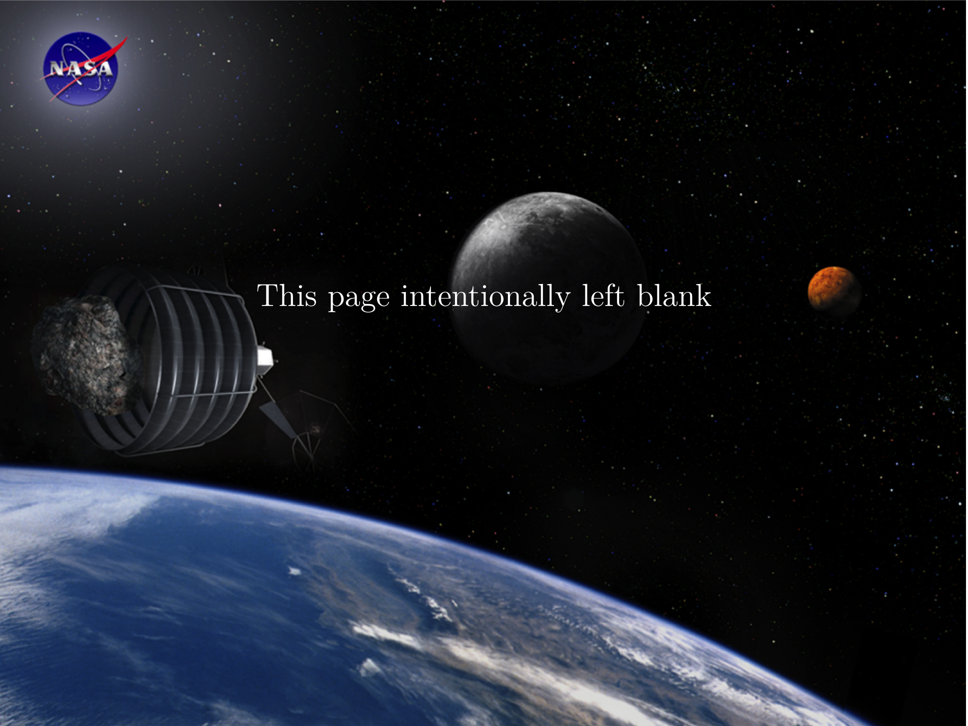
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Radiation Shielding in Extravehicular Mobility Units

Institution:
Wright State University

Presenters:
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Advisor:
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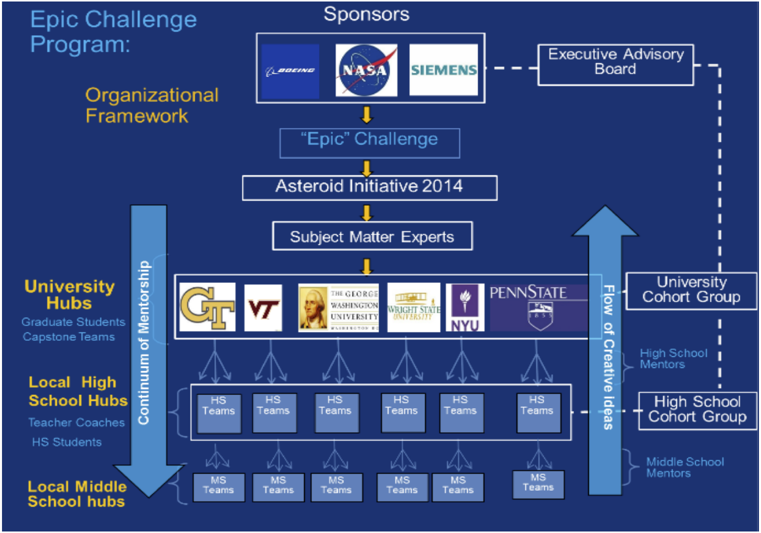
2 December 2014

ICED Grand Challenge: Asteroid Redirect Mission



Definition of Problem: Astronaut Radiation Exposure

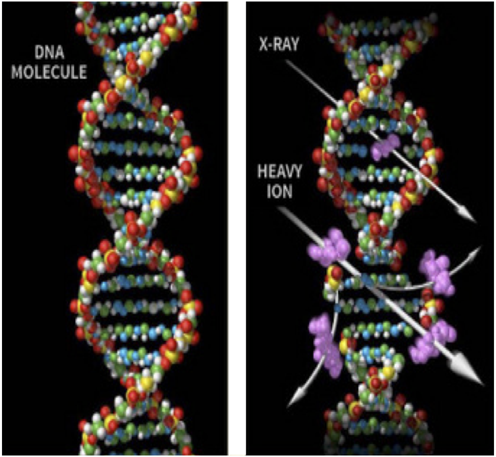


Figure: Image from [14].

- Cosmic radiation takes form of **subatomic particles**
- High speed particles **tear through DNA** molecules
- Can split DNA molecules or damage instructions for cell reproduction [14]

Definition of Problem: Astronaut Radiation Exposure

Mission	Total Duration	Lunar Surface Duration	Average Radiation Dose*
Apollo 11	08 days, 03 hrs, 13 mins	21 hrs, 38 mins	0.18 rad
Apollo 12	10 days, 4 hrs, 31 mins	31 hrs, 31 mins	0.58 rad
Apollo 14	09 days, 01 min	33 hrs 31 mins	1.14 rad
Apollo 15	10 days, 01 hr, 11 mins	66 hrs, 54 mins	0.30 rad
Apollo 16	11 days, 01 hr 51 mins	71 hrs, 2 mins	0.51 rad
Apollo 17	12 days, 13 hrs, 51 mins	74 hrs, 59 mins	0.55 rad

Depth of Radiation Penetration and Exposure Limits for Astronauts and the General Public (in Sv)				
	Exposure Interval	Blood Forming Organs (5 cm depth)	Eyes (0.3 cm depth)	Skin (0.01 cm depth)
Astronauts	30 Days	0.25	1.0	1.5
	Annual	0.50	2.0	3.0
	Career	1-4	4.0	6.0
General Public	Annual	0.001	0.015	0.05

Figure: Radiation exposure on Apollo missions and exposure limits for astronauts vs. general public. Image from [5].

Definition of Problem: Astronaut Radiation Exposure

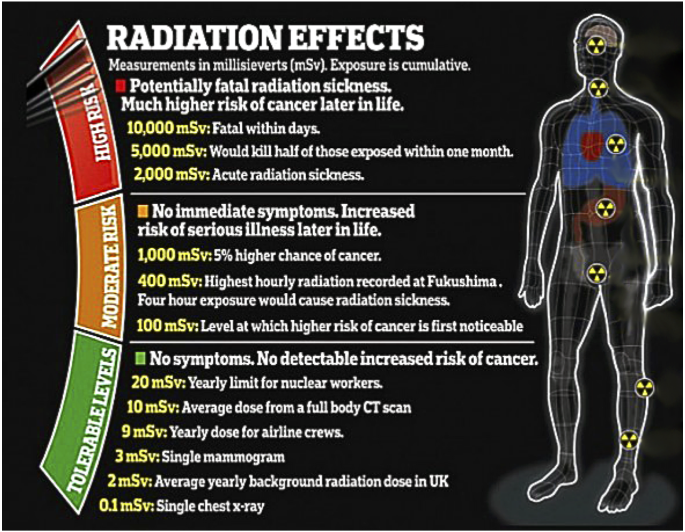


Figure: Image from [10].

Definition of Problem: The Nature of Radiation in Space

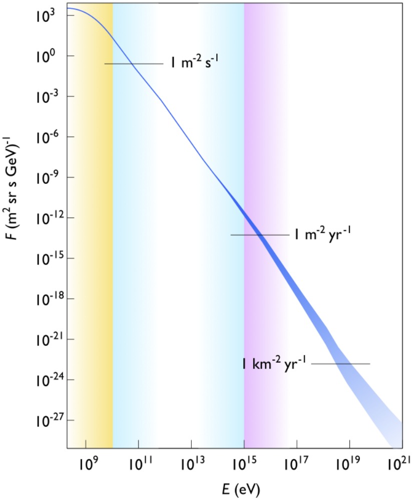


Figure: Flux $F(E)$ as a function of energy E. Image from [6].

- High energy cosmic radiation spectrum.
- Cosmic radiation energy may exceed 10^8 TeV!
- $F(E) \propto E^{-\gamma}$

$$\gamma \approx 2.7 - 3.0.$$

Current State of Things: Extravehicular Mobility Unit (EMU)

EMU Components:

i. Helmet
ii. Hard upper torso (HUT)
iii. Lower torso assembly (LTA)
iv. Arm assembly

Life Support Systems:

i. Primary life support system (PLSS)
ii. Liquid cooling and ventilation garment (LCVG)
iii. Extravehicular visor assembly (EVVA)

Current State of Things: Extravehicular Mobility Unit (EMU)

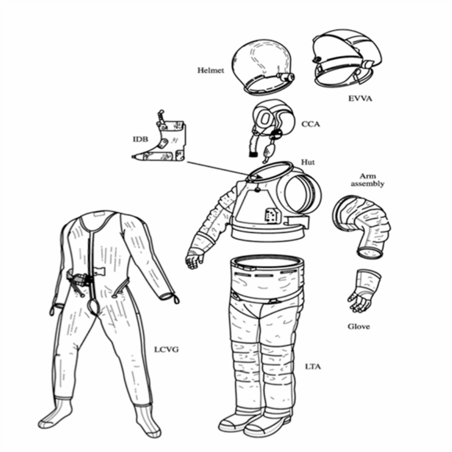


Figure: Components and life support systems of EMU. Image from [1].

Current State of Things: EMU Layers

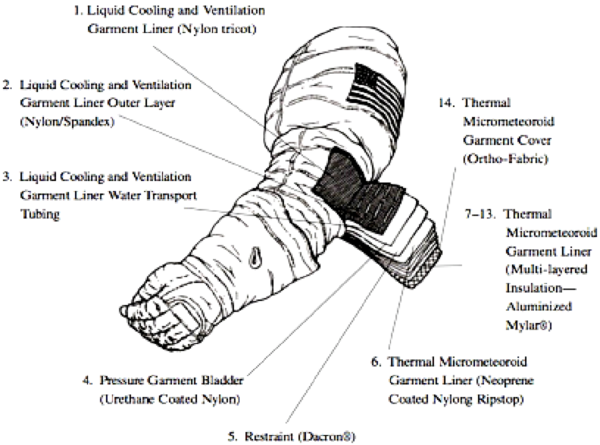


Figure: Layers of arm assembly. Image from [1].

Current State of Things: EMU Layers

Table: List of material, areal density and purpose of each EMU layer.

Layers	Material	Areal Density (g/cm^2)	Purpose
1	Nylon fabric	0.154	Inner layer of LCVG
2	Nylon fabric	0.154	Outer layer of LCVG
3	Nylon fabric	0.014	Pressure bladder
4	Polyester	0.021	Pressure restraint
5	Nylon fabric	0.025	Thermal insulation inner layer
6–12	Aluminized mylar	0.014	Thermal insulation system
13	Orthofabric©	0.049	Thermal insulation outer layer

Project Proposal: Outline

Solution:

Test and analyze potential material candidates to incorporate as additional layer of EMU.

Optimal Material Properties:

i. High attenuation coefficient (i.e., radiation shielding)
ii. Inexpensive (i.e., light weight)
iii. Nontoxic
iv. Pliable
v. Thermally resistive

Project Material: Identified Potential Materials

<u>Viable Materials:</u>

i. Boron nitride nanotube (BNNT)
ii. Polyethylene
iii. Aerogel multifoil

<u>Impractical Materials:</u>

i. BNNT with hydrogen (H_2)
ii. Demron©

Project Materials:
Boron nitride nanotube (BNNT)

Figure: Sample of BNNT. Image from [8].

Project Materials:
Boron Nitride Nanotube (BNNT)

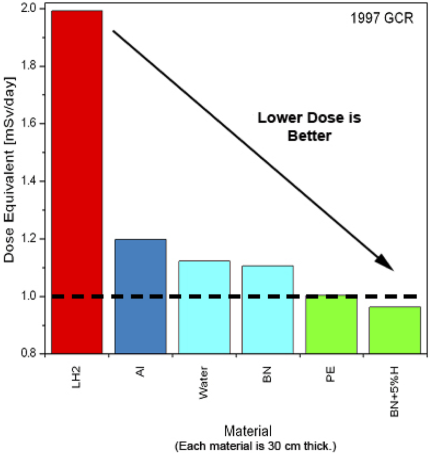


Figure: Comparison of different shielding material. Image from [7].

Project Material: Boron Nitride Nanotube (BNNT) with Hydrogen

Boron Nitride Nanotube (BNNT):

i. Strongest fiber that will ever be made (along with carbon nanotube)

ii. Maintains strength up to 900 °C ($\approx$ 1650°F)

iii. High thermal neutron absorbing efficiency

Hydrogen (H_2):

i. Fragments heavy ions in galactic cosmic rays

ii. Effectively stops protons in solar particle events

iii. Absorbs thermal neutrons

Project Material: Polyethylene

Material Properties:

i. High hydrogen content
ii. Reduced collision fragmentation due to lack of large nuclei
iii. High mass density

Figure: Sample of polythylene. Image from [12].

Project Material: Aerogel Multifoil

Material Properties:

i. 95% air

ii. Foil component slows and breaks up incident particles

iii. Aerogel converts kinetic energy to thermal and mechanical energy

Figure: Sample of aerogel multifoil. Image from [11].

Project Material: Demron© Suit

Figure: Image from [13].

- Radiation blocking fabric
- Radiation attenuation comparable to lead shielding
- Lightweight and flexible
- Made of polyethylene and liquid metal

Project Material: Summary

Table: List of candidate materials with properties (i.e., linear attn. μ, mass density ρ, thermal cond. k, molar mass M, cost C.) Table based on average values. Linear attenuation values taken at 1 GeV [2, 3, 4]. Other values taken from [15].

	BNNT w/ H_2	**Polyethylene**	**Aerogel**	**Demron**
μ **(cm^{-1})**	0.03[1]	0.02	0.02[2]	0.05[3]
ρ **(g/cm^3)**	1.55	0.95	0.24	3.14
k **(W/m·K)**	600	0.5	0.02	0.2
M (g/mol)	26.83	28.03	208.33	28.03
C **(\$/kg)**	2.5 mil	6.00	420	300

[1] Calculated with 41.07% B, 48.53% N, 5% H_2.
[2] Calculated with 95% air and 5% $Si(OCH_3)_4$.
[3] Taken at 1 MeV.

Project Methods: Resources

Facilities:

- Wright State Medical Imaging Lab
- Brookhaven National Laboratory Particle Collider

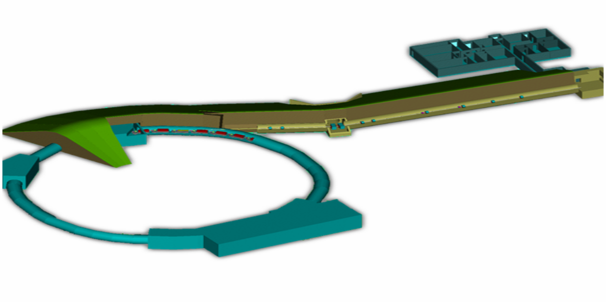


Figure: Brookhaven particle collider. Image from [9].

Project Methods: Resources

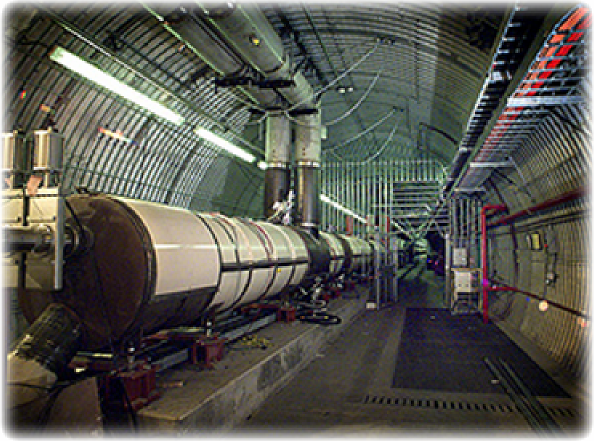


Figure: Brookhaven particle collider. Image from [9].

Project Methods: Testing Needs & Desires

Table: List of material / facility needs and desires.

Needs	Desires
BNNT	BNNT with H_2
Polyethylene	Spacesuit
Aerogel multifoil	Demron suit
WSU Medical Imaging Lab	Brookhaven National Lab

Project Considerations: Constraints

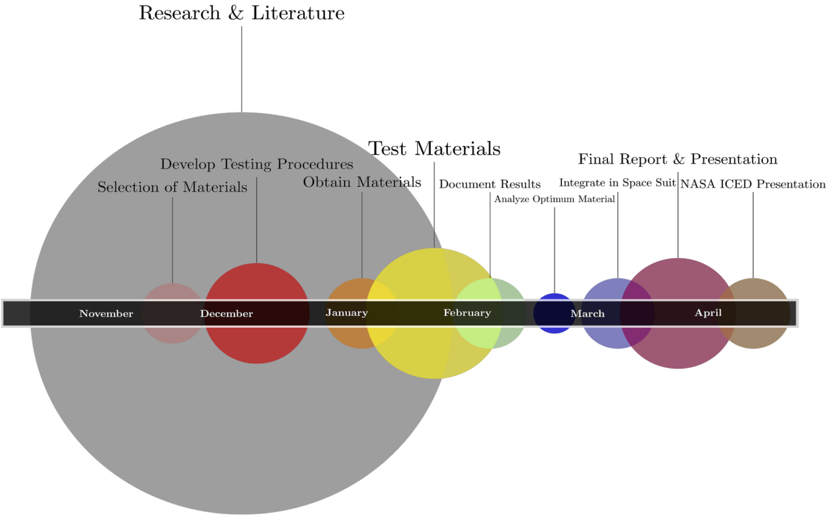
Constraints:

- Mass
- Costs \$10,000 per lb to put object into space

Costs:

- BNNT – \$2.5 mil/kg
- Aerogel Multifoil – \$417/kg
- Polyethylene – \$18/kg
- Demron© – \$300/kg

Project Methods: Timeline



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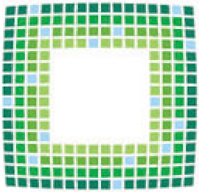

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