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# Evaluating the Effectiveness of Shielding Material, Vehicle Shape and Astronaut Position for Deep Space Travel

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# Evaluating the Effectiveness of Shielding Material, Vehicle Shape and Astronaut Position for Deep Space Travel

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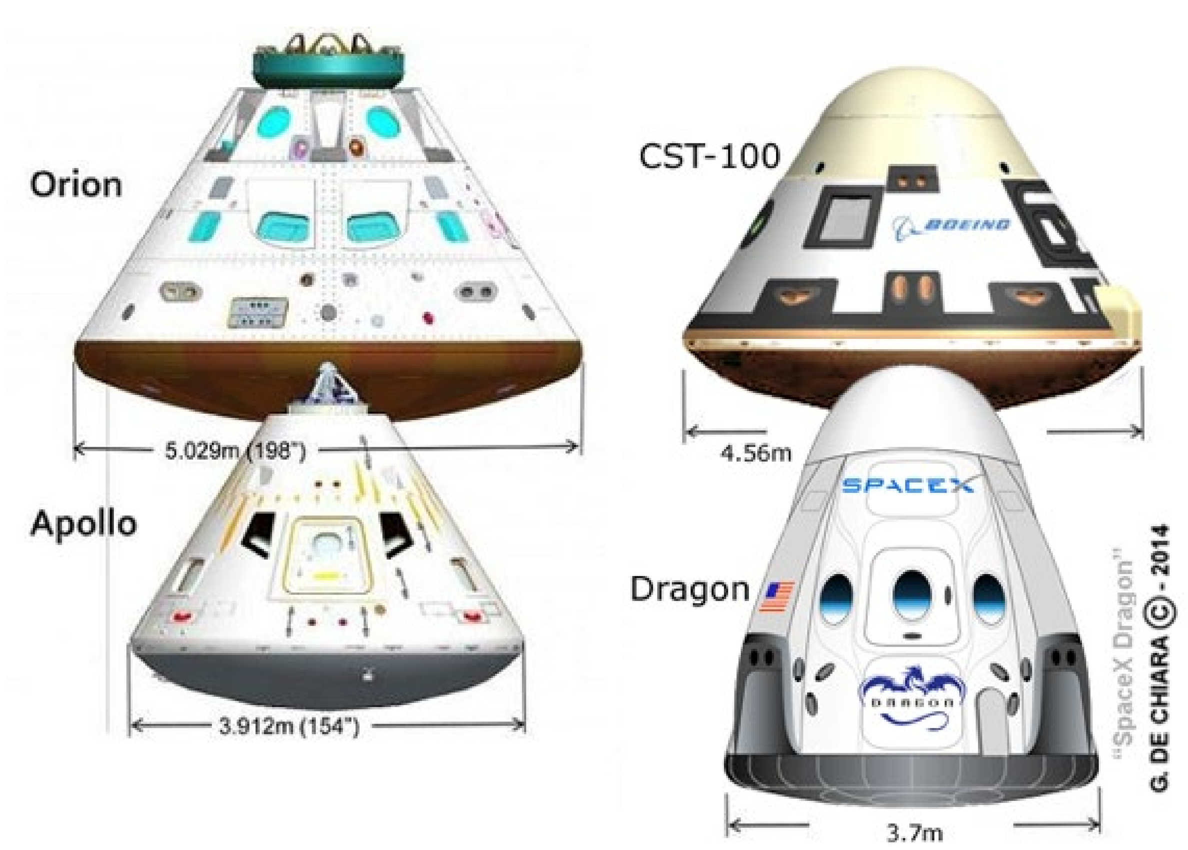
## Abstract

To successfully extend crewed missions into deep space, radiation protection must be in place to shield astronauts from Galactic Comic Rays (GCRs) and Solar Particle Events (SPEs). Previous crewed missions, which were from 1968 to 1972 and had durations less than 13 days, consisted of the truncated cone made pronominally of aluminum. Since traveling to Mars is estimated to take between 200 to 400 days each way, it is important to evaluate the shielding ability of a wide range of materials to effectively protect astronauts during these extended missions. Using NASA Langley's OLTARIS model, this study includes evaluating the shielding ability of 59 materials categorized by metals, polymer, composites and fuels, liquid gases and hydrides. Analyses also include using vehicle shape and astronaut position to further increase radiation protection, using a sphere a right circular cylinder.

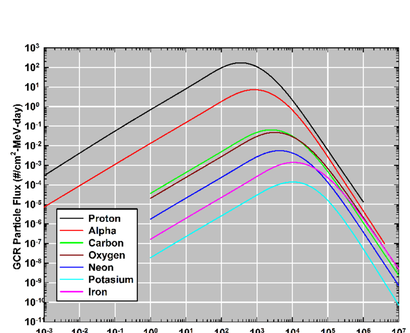
Results show that the fuels, liquid gases and hydrides are the most effective shielding materials, while metals perform the worst. The best performing polymers, composites or metals are polyethylene, polyethylene epoxy and polyethylene with 30% boron. Hydrogen storage did show potential in lowering exposure, but required 15% H in carbon nanotubes to reproduce the shielding ability of polyethylene. Additionally results show that positioning an astronaut closer to the space vehicle wall does significantly decrease the radiation risk compared to when the astronaut is placed in the center. Further analysis is currently being done to evaluate if this pattern is also highlighted in Monte Carlo codes.

## Motivation[1]

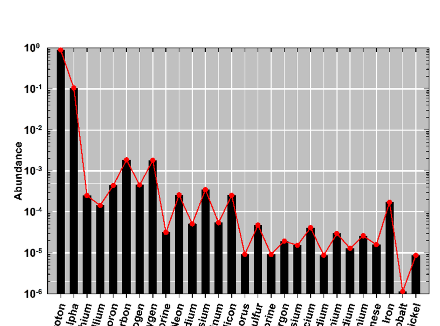



## Boundary Condition

**Galactic Cosmic Rays (GCRs)**
- Accounts for the majority of the background radiation.
- Composed of highly energetic and fully ionized elements
  - Protons
  - Alphas
  - Elements ranging from Li to Ni (5 < A < 58)
- Energies reach up to several hundred GeV per nucleon.
- Even though the abundance of heavy particles is relatively low, they contribute to approximately 86% of the total dose equivalent

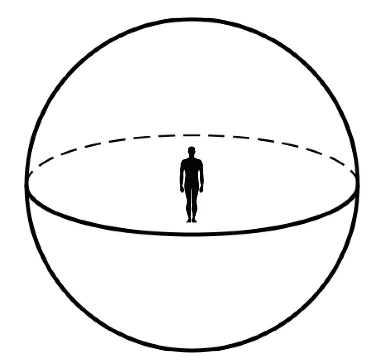
**1977 solar minimum[2,3]**
- Design basis GCR spectrum used as a standard in the historical research.
- The abundances for species heavier than nickel are typically many orders of magnitude less than that of iron 56



## Model Configuration

**NASA OLTARIS (On-Line Tool for the Assessment of Radiation In Space) Model Version 3.5[4,5,6]**

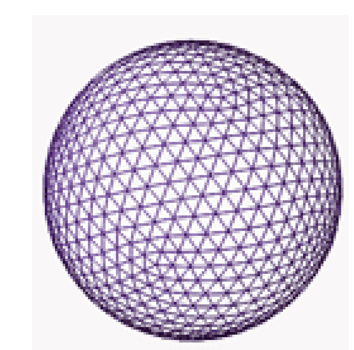
**Spherical Shell**



**Shielding Thicknesses Used**
0.01, 0.1, 0.3, 0.5, 0.75, 1, 3, 5, 7.5, 10, 30, 50, 75, 100, 300, 500, 750, 1000 g/cm$^2$

**Female Adult voXel (FAX)**
2005 version

**1002 Geodesic Ray Distributions**

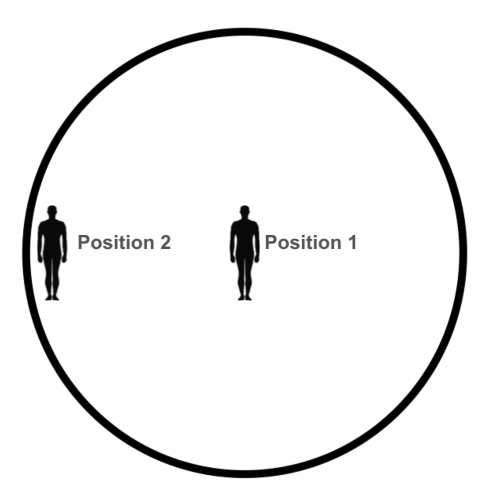


**Ray-by Ray Method**
Evaluating the material, scattering and absorption long each ray.

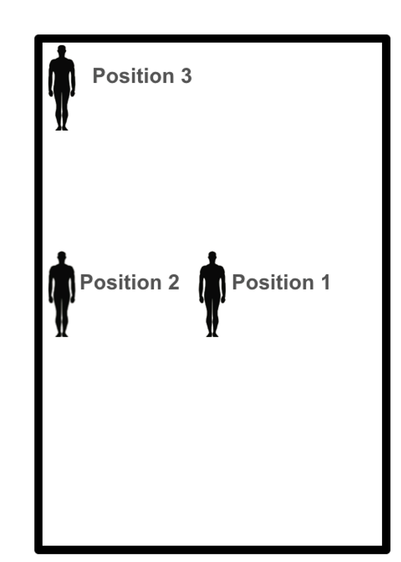
## Materials

| Metals | Polymers | Composites |
|---|---|---|
| Reds and Pinks ▲ | Purples and Blues ● | Greens and Cyans ■ |
| Aluminum | Polyethylene | Graphite Epoxy (51/49) |
| Aluminium Alloy 2195 | Acrylic | IM7/977-3 Graphite Epoxy |
| Martian Regolith | Water | Borated Polyethylene (Natural) |
| Lunar Regolith | Epoxy | Borated Polyetherimide (Natural) |
| | Polyetherimide/Ultem 1000 | Boron Nitride Nanotubes ($^{10}B$) |
| | Polyimide | Borated Polyethylene Epoxy - Natural |
| | Polysulfone | Lunar Regolith - 20% Epoxy |
| Fuels, Hydrides & Liquid Gases | Noryl 731 | Carbon Nanotubes w/ 6.5% H |
| Browns and Yellows ▼ | Tissue | Boron Nitride Nanotubes w/ 7.14% H |
| Methane | Carbon Nanotube | Martian Regolith - 20% Epoxy |
| Liquid Hydrogen | Polyethylene Epoxy | Boron Nitride Nanotubes (Natural) |
| Lithium Hydride - $^6Li$ | Carbon Nanotubes with 400at% H | Carbon Nanotubes w/ 20% H |
| Lithium Hydride - Natural | Martian Regolith w/ 20% Polyethylene | Polyethylene Epoxy with Carbon |
| | Lunar Regolith w/ 20% Polyethylene | Boron Nitride Nanotubes w/ 20% H |
| | Carbon Nanotubes with 200at% H | Borated Polyethylene - $^{10}B$ |

## Vehicle Shape & Astronaut Position

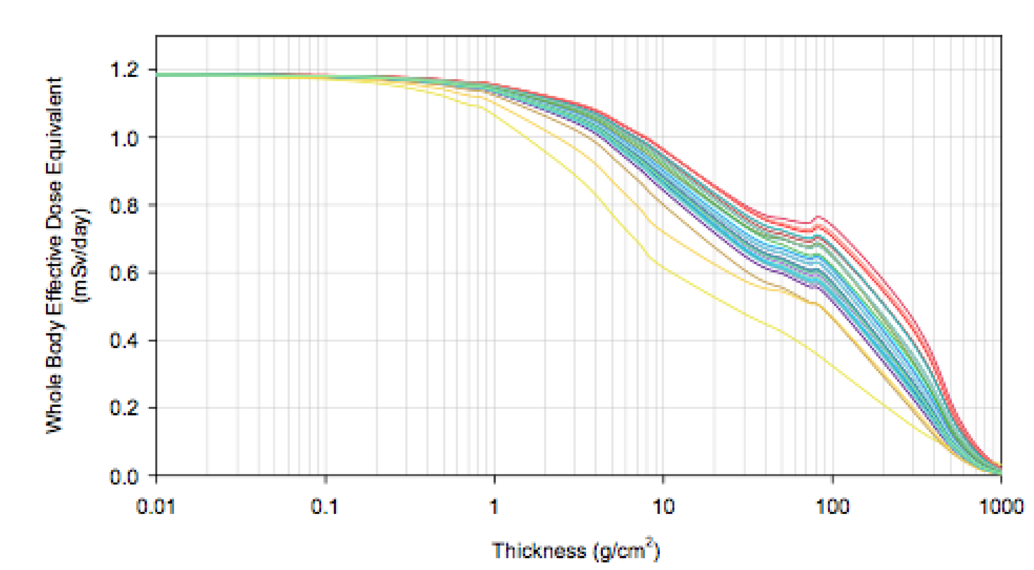


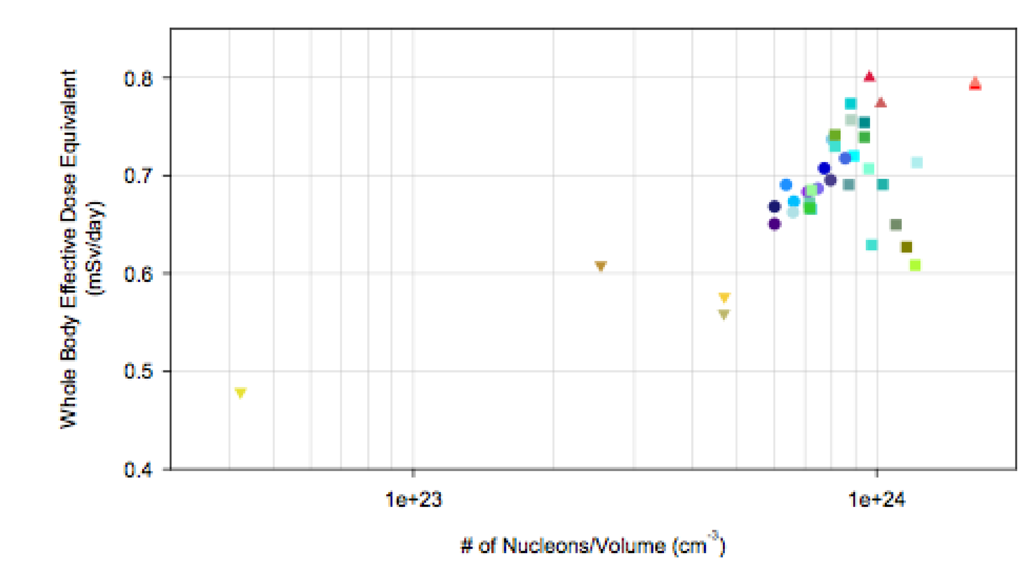

**Vehicle**
Circle with radius of 4.035m
**Astronaut Position**
Position 1 = (0,0,0)
Position 2 = (4.0,0,0)

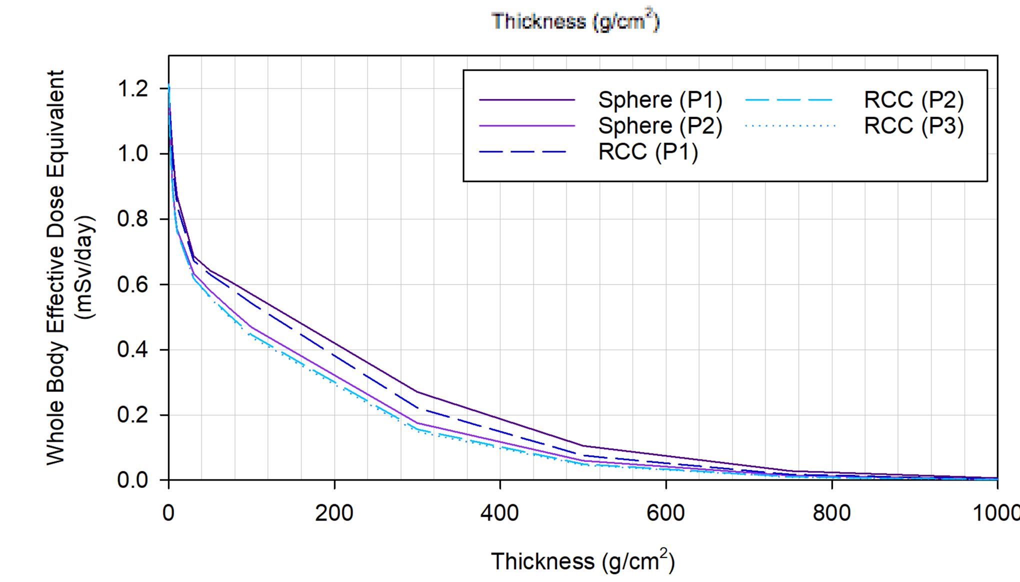


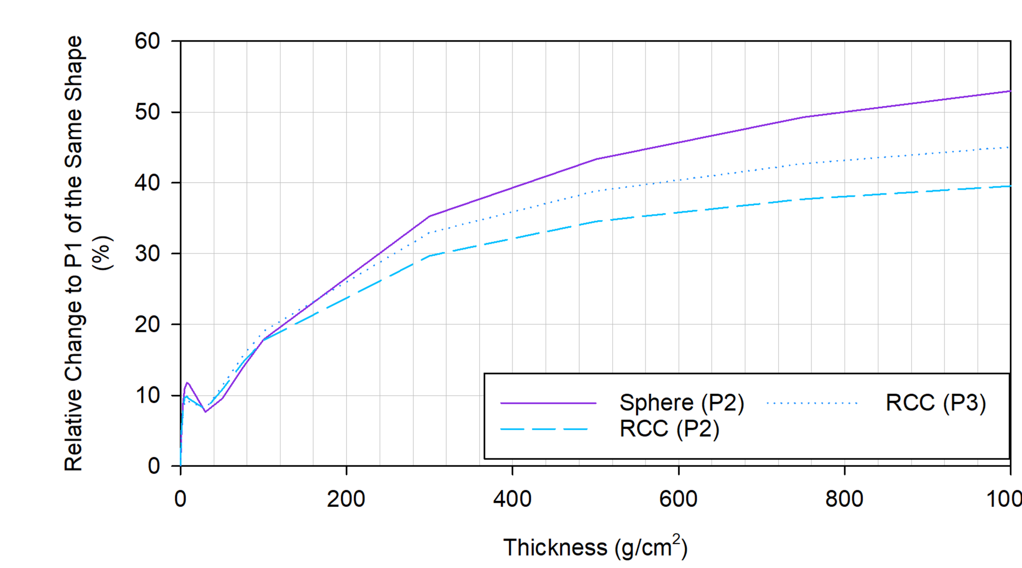

**Vehicle**
Right Circular Cylinder with radius of 3.0m and height of 5.0m
**Astronaut Position**
Position 1 = (0,0,0)
Position 2 = (2.99,0,0)
Position 3 – (2.99,0,4.99)

## Results and Analysis




## Results and Analysis

- Polymer and Composites outperform Aluminum
- The higher the hydrogen contents the better the material's shielding ability, as defined by the ED
- Polyethylene (PE) outperforms all other feasible spacecraft materials, followed by PE epoxy and boronated PE.
- Positioning a human phantom closer to a wall does significantly decrease the ED. This pattern is not dependent on material nor boundary condition, but the mean shielding thickness a source ray must travel through for the GCR boundary condition.
- For shielding thicknesses greater than 30 g/cm$^2$ for polyethylene and 100g/cm$^2$ for aluminum, the results suggest that having astronauts' habitats and work areas located further from the center will help protect astronauts longer from deep space radiation.

## References

[1] Giuseppe De Chiara, Aerospace Illustrator, 2014
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from 1977 to present, Advances in Space Research 37 (9) (2006) 1727 – 1733.
[3] P. O'Neill, Badhwar O'neill 2010 galactic cosmic ray flux model revised, IEEE Transactions on Nuclear Science 57 (2) (2010) 3148 – 3153.
[4] R. Singleterry Jr., et al. Oltaris: On-line tool for the assessment of radiation in space, Acta Astronautica 68 (2011) 1086–1097.
[5] R. Singleterry Jr., S. Blattnig, Clowdsley, G. M.S., Qualls, C. Sandridge, L. Simonsen, J. Norbury, T. Slaba, S. Walker, F. Badavi, J. Spangler, A. Aumann, E. Zapp, R. Rutledge, K. Lee, R. Norman, Oltaris: On-line tool for the assessment of radiation in space, Tech. rep., NASA Technical Paper 2010-216722 (July 2010).
[6] J. Spangler. Oltaris, on- line tool for the assessment of radiation in space [online].