RADIATION MITIGATION TECHNOLOGIES

America's Future in Civil Space

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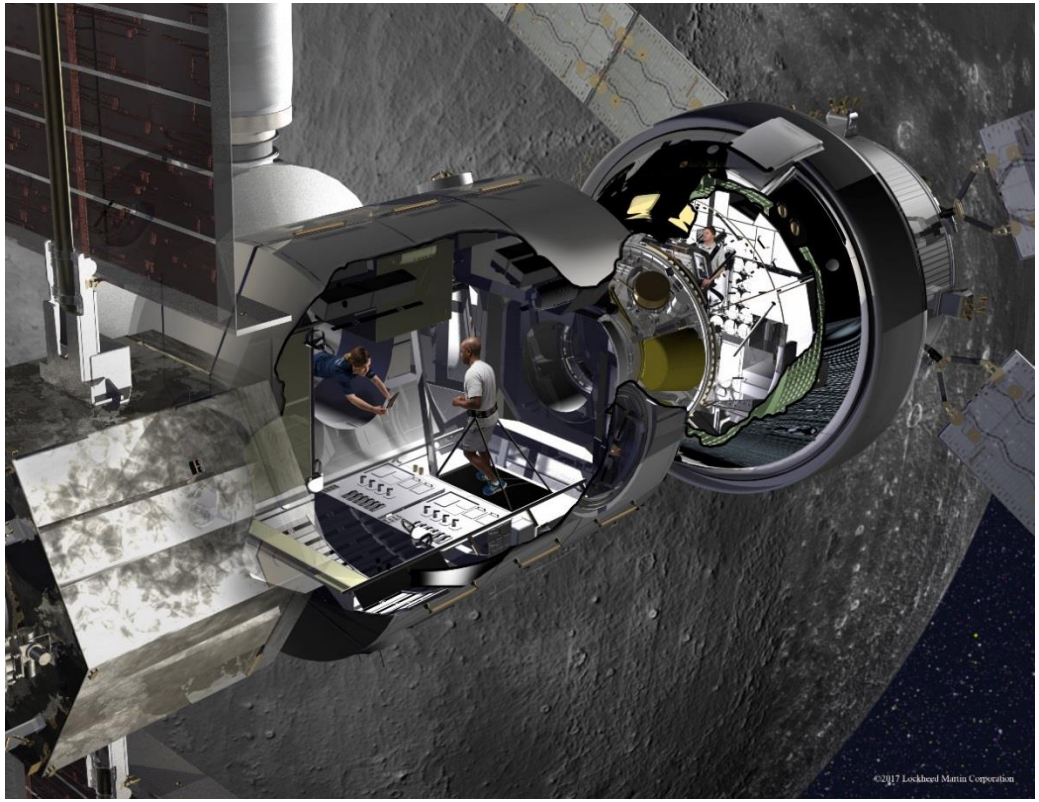
Introduction

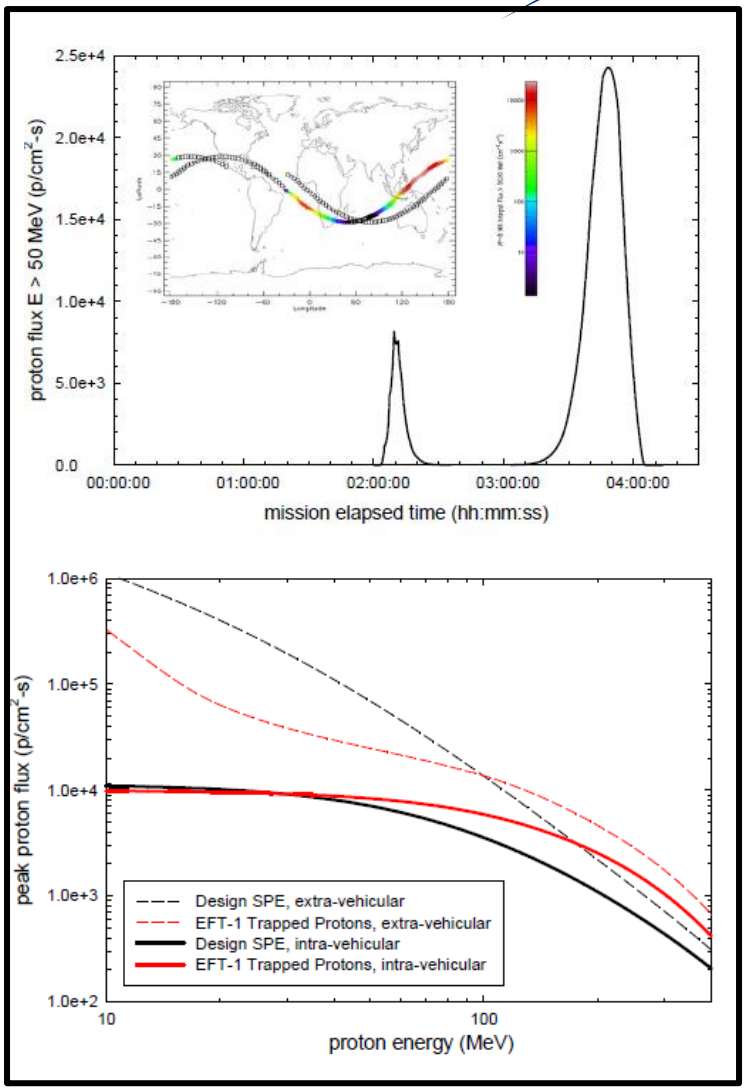
- Astronauts in deep space will experience greater radiation doses than in previous space missions
  - Not protected by Earth's Magnetic Field
  - Longer missions
- Current designs use vehicle shielding plus a 'storm shelter'
- Ongoing Research reduces uncertainty and offers new techniques for protection



Deep Space Gateway – Built up during periodic extended stay Orion missions

Space Radiation

- **Primarily high energy ions (vs. gamma or X-rays)**
  - **Low Z materials most effective in shielding**
- **Solar Particle Events (SPE) are episodic eruptions of energetic particles**
  - **Coronal Mass Ejections, Solar Magnetic activity**
- **Galactic Cosmic Radiation (GCR) is a continuous background**
  - **Higher energy than SPE**
  - **Varies inversely with Solar cycle**
- **Ongoing Research**
  - **Biological Responses: Central Nervous System, Cardiology, Lifetime Cancer risk**
  - **Environment: Timing of SPE's**
  - **Transport Modelling: Continuously improving flight validated models**



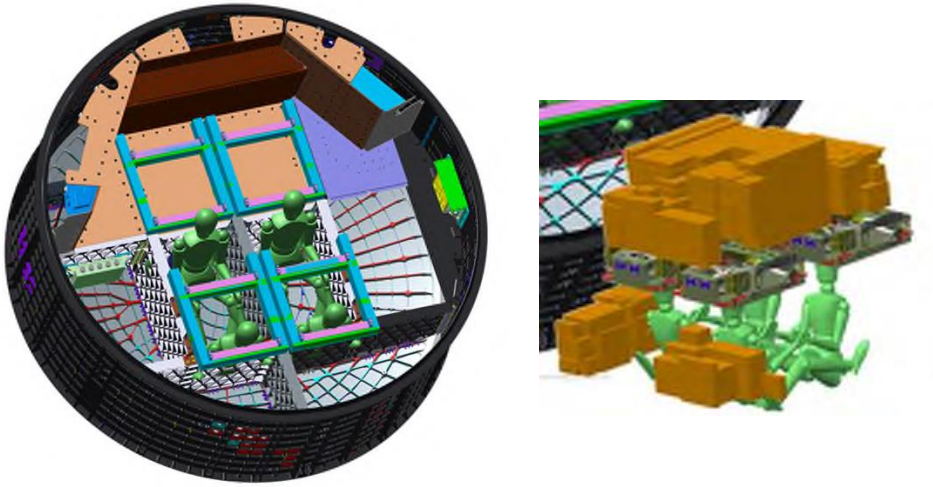
Orion EFT-1 Flight Results

Reducing Radiation Exposure

- Design and build into vehicles
- Nearly Eliminate Acute Effects
  - Early Warning, Operational Measures (e.g. EVA return-to-vehicle)
- Reduce uncertainty in biological and physics models
  - Tighten confidence intervals
  - Improve space weather understanding
- Reduce parasitic shielding mass
  - Use consumables, water or recycled plastics
- Ergonomic Personal Protection Equipment
- Crew Characteristics
- Apply ALARA

Radiation Protection

- Spacecraft structure shielding
- Internal Equipment shielding
- Hardened Electronics protected by shielding plus software
- Storm Shelter Reconfiguration
  - Water, food, equipment moved to optimize shielding
- Future Spacecraft Design
  - Configure for crew protection
  - Use recycled materials
  - Crew quarters surrounded by H20

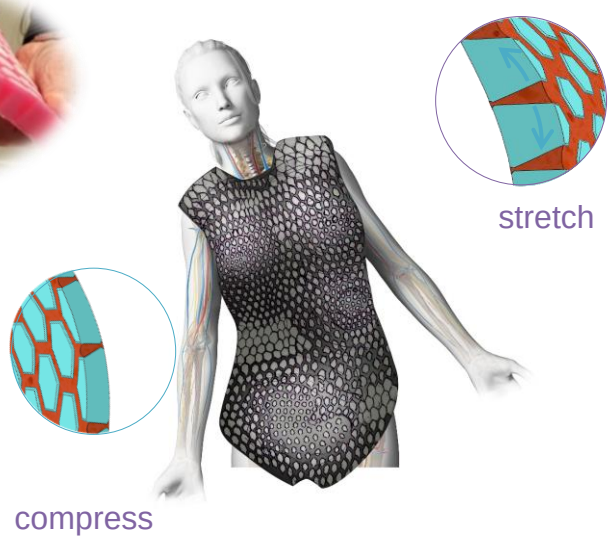


Orion Crew Cabin Reconfigured for Storm Shelter Protection

Historical Radiation Shielding for U.S. Human Spacecraft		
Spacecraft	Approximate Shielding	Notes
Apollo	3-5.5 g/cm^2 Al	Limited duration habitability
Skylab	1.5-2 g/cm^2 Al	Interior “vault” included for contingency storm shelter
ISS US Lab, Destiny	10-15 g/cm^2 Al	Increased effective shielding due to interior equipment
Orion	15 g/cm^2 Al	Zero mass storm shelter obtained by reconfguration

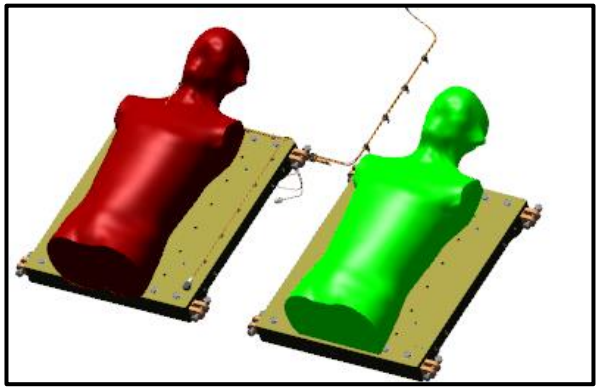
Personal Protective Equipment

- **Selective Shielding Based on Tissue Radiation Sensitivity**
- **Differentially protect Stem Cells**
- **The AstroRad – developed by StemRad Ltd / LM team**
  - **Complements storm shelter during SPE**
  - **Contoured for preferential organ, stem cell shielding**
  - **Designed for comfort**

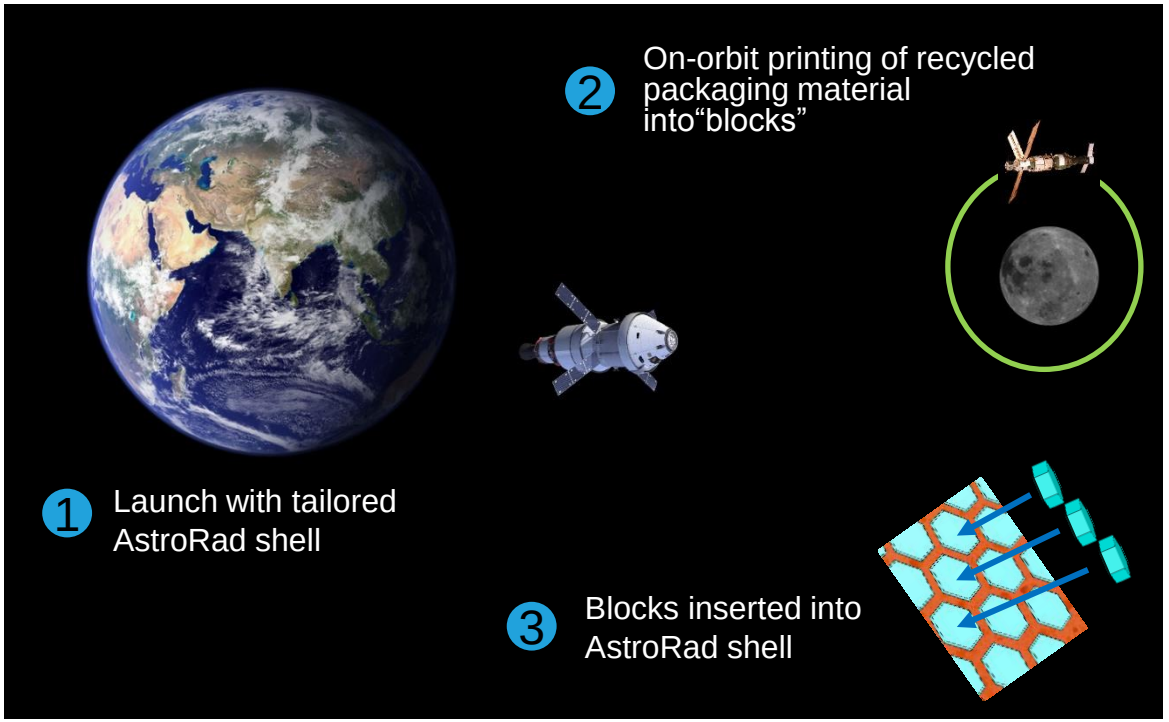


Future Applications

- **Orion EM-1 International Experiment (MARE)**
  - **Cis Lunar and Radiation Belt passage**
  - **Dosimetry inside DLR 'Matroshkas' with and without ISA Vest**
- **Cis-lunar and Mars Missions**
  - **Include recycled material to minimize parasitic mass**



Matroshka AstroRad Radiation Experiment



Potential Future Use for Long Duration Missions

Summary

- Orion and future vehicles are designed for radiation protection
- Research is reducing uncertainty in biological responses and Space Weather forecasting
- Ongoing work will further reduce crew risk