Solar Particle Event Protection Requirements for Exploration Habitats

Martha Clowdsley[1] and Edward Semones[2]

[1]NASA Langley Research Center, Hampton, VA
[1]NASA Johnson Space Center, Houston, TX

Solar Energetic Particles (SEP), Solar Modulation and Space Radiation: New Opportunities in the AMS-02 Era #2

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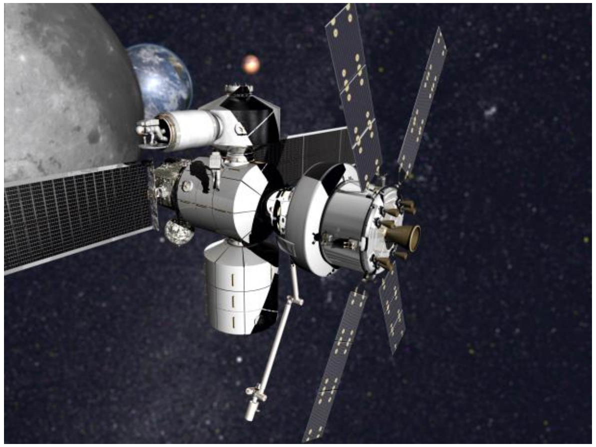
Overview

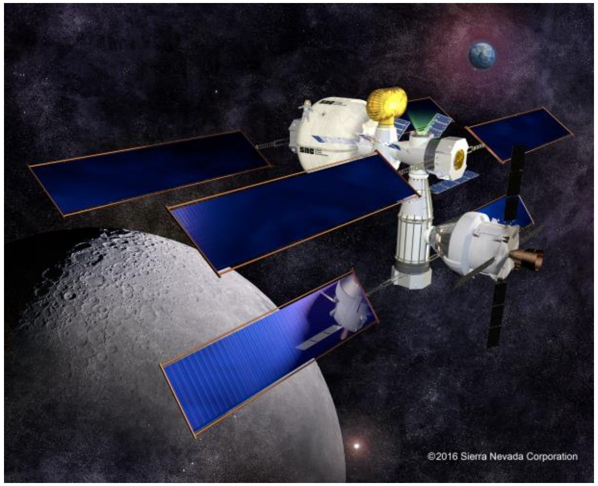
- NASA exploration habitat development efforts
- NASA Solar Particle Event (SPE) protection concepts
- Proposed SPE protection requirement for habitat development
- NASA Permissible Exposure Limits (PELs)
- Results of AES Storm Shelter Sizing Analysis
- Summary

NextSTEP Habitat Development

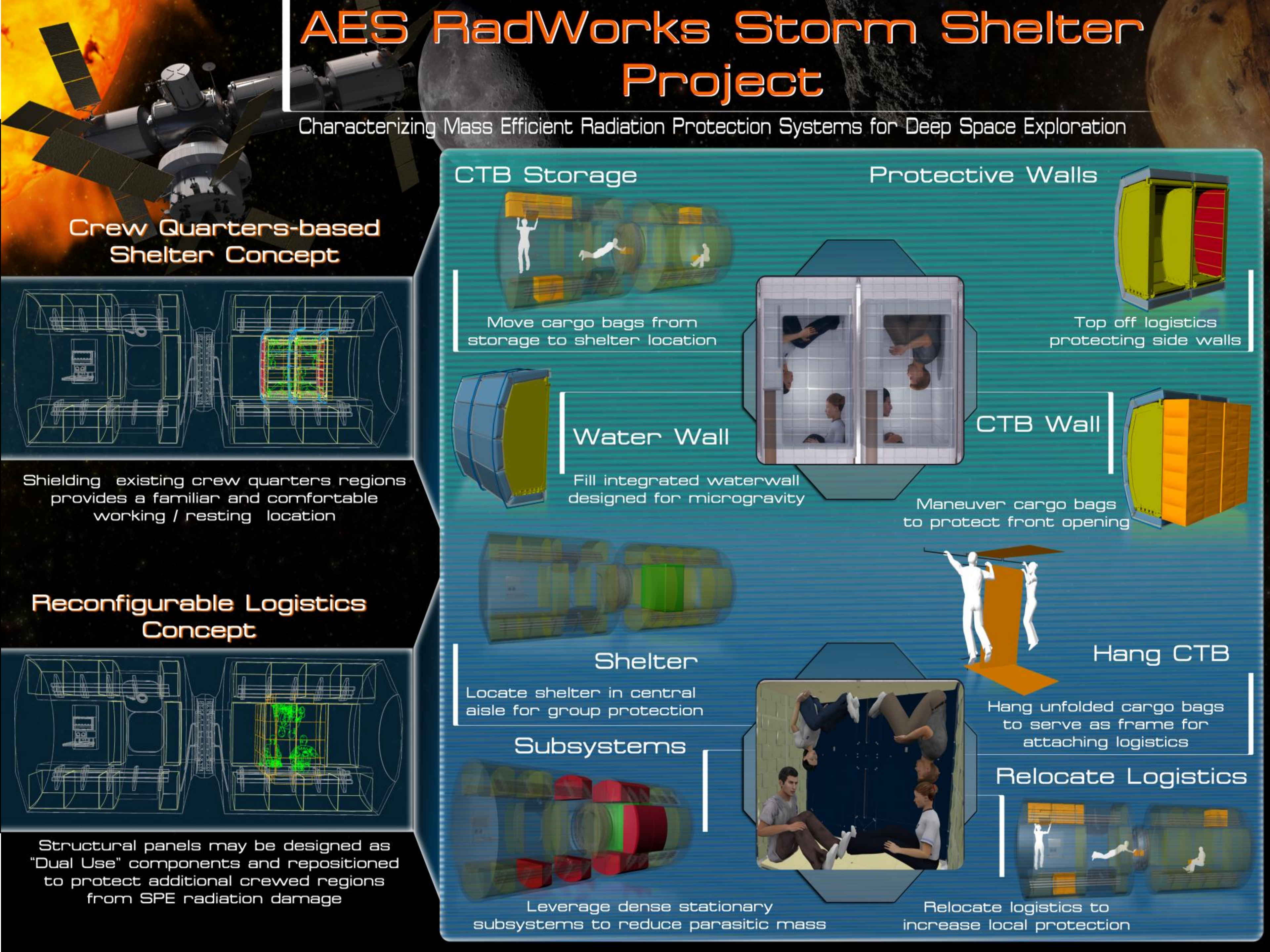
- Development of habitation systems for Deep Space Gateway missions in the cis-lunar space has already begun under the **Next Space Technologies for Exploration Partnerships (NextSTEP)**.
- NextSTEP-1
  - Initial concepts
- NextSTEP-2
  - 6 commercial partners: Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada Corporation, and NanoRacks
  - Developing habitation systems
  - Collaborating with NASA to perform integrated ground testing of onboard systems
- **Habitat designers need guidance for Solar Particle Event (SPE) protection!**



Lockheed Martin Concept



Sierra Nevada Concept


AES RadWorks Storm Shelter Project
Characterizing Mass Efficient Radiation Protection Systems for Deep Space Exploration
Crew Quarters-based Shelter Concept
Shielding existing crew quarters regions provides a familiar and comfortable working / resting location
Reconfigurable Logistics Concept
Structural panels may be designed as "Dual Use" components and repositioned to protect additional crewed regions from SPE radiation damage
CTB Storage
Move cargo bags from storage to shelter location
Protective Walls
Top off logistics protecting side walls
Water Wall
Fill integrated waterwall designed for microgravity
CTB Wall
Maneuver cargo bags to protect front opening
Shelter
Locate shelter in central aisle for group protection
Hang CTB
Hang unfolded cargo bags to serve as frame for attaching logistics
Subsystems
Leverage dense stationary subsystems to reduce parasitic mass
Relocate Logistics
Relocate logistics to increase local protection

NASA Protection Concepts

- Crew quarters based and reconfigurable logistics shelter concepts
  - Placed in a notional 180 day, 4 crew ISS derived cis-lunar habitat

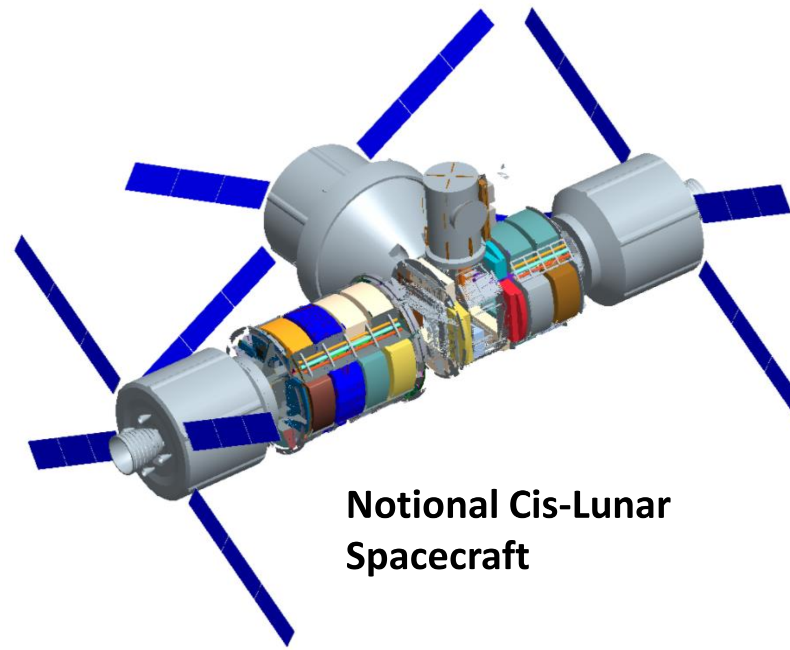
Crew Quarters

Pantry

Water Wall

Reconfigurable Logistics Shelter

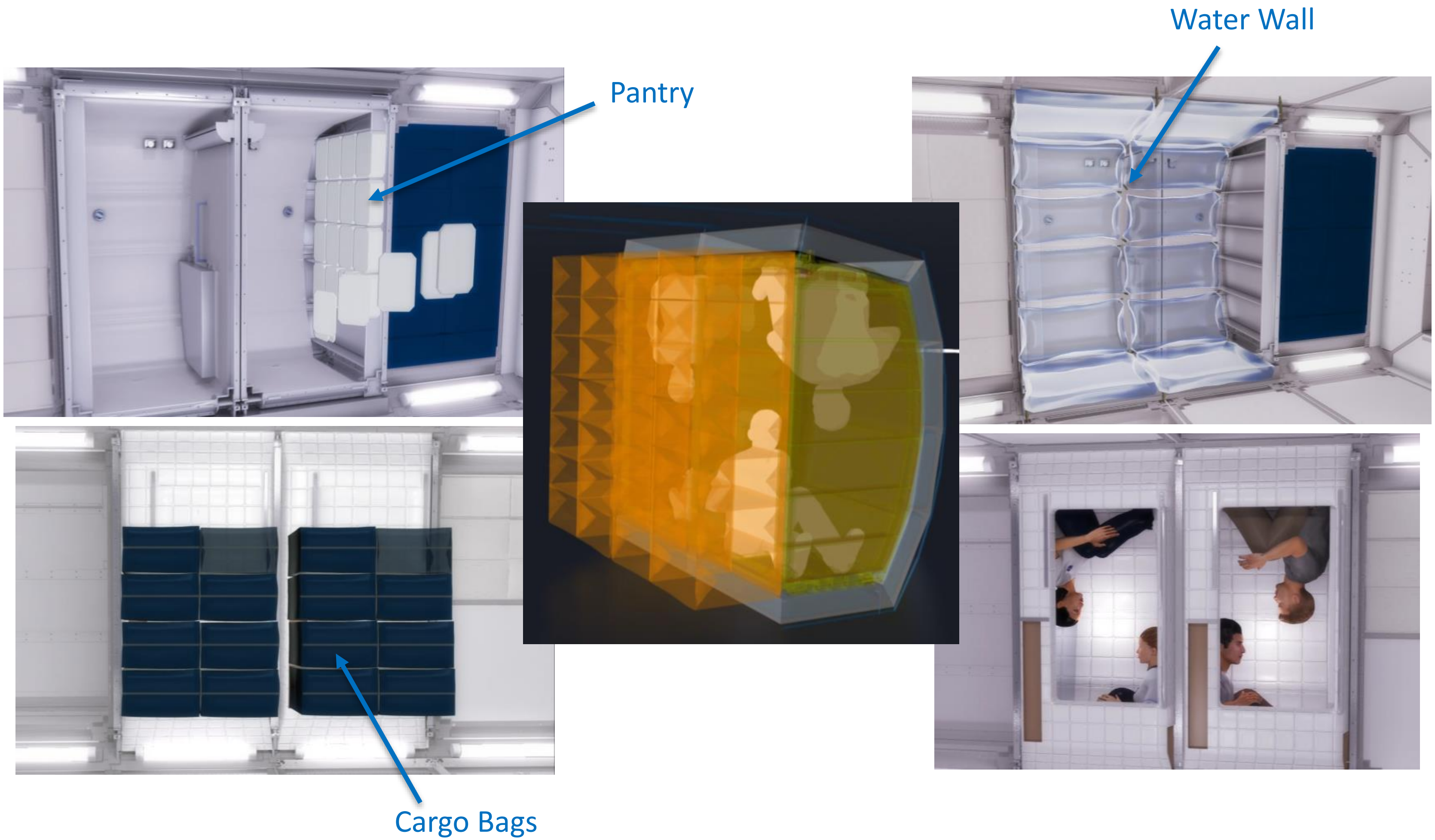
Attachment Mechanisms for Logistical Materials (food and trash bricks)



Notional Cis-Lunar Spacecraft

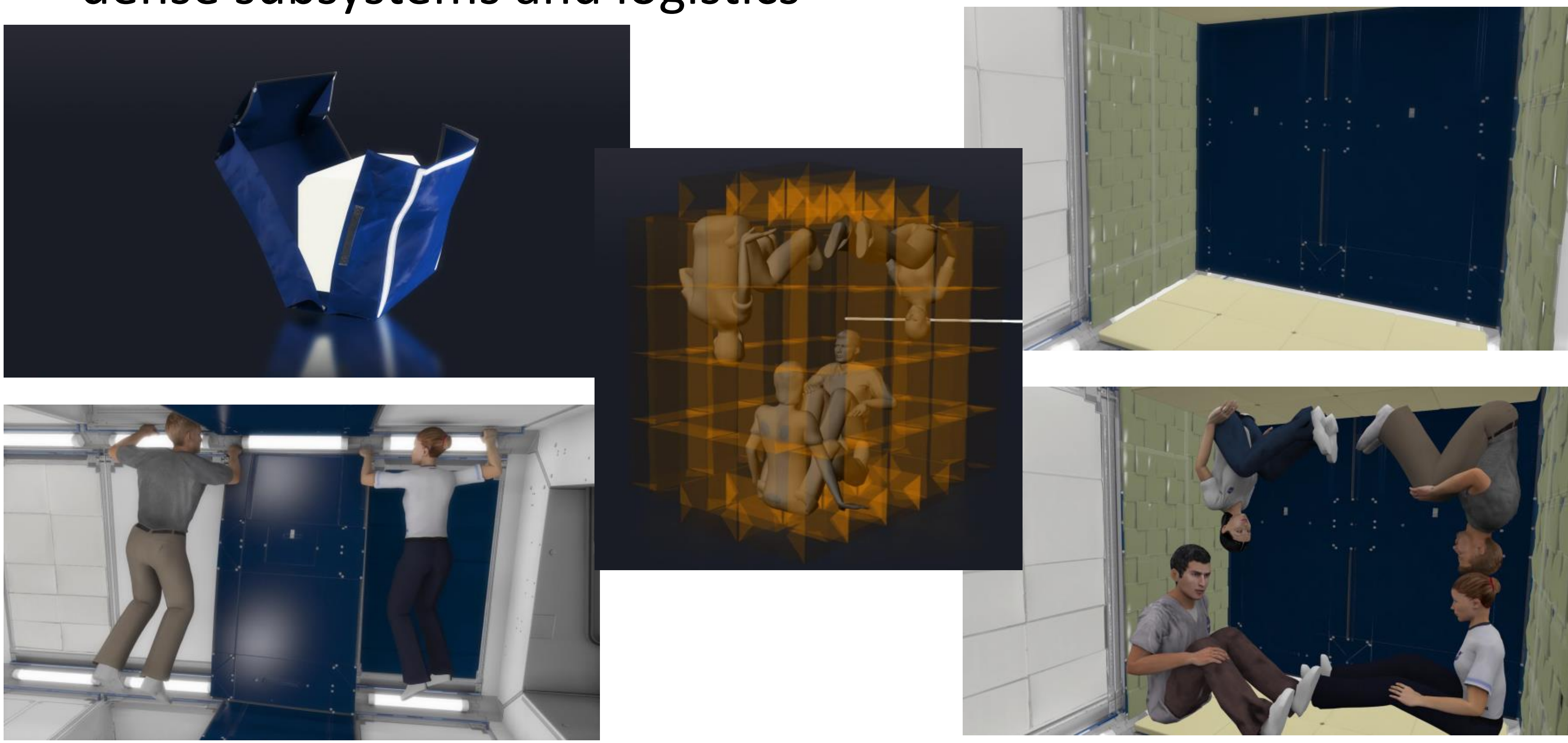
Crew Quarter Concepts

- Crew quarters derived shelter with logistics “pantries” on side walls and arrangement of cargo bags shielding the door



Reconfigurable Logistics Shelter Concepts

- Protect the entire crew in a centralized area surrounded by dense subsystems and logistics



Cargo bags unfold to become shelter walls.

Logistical materials (food, trash, etc.) attach to the cargo bag walls to augment protection.

Wearable Protection Concepts

Radiation Protection Garment

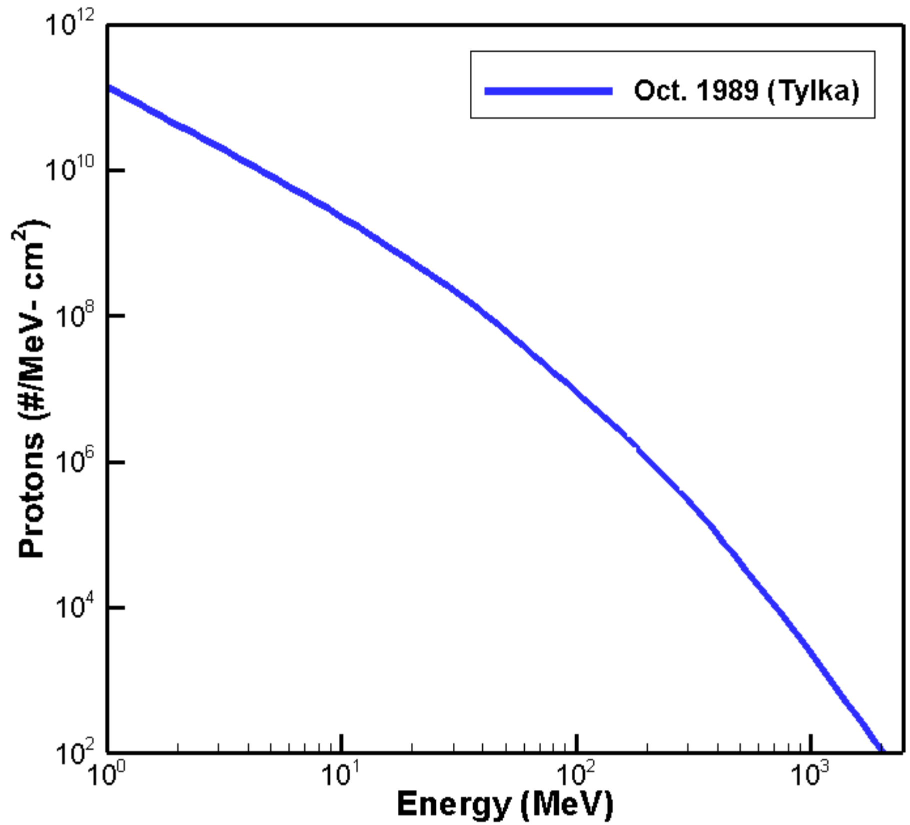
Blankets and Sleep Restraints

Proposed SPE Protection Requirements for Gateway Habitats

- The habitat shall provide protection to ensure that gray equivalent to astronaut blood forming organs (BFO) does not exceed 250 mGy-Eq. for the design SPE.
- The design reference SPE environment is equivalent to the sum of the proton spectra for the events which occurred during October 1989 (Alan Tylka models).
- If the protection system requires assembly, assembly must take no more than 30 minutes.
- Spacecraft protection systems shall be designed to ensure that astronaut radiation exposure is kept As Low As Reasonably Achievable (ALARA).

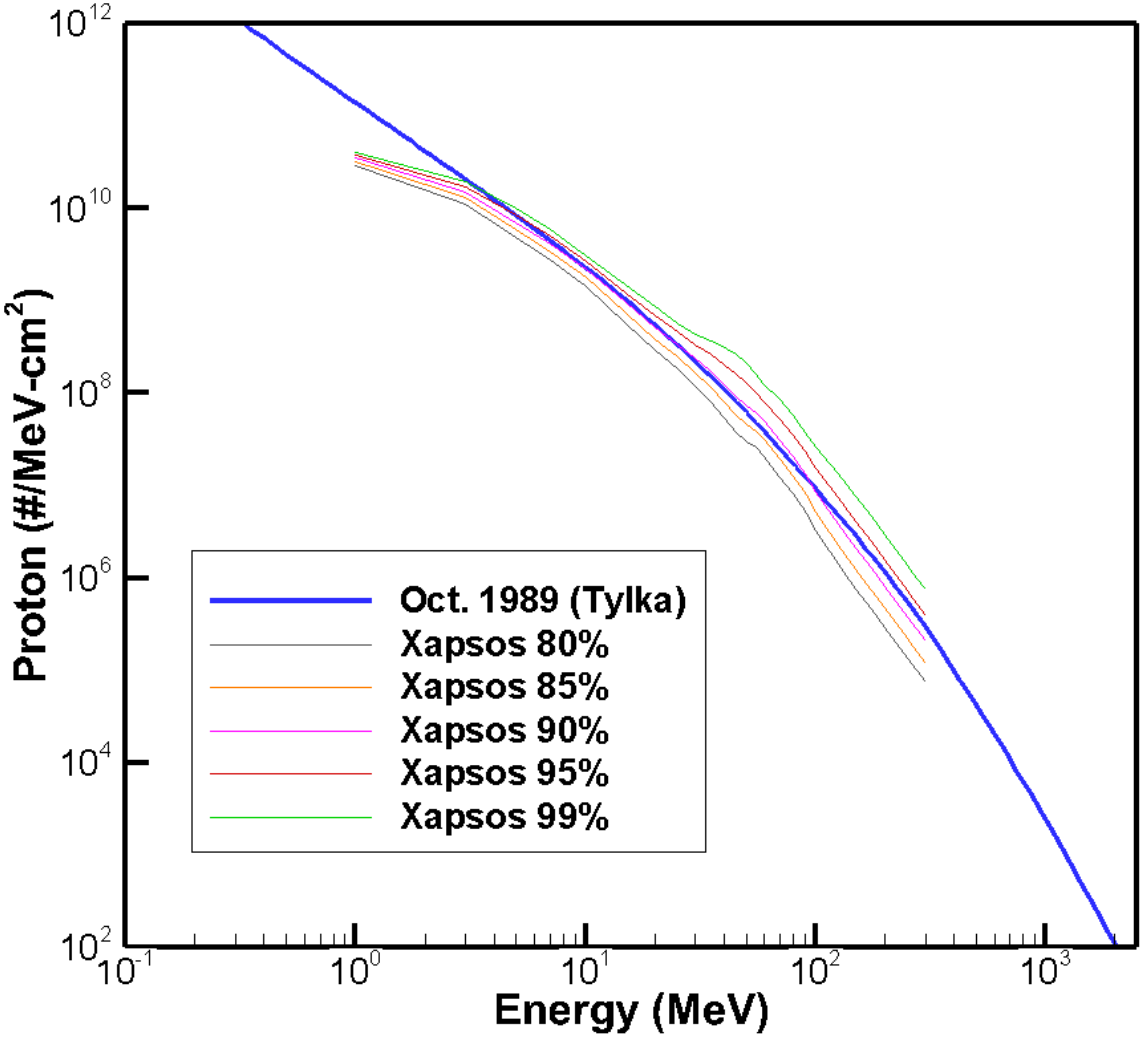
Proposed Design Reference SPE Environment

The combined proton fluence for the events that occurred on October 19, 22, and 24, 1989 represent the most intense SPE environment occurring during a 30 day period during the era of satellite measurements.



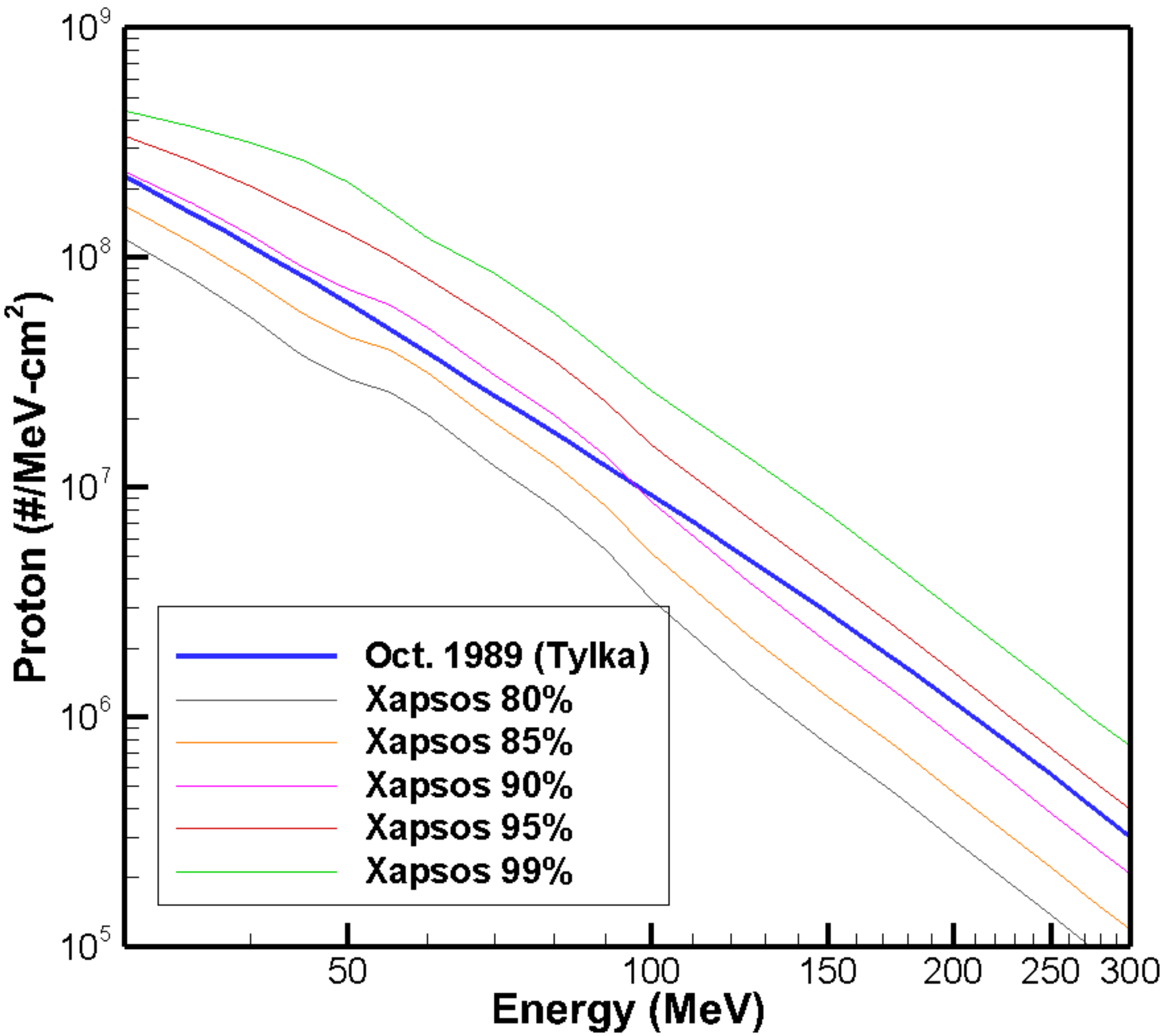
Energy Spectrum for Proposed Design Reference SPE Environment – Equivalent to the Sum of the Proton Spectra for the Events which Occurred During October 1989 as Modelled by Tylka.

Comparison to Xapsos Model Percentile Events



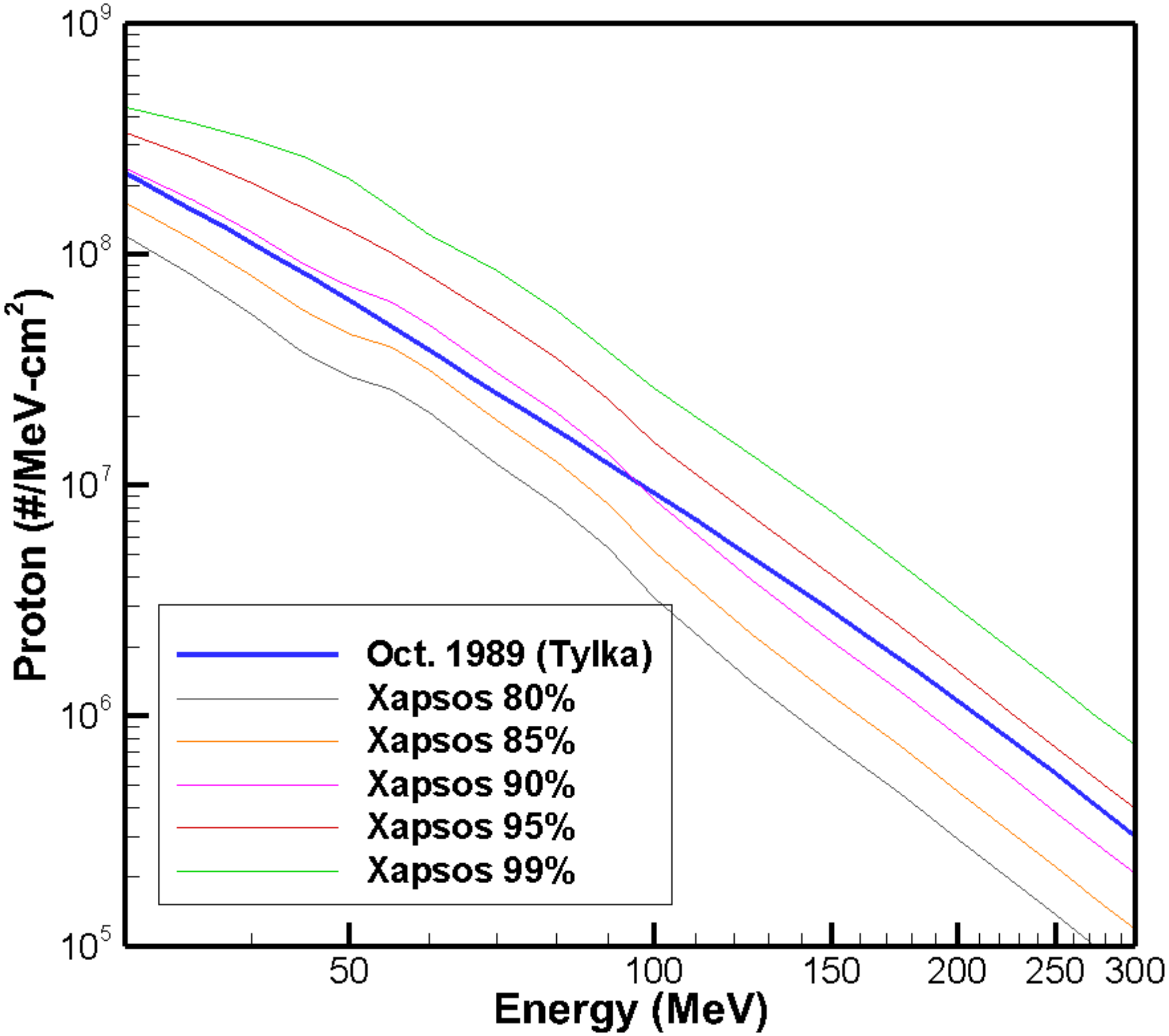
The proposed design basis SPE environment compared to percentile events for a 1 year mission (Xapsos model).

Comparison to Xapsos Model Percentile Events



The proposed design basis SPE environment is approximately equivalent to a 90 percentile event for a <u>1 year mission</u> (Xapsos model).

Comparison to Xapsos Model Percentile Events



Percentile events for a 30 day period can be roughly approximate using the equation:

$1 - P_{30} = (1 – P_{365})/12$

The proposed design basis SPE environment is approximately equivalent to a 99 percentile event for a <u>30 day period.</u>

Vetting of the SPE Protection Requirement

- The requirement was developed by the members of the AES Radiation Steering Committee.
- The requirement was discussed with international partners at a radiation environments and risk analysis Technical Interchange Meeting (TIM) in Moscow in April 2016.
- A storm shelter requirements workshop was held in January 2017 at NASA Langley Research Center to gather input from radiation environment experts.
  - Current and retired members of the space radiation community from NASA LaRC, NASA JSC, NASA GSFC, NASA MSFC, JPL, the University of Tennessee, Southern New Hampshire University, Southwest Research Institute, and Lockheed Martin participated.
- A final review of this requirement will take place at another radiation TIM in Moscow in June 2017.

NASA PELs (from NASA-STD-3001-Vol1-Rev.A)

4.2.10.1 - Planned career exposure to ionizing radiation shall not exceed 3 percent Risk of Exposure-Induced Death (REID) for cancer mortality at a 95 percent confidence level to limit the cumulative effective dose (in units of Sievert) received by an astronaut throughout his or her career.

4.2.10.2 Planned radiation dose shall not exceed career and short-term limits as defined in table 1, Dose limits for Short-Term or Career non-cancer Effects (in mGy-Eq. or mGy).

Table 1—Dose Limits for Short-Term or Career Non-Cancer Effects (in mGy-Eq. or mGy)

Note: RBEs for specific risks are distinct as described below.

Organ	30-day limit	1-Year Limit	Career
Lens*	1,000 mGy-Eq	2,000 mGy-Eq	4,000 mGy-Eq
Skin	1,500	3,000	6,000
BFO	250	500	Not applicable
Circulatory System**	250	500	1000
CNS***	500 mGy	1,000 mGy	1,500 mGy
CNS*** (Z≥10)	-	1,00 mGy	2,50 mGy

*Lens limits are intended to prevent early (<5 yr) severe cataracts, e.g., from a solar particle event. An additional cataract risk exists at lower doses from cosmic rays for sub-clinical cataracts, which may progress to severe types after long latency (>5 yr) and are not preventable by existing mitigation measures; however, they are deemed an acceptable risk to the program.

**Circulatory system doses calculated as average over heart muscle and adjacent arteries.

***CNS limits should be calculated at the hippocampus.

4.2.10.3 Lifetime fatality risks for non-cancer circulatory and CNS diseases shall be limited as defined by career dose limits in table 1.

4.2.10.4 Exploration Class Mission radiation exposure limits shall be defined by NASA based on NASA-requested recommendations from the National Academy of Sciences, the Institute of Medicine, and the National Council on Radiation Protection (NCRP).

4.2.10.5 In-flight radiation exposures shall be maintained using the as low as reasonably achievable (ALARA) principle.

Additional Guidance (from NASA-STD-3001-Vol2)

- Crew occupational exposure to ionizing radiation is managed through system design, in-flight monitoring and procedures, mission architecture and planning, and the application of appropriate countermeasures.
- The program shall set system design requirements to prevent potential crewmembers from exceeding PELs as set forth in NASA-STD-3001, Volume 1.
- The program shall design systems using the ALARA principle to limit crew radiation exposure.
- The program shall specify the radiation environments to be used in verifying the radiation design requirements.

Orion Requirement

- The system shall provide protection from radiation exposure consistent with ALARA principles to ensure that effective dose (tissue averaged) to any crewmember does not exceed the 150 mSv, for the design SPE, as specified in SLS-SPEC-159 Cross-Program Design Specification for Natural Environments (DSNE).

- The DSNE specifies that the design reference SPE environment is given by the parameterization of the event total proton integral spectrum of J. H. King's "Solar Proton Fluences for 1977-1983 Space Missions." This omnidirectional proton spectrum is given in the inclusive energy range [0.01, 1,000] MeV by the following expressions:

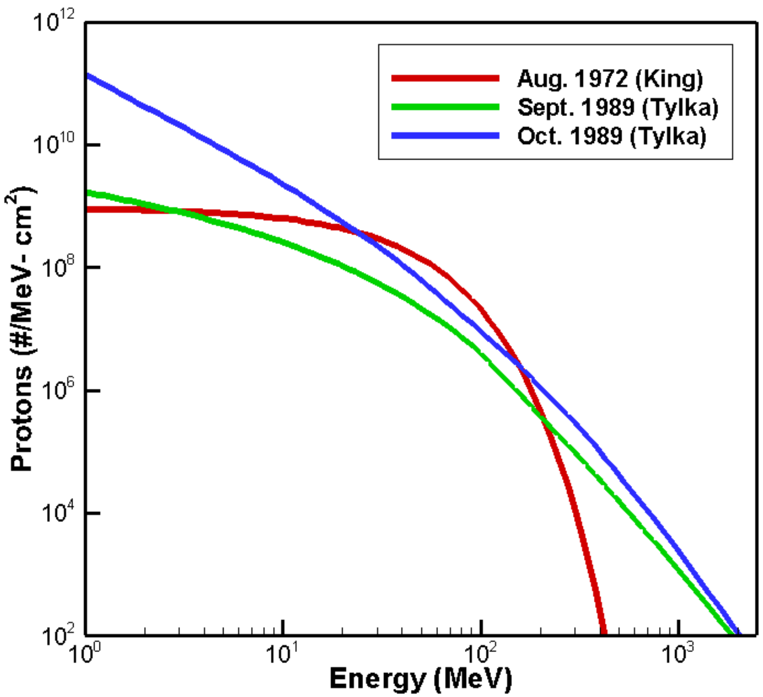
  Integral: $J(>E) = J_0 \exp[(30-E)/E_0]$

  Differential: $J(E) = (J_0/ E_0) \exp[(30-E)/E_0]$

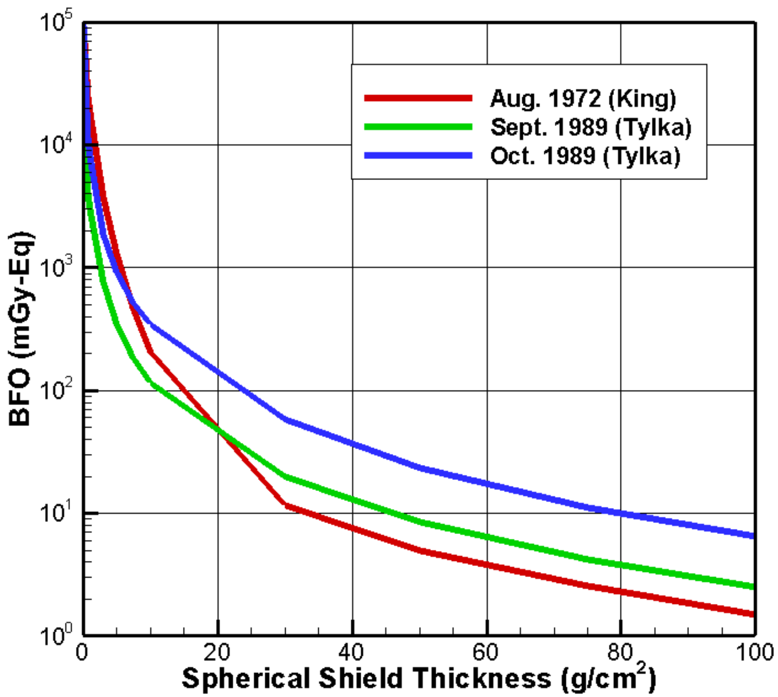
  With J_0 = 7.9x109 particles/cm2, and E_0 = 26.5 MeV

Astronaut BFO Gray Equivalent

Environment Models for Historic Events



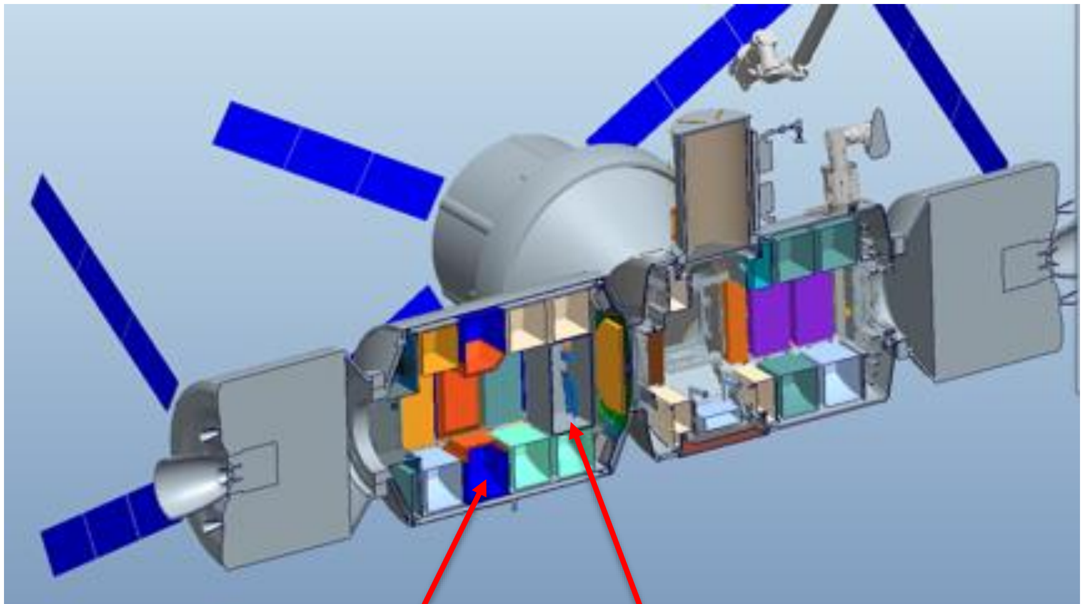
BFO Gray Equivalent Versus Aluminum Shield Thickness



- For heavily shielded spacecraft, the October 1989 environment requires the most shielding.

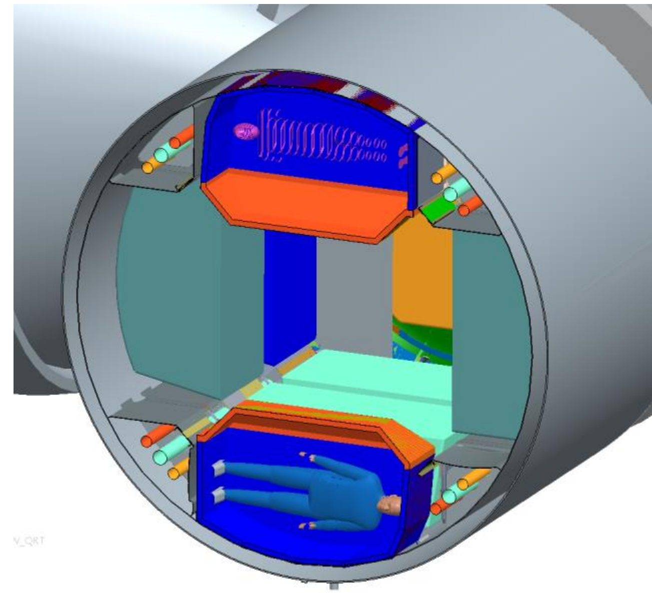
AES Storm Shelter Sizing Analysis

Reconfigurable Storm Shelter Concept



Crew Quarters **Storm Shelter**

Crew Quarters Concept



- All of the mass surrounding the astronauts impacts their radiation exposure.
- For these two concepts, ~4 inches of shielding reduced astronaut effective dose to ~120 mSv.
- In both cases, there were sufficient quantities of food, water, and equipment to create the storm shelters without adding parasitic mass.

Summary

- A set of SPE protection requirements have been developed for Gateway habitats.
- These requirements will ensure that NASA's 30-day permissible exposure limits are met.
- These requirements will provide habitat designers with the guidance they need for minimal mass spacecraft design.

Questions?

Back-up

Can a Standard Shield Thickness Be Defined?

- This would be easiest for vehicle designers to deal with, but….
- Shielding provided by vehicle or habitat structure and onboard equipment and supplies varies greatly.
  - Smaller vehicles and/or habitats designed for shorter missions are likely to provide less shielding in some directions.
  - Habitats designed for longer duration missions will contain more supplies and consumables, and could be designed to provide more uniform shielding.
- Astronaut exposure may be dominated by thin shielding over relatively small angles.
- Defining a standard "one size fits all" shield thickness, based on average vehicle shielding, could lead to higher than expected astronaut exposure.
- Defining one standard shield thickness that ensures a minimal astronaut risk for all vehicles will lead to non-optimal, massive shielding solutions.
- With the optimal placement of onboard equipment and supplies, it may be possible to design an SPE shield which requires no parasitic mass.

Radiation Protection Requirements – 2 Parts

Design Basis SPE or SPEs

- One fit to one historical SPE
  - Simplest method with multiple examples in the published literature
  - Magnitude and spectral shape of historic SPE vary greatly and can have a large impact on astronaut exposure. Which one would you choose?
- A probabilistic SPE model based on historic data
  - Accounts for the varying nature of historic SPE and is simpler than the probabilistic approach described below
  - Defining a percentile event is challenging and assumes an astronaut's exposure at a given percentile can be calculated using the external SPE spectrum for that percentile
- A probabilistic approach in which exposure quantities are calculated for a database of historic SPE spectra
  - Statistics are performed on the dosimetric quantity of interest
  - Additional evaluation is needed

Exposure limit

- dose, dose eq., or gray-eq. to specific organs/tissues
- Effective dose equivalent
- Risk of Exposure Induced Death (REID)