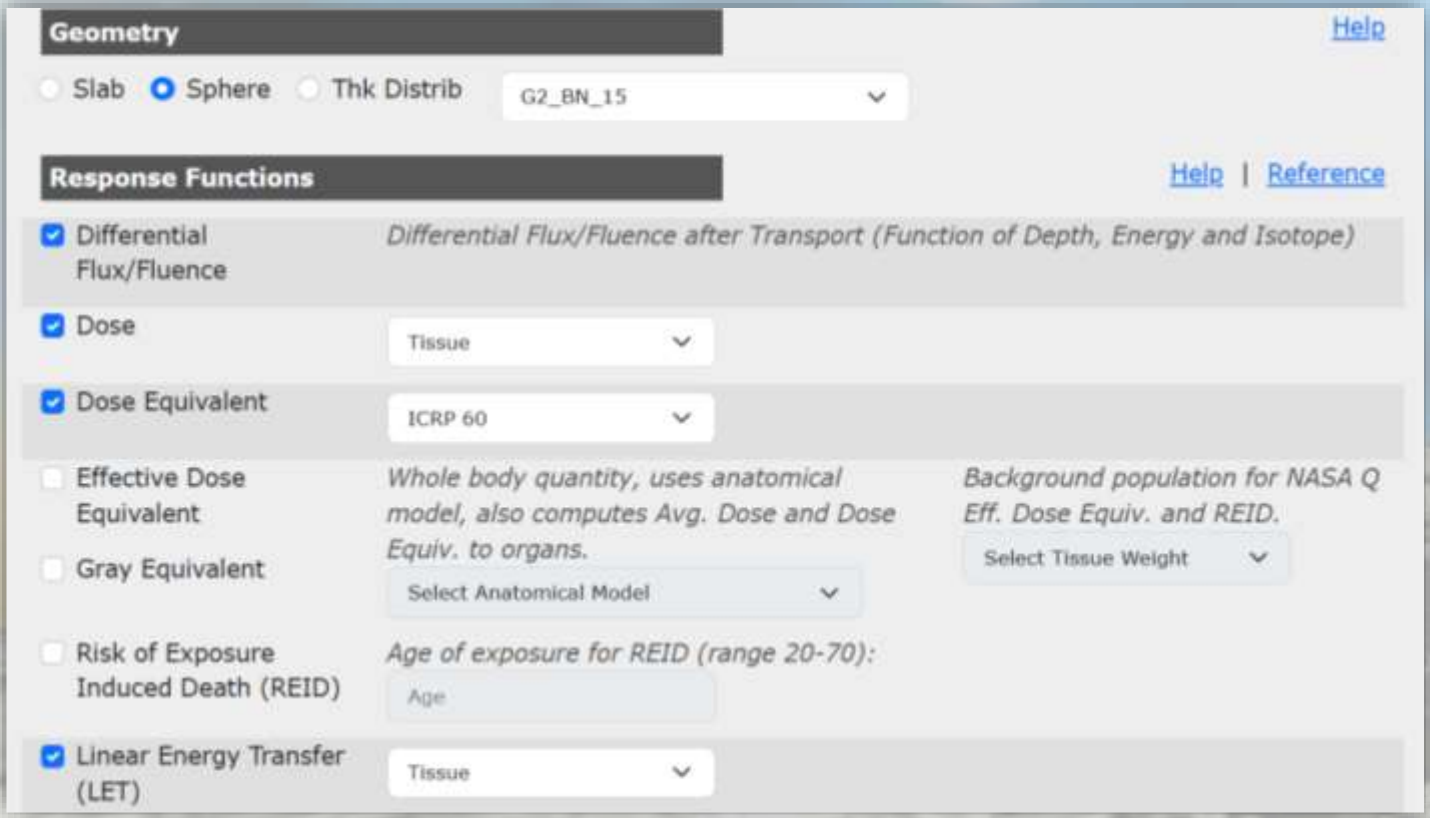
- Environments –
  - Free Space
  - Lunar Surface
  - Martian Surface (MarsGRAM)
- Radiation Type –
  - Galactic Cosmic rays (GCR)
  - Solar Particle Events (SPE)
- Radiation Models –
  - BON2020 (GCR)
  - OCT198 (SPE)
  - Solar Modulation (e.g. φ = 400 MV)
- Mission Duration –
  - Customizable: 1 day to 30 days



SIMULATION PARAMETERS

OLTARIS allows uses to define material properties, geometry, and shielding configurations to analyze radiation effects and generate meaningful outputs.

- Geometry Types –
  - Slab
  - Sphere
  - Cylinder
- Aerial Density – maximum 15 g/cm³
- Outputs –
  - Dose Equivalent
  - Particle Flux vs Kinetic Energy
  - LET Spectra
- Target Types –
  - Human tissue
  - Silicon
- Materials –
  - In-built: Al, water
  - Customizable



Importance of this comparative analysis

☐ **Enhances Astronaut Safety:**
Helps identify materials that better reduce biological radiation risks from GCR and SPE.

⚙ **Improves Material Efficiency:**
Assesses if Boron Nitride (BN) can offer equal or better protection than Aluminum (Al) with less mass or secondary radiation.

Environment-Specific Optimization:
Enables tailored shielding strategies for different radiation conditions in free space, lunar and Martian environments.

📊 **Data-Driven Approach:**
Combines physical modeling with simulation to guide practical material selection.

PROJECT PARAMETERS

- **Environment** – GCR Free Space
- **GCR Environment Model** – BON-2020
- **Solar Modulation, ϕ** = 400 MV (solar minimum condition)
- **Mission duration** – 1 day
- **Geometry** – Sphere (provides a larger and all directional surface for interaction – thus blocks more radiation)
- **Areal density** – 5, 10, 15 g/cm^3
- **Response function** – Dose Equivalent (ICRP 60); Differential Flux; Dose (Tissue)

KEYWORDS

1. **Radiations –** These are harmful high energy particles from Sun and beyond the solar system that can penetrate into spacecrafts and human tissues.
2. **GCR –** They are high-energy, charged particles that originate from outside our solar system, likely from supernovae and other energetic astrophysical events in the galaxy.
3. **SPE –** They are sudden bursts of high-energy charged particles, primarily protons, released from the Sun during solar flares or coronal mass ejections (CMEs).
4. **Dose –** It is the amount of radiation absorbed by a material or tissue.
5. **Dose Equivalent –** It measures the biological effect of radiation on tissue, that is how harmful the type of radiation is.

$$\text{Dose Equivalent (Sv)} = \text{Absorbed Dose (Gy)} \times \text{Radiation Weighting Factor } (\mathrm{w_r})$$

6. **Flux –** It is the rate at which the radiation particles pass through a cross section.

$$Flux(\boldsymbol{\phi}) = \frac{Number\ of\ particles\ (dN)}{Time\ duration\ (dt)\ .\ Area\ of\ cross{-}section\ (dA)}\ \text{particles/cm}^2\text{/s}$$

7. **Kinetic Energy –** The energy carried by fast-moving charged particles like protons or heavy ions.
8. **Solar Modulation –** It is a phenomenon where the solar activity affects the intensity and energy spectrum of solar cosmic rays as they travel through the heliosphere.

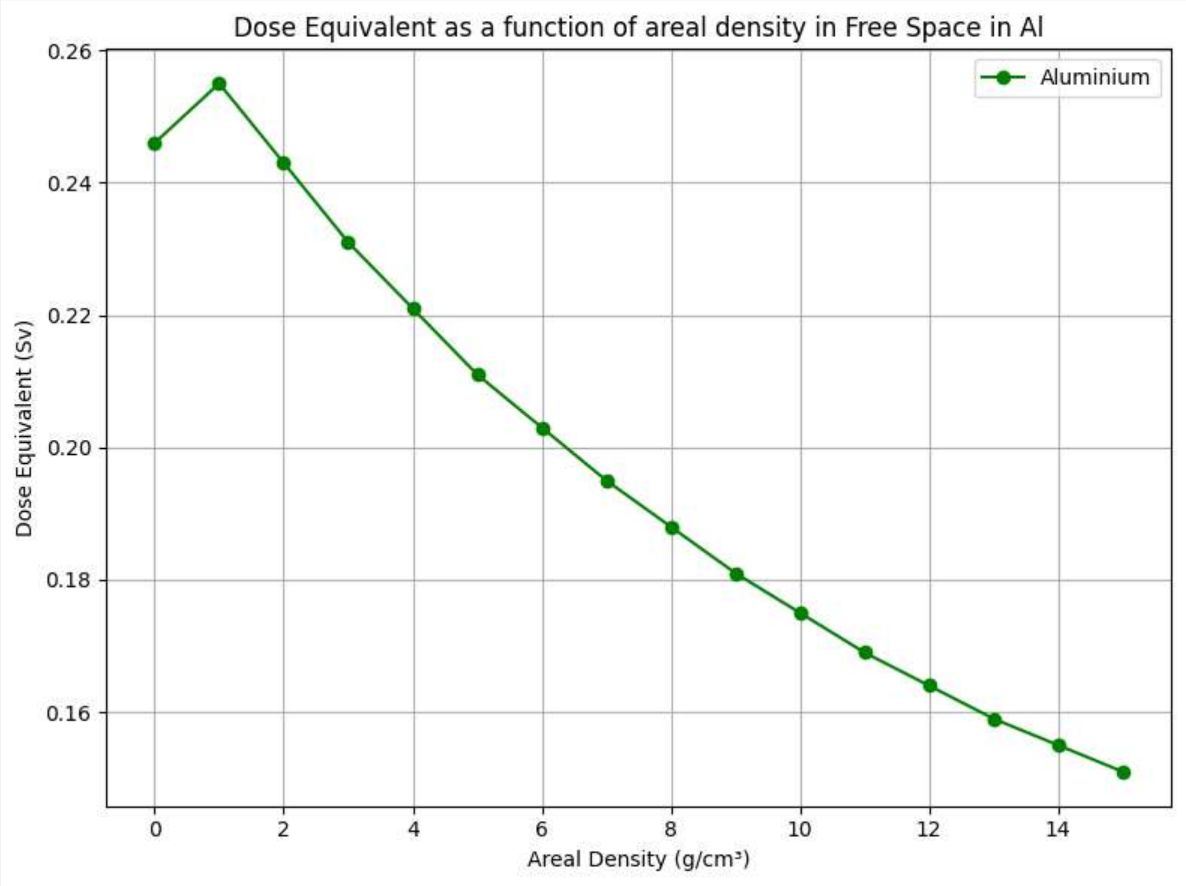
RESULTS

In this project we have studied, plotted and analyzed the following –

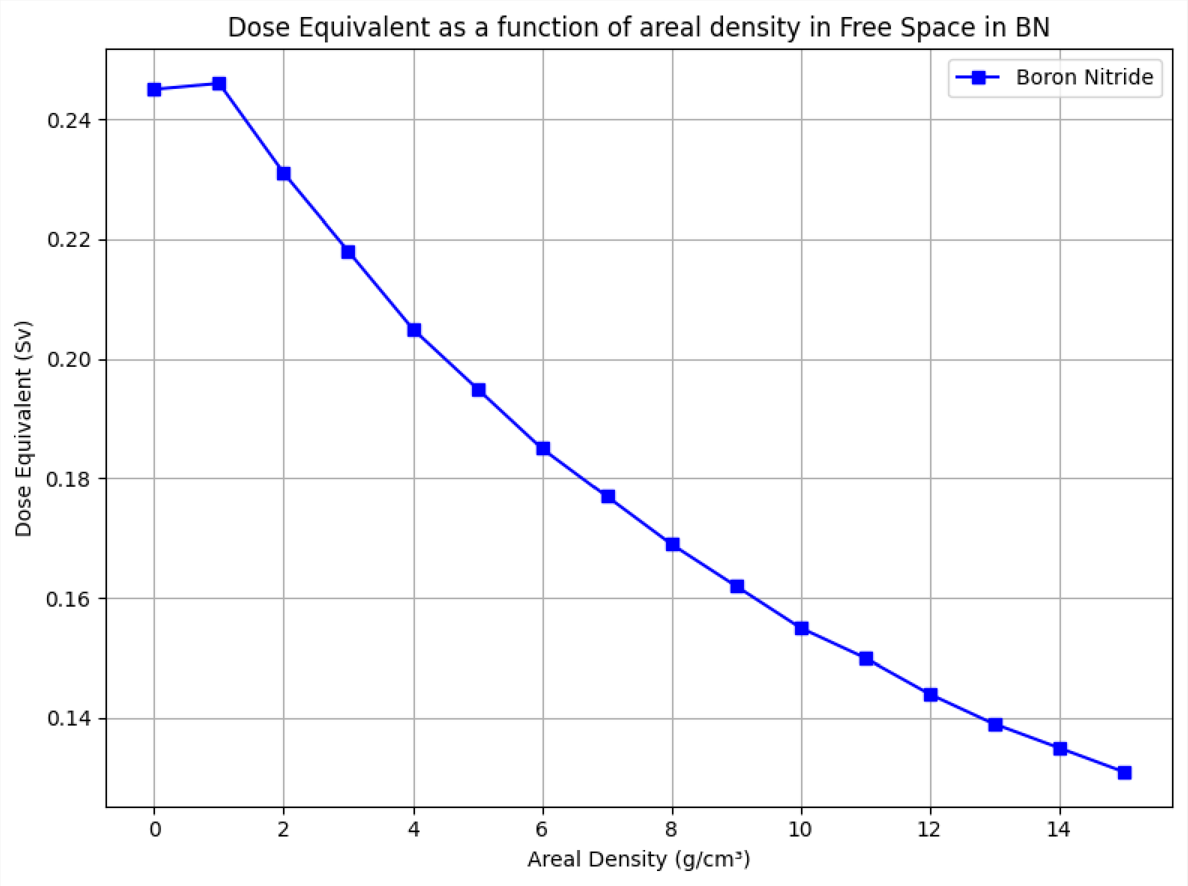
1. Dose Equivalent as a function of Areal Density in Free Space
2. Flux of –
    1. Protons
    2. Alpha particles
    3. Fe56

as a function of kinetic energy after transport in Free Space

DOSE EQUIVALENT V/S AREAL DENSITY

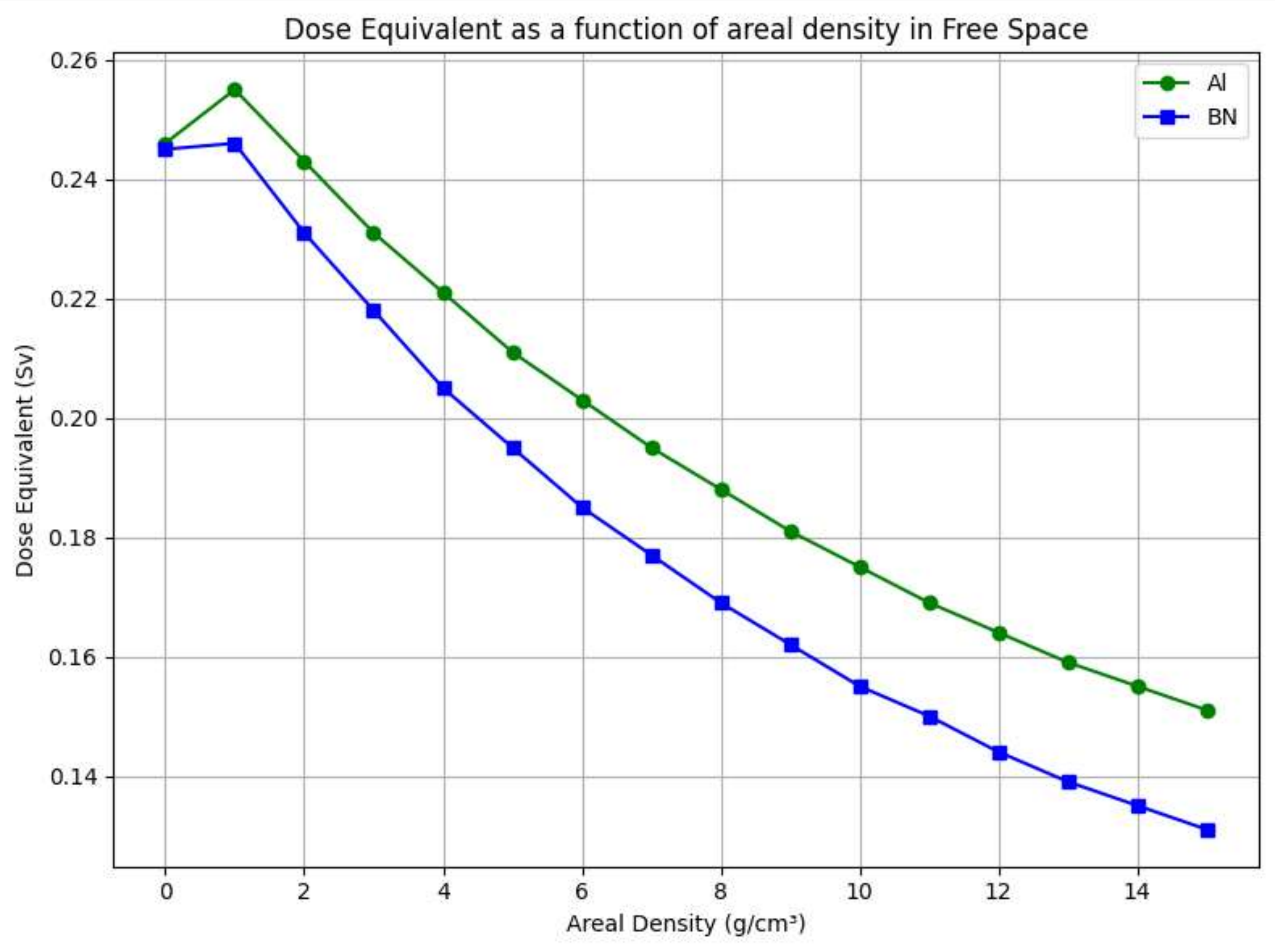


ALUMINIUM

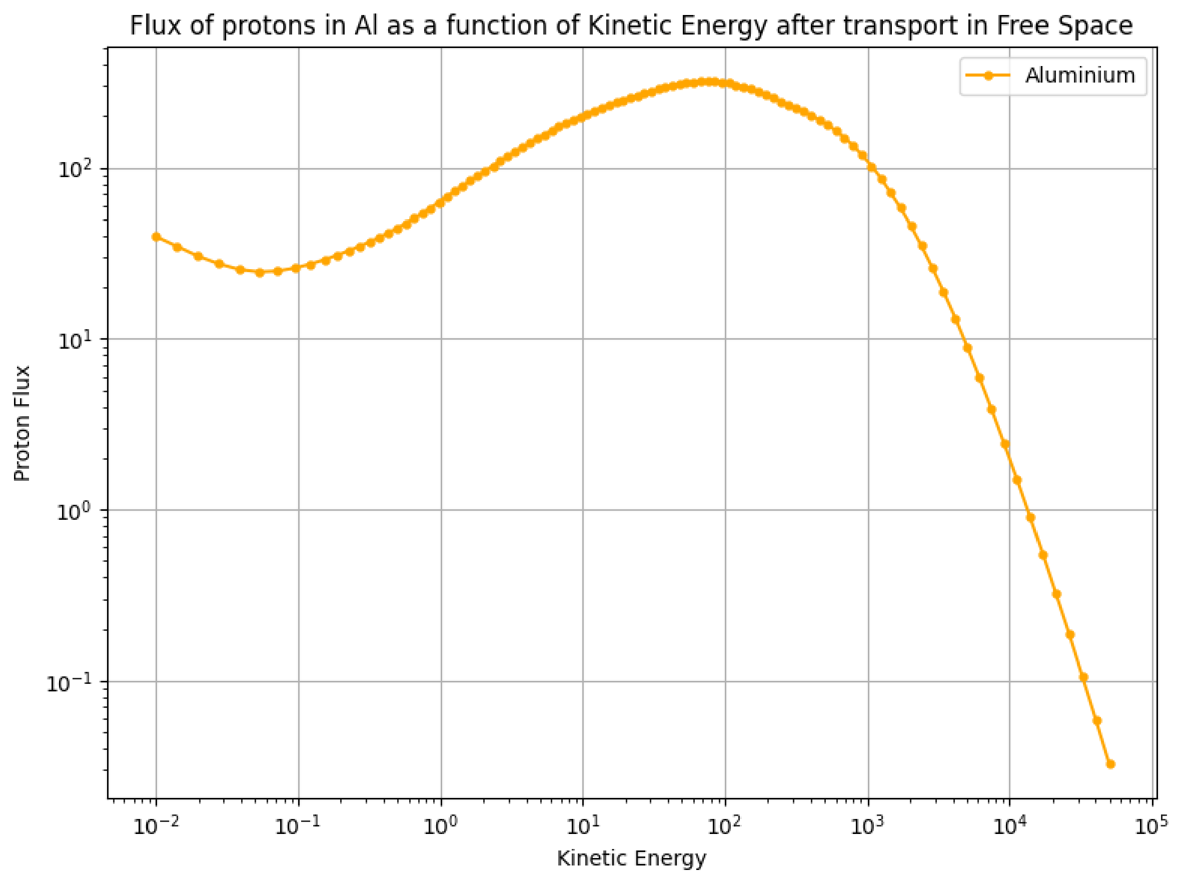


BORON NITRIDE

- At zero thickness, both Al and BN start with the same dose equivalent – unshielded radiation exposure.
- With increase in areal density, dose equivalent decreases for both but for BN it decreases more rapidly.
- We see a jerk in Al before it begins to reduce, this maybe due to secondary particle buildup.
- But as thickness increases the gap between the two plots increases indicating that BN becomes more effective in shielding the radiations.



FLUX V/S KINETIC ENERGY OF PROTON



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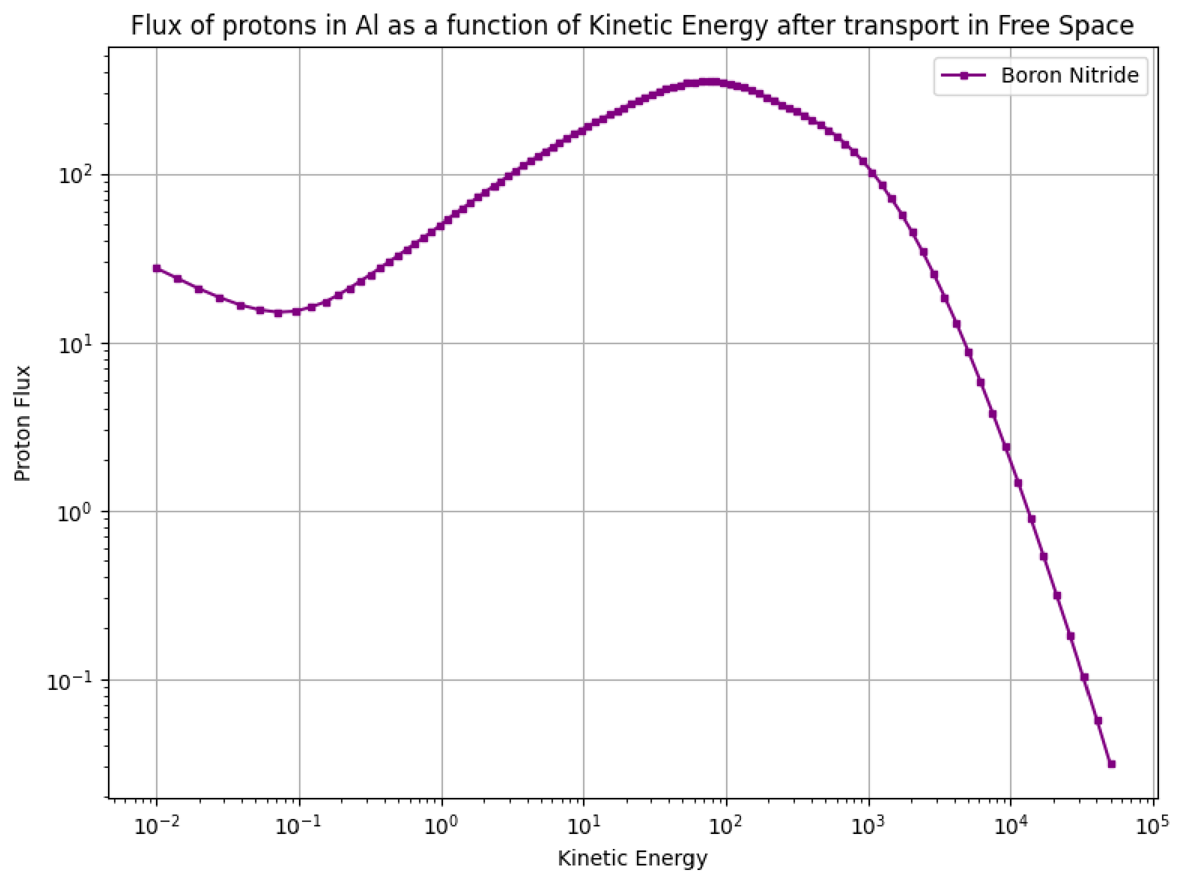
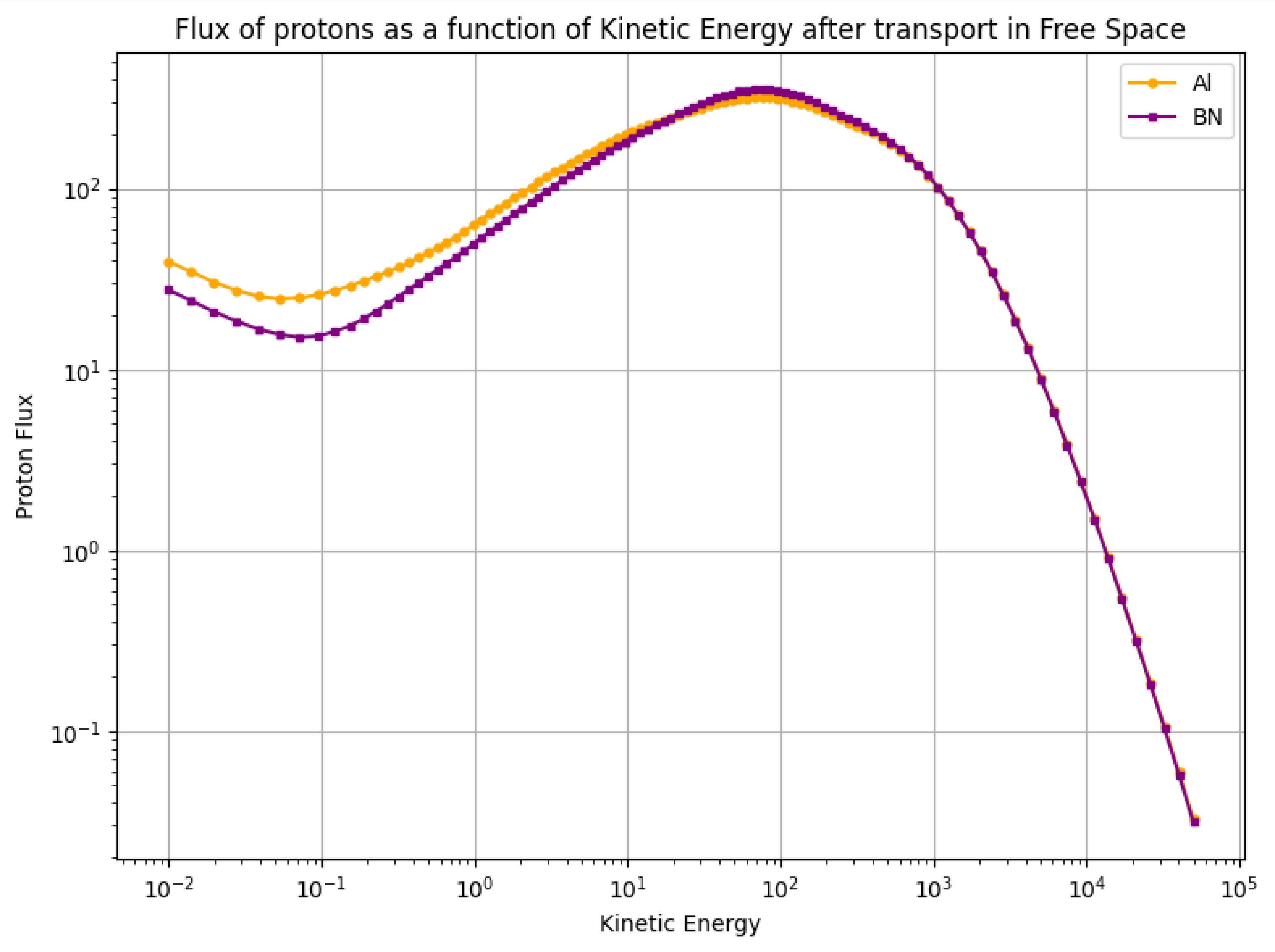
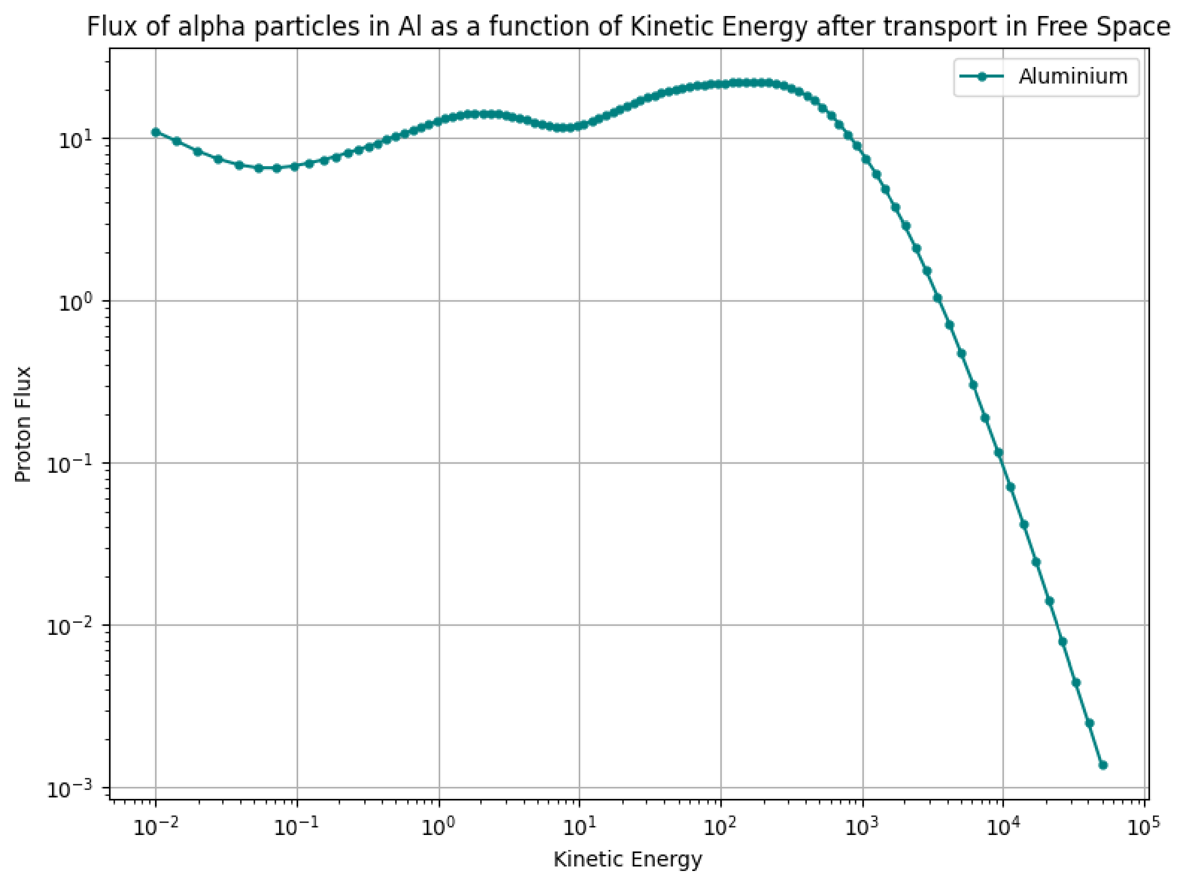


BORON NITRIDE

- At low energies, BN shows lower proton flux than Al – thus it blocks low energy photons right from the beginning.
- In moderate energy region, BN continues to show a lower flux.
- The peak represents the energy where most protons emerge after passing through the shield.
- BN's peak is still lower than Al's peak – thus the former blocks more protons.
- But, in peak energy regions, the flux falls and converges gradually since high energy particles are hard to catch or deflect; with BN still a slightly below Al.



FLUX v/s KINETIC ENERGY OF ALPHA PARTICLES



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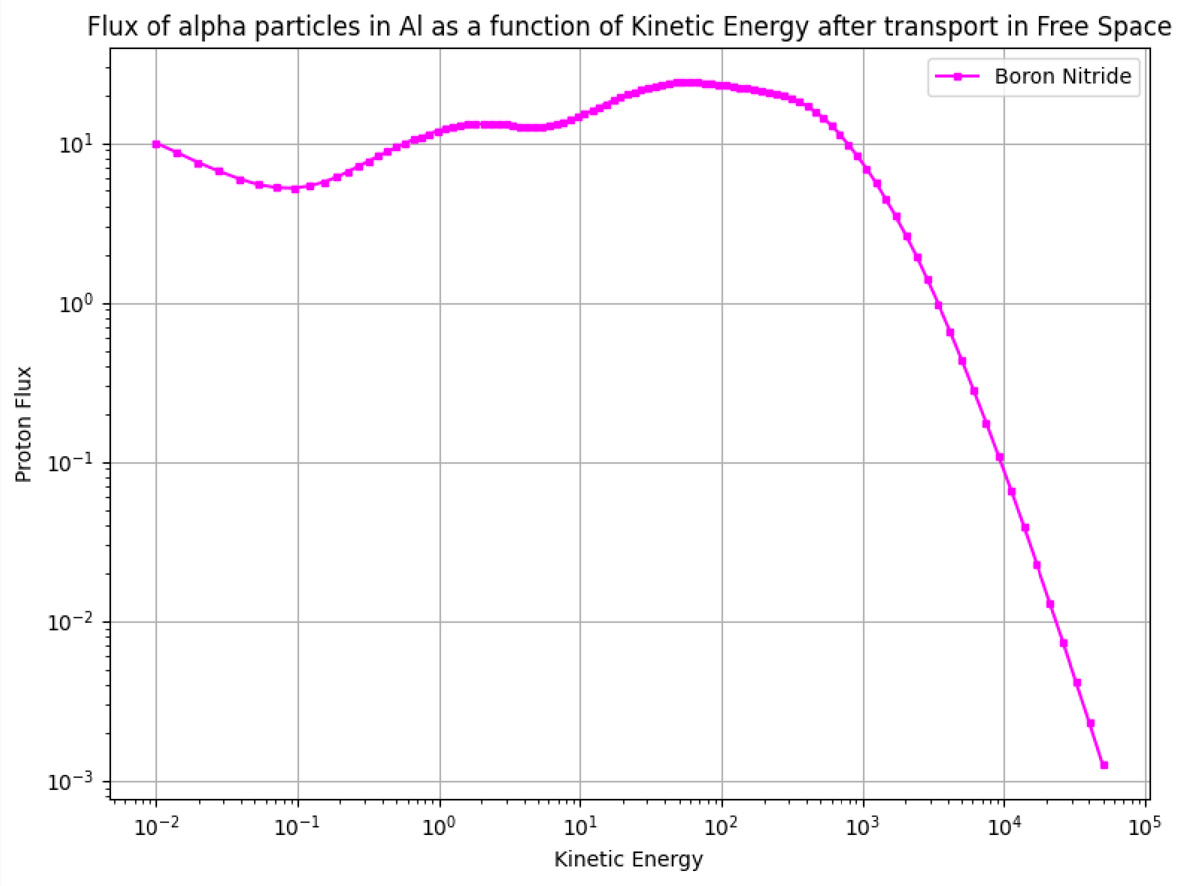
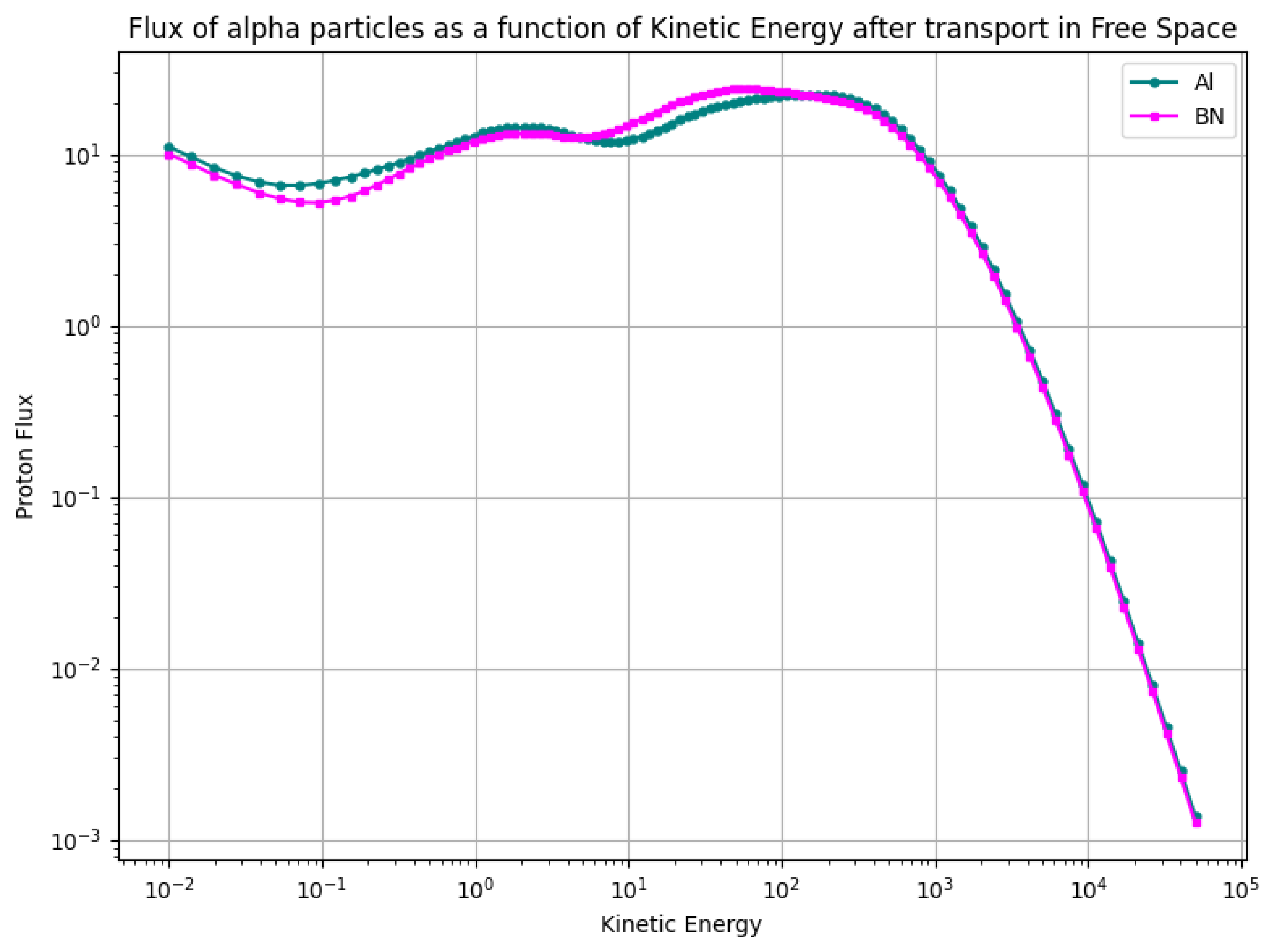
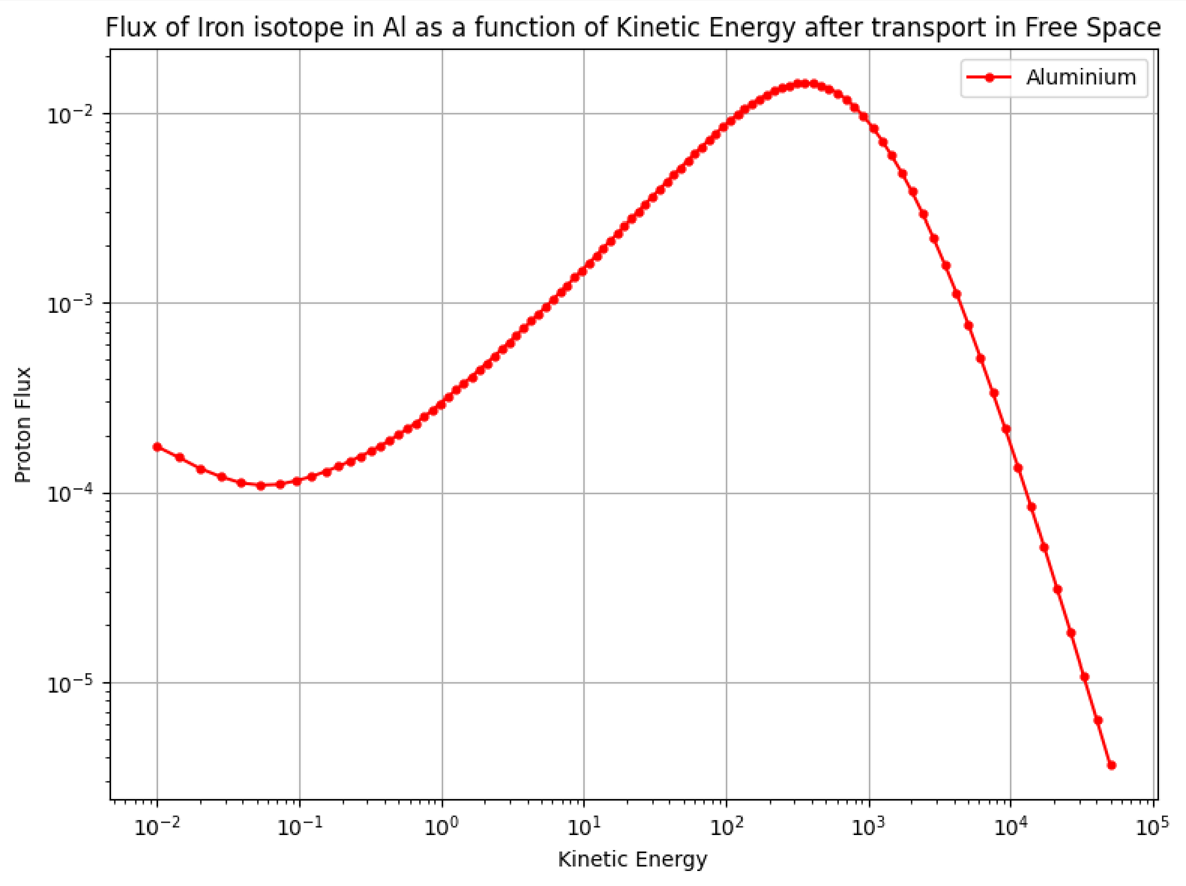


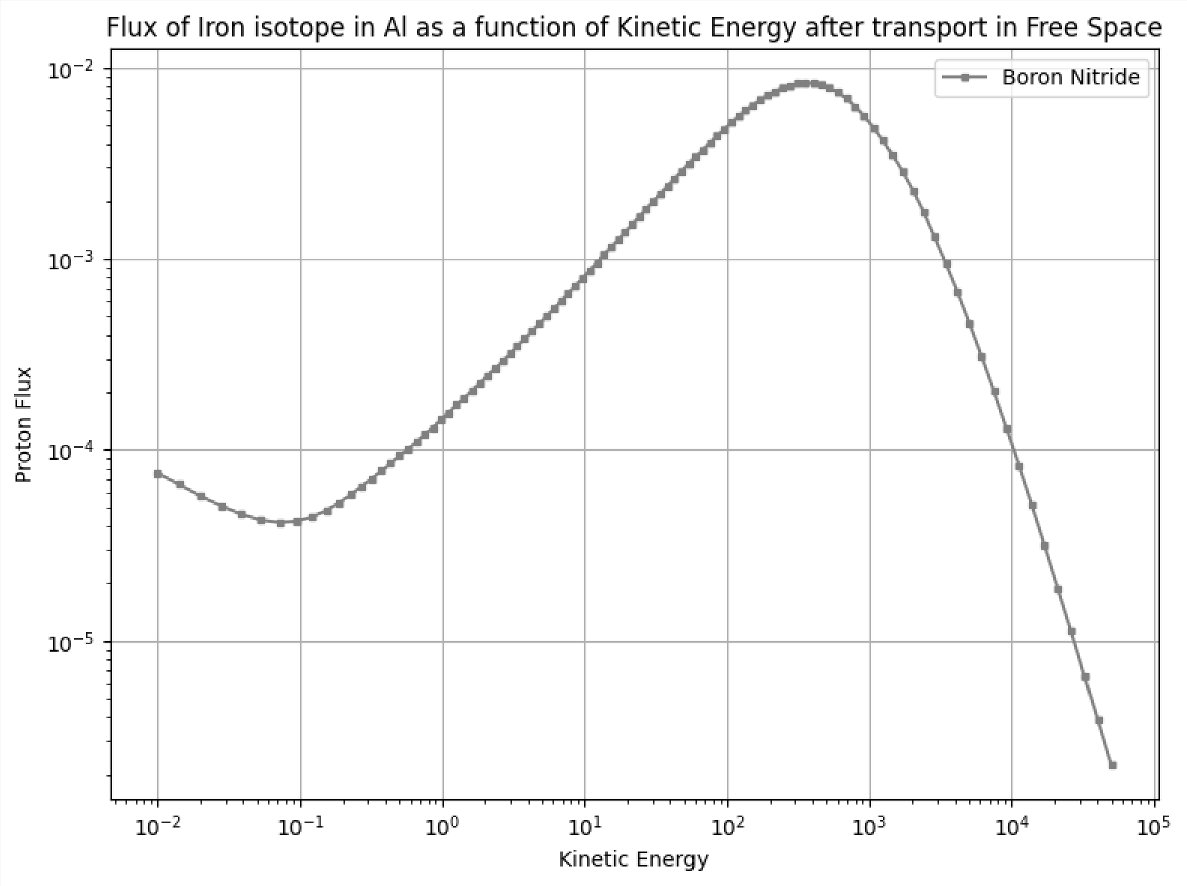
BORON NITRIDE

- At low energies, BN shows lower alpha flux than Al – which are biologically significant due to higher ionizing potential.
- In moderate energy region, the wave-like shape shows how alpha particle flux varies non-linearly with energy due to complex interactions with the shielding material which can be due to different energies, secondary particle production or nuclear interactions.
- The peak represents the energy where most alpha particles emerge after passing through the shield.
- BN's peak is still lower than Al's peak – thus it absorbs or deflects more particles even at the energy at where they are intense.
- At very high energies the alpha particles are highly penetrating thus the shielding difference between the two reduces to minimum.



FLUX V/S KINETIC ENERGY OF IRON ISOTOPE (FE56)

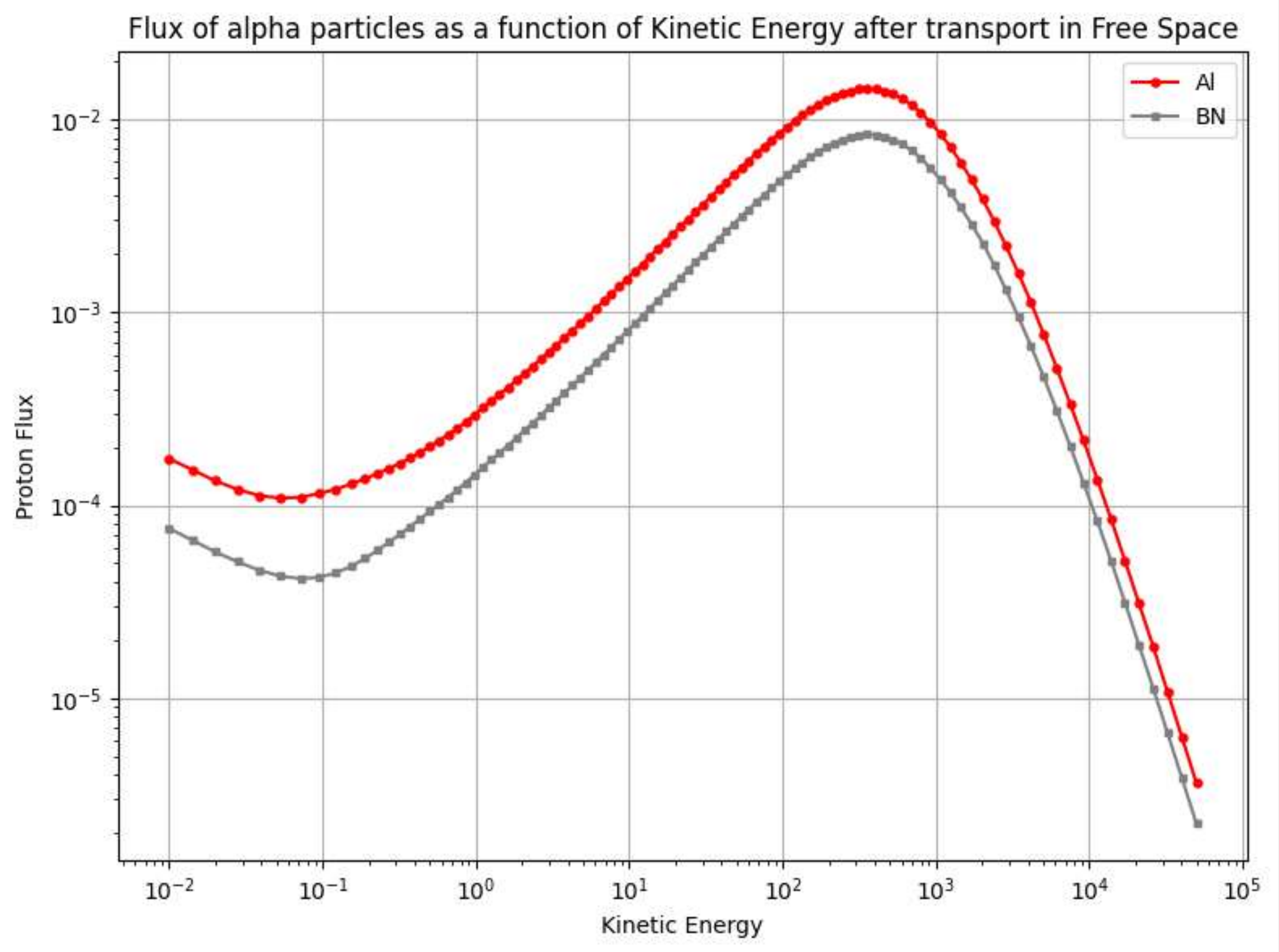




ALUMINIUM

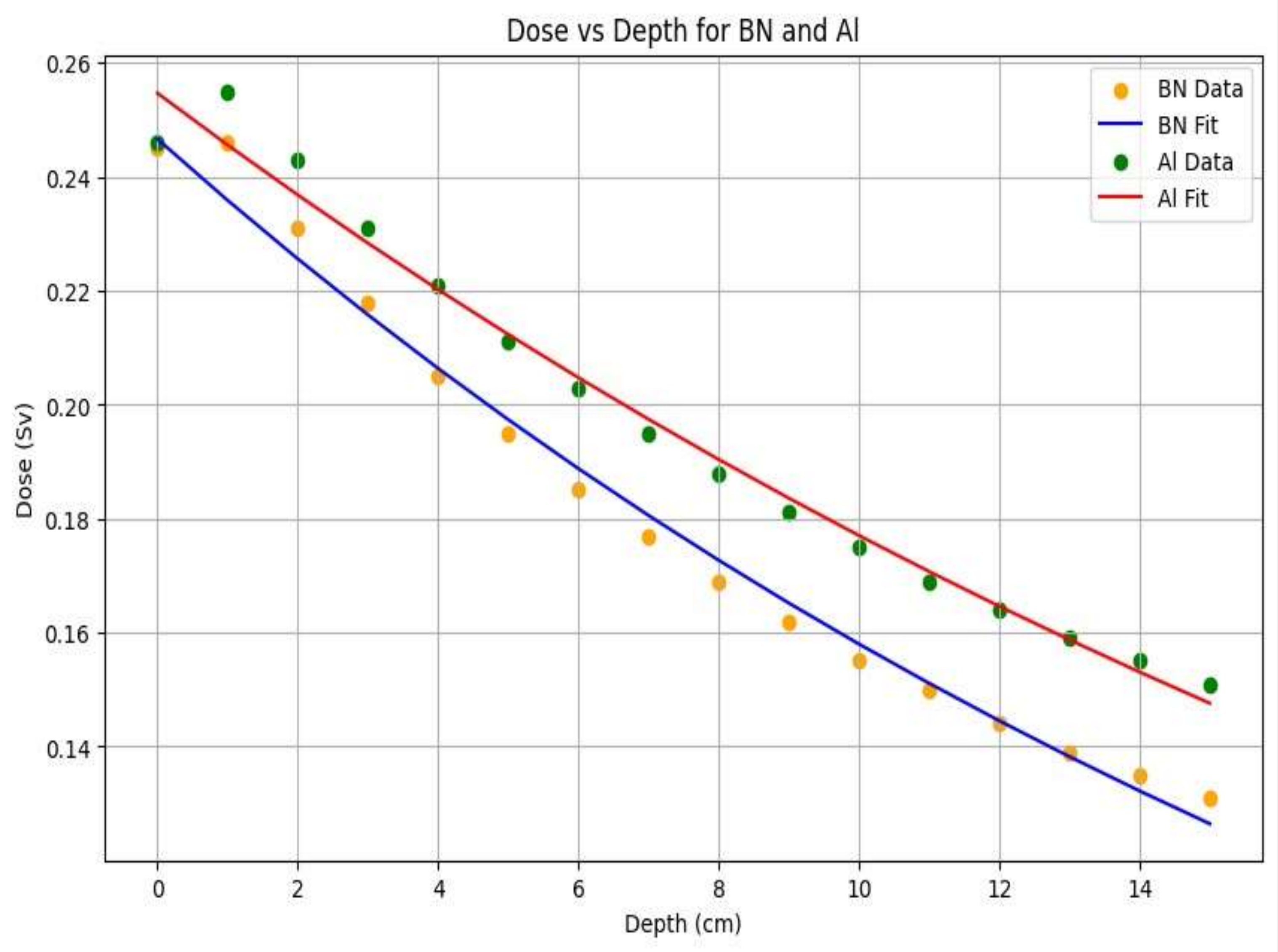
BORON NITRIDE

- At low energies, BN shows lower iron flux than Al – it attenuates more low-energy iron particles which are highly ionizing and thus biologically harmful.
  - The dip indicates that shielding is most effective and BN having a deeper dip outperform Al's ability to block incoming particles.
  - The peak represents the energy where most iron particles emerge after passing through the shield.
- BN's peak is still lower than Al's peak – thus it absorbs or deflects more particles even at the most intense point of the energy spectrum.
  - At very high energies, the flux falls sharply for both, though the gap reduces – BN still lower than Al.



LINEAR REGRESSION

- Both the materials show a downward linear trend – that is when areal density increases, the log of dose equivalent decreases.
- Thus, radiation exposure decreases as areal density increases.
- Linear Regression of BN is steeper than Al – indicating that BN is more effective per unit thickness at reducing radiation dose.
- Therefore, you need less BN than Al for same level of protection – that is less weight less cost.



CONCLUSION

The study compared the shielding performance of BN and Al against GCR in Free Space in the view of some metrics viz. Dose Equivalent and Flux where Areal Density and Kinetic Energy were the key parameters.

We saw that as the areal density increases, the dose equivalent for both Al and BN decreases but the decrease in BN is more significant than Al for all areal densities. Even at lower densities BN is more effective in blocking radiations, thus, reducing spacecraft weight.

From the Flux vs KE graphs we saw that BN was more effective in shielding since it allowed very few alpha particles and photons (protons) to pass through it. Moreover, it shows less secondary particle radiation like nuclear fragmentation from collision with high energy particles.

The Linear Regression curve of BN is steeper (more negative) than Al indicating that BN reduces radiation dose faster with increasing thickness – that is BN curve fits more accurately with the original data points.

Therefore, BN outperforms Al and is more promising radiation shielding material for deep space missions.


THANK YOU!