Galactic Cosmic Radiation Shielding: Science on the Lunar Surface

Lisa C.Simonsen[1], Tony C. Slaba[2]

[1] NASA Head Quarters, Washington DC
[2] NASA Langley Research Center, Hampton VA

Key Non-Polar Destinations Across the Moon to Address Decadal-level Science Objectives with Human Explorers: Panel on Human and Biological Science - In-person/hybrid Meeting #1

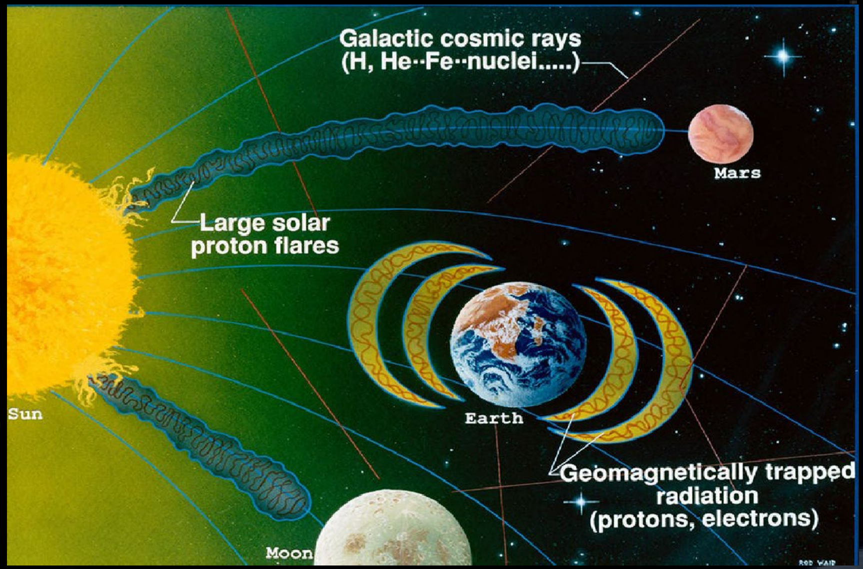
Outline

- Space environment challenges and mission exposures
- Galactic cosmic ray shielding and gaps
- Lunar shielding experiment to address gaps
- Summary

Space Radiation Environment Challenges

Solar Proton Events (SPE)

- Low to medium energy protons (mainly <100 MeV)
- Travel along magnetic field lines
- Can arrive quickly if well connected to vehicle
- Real time dosimetry and shielding mitigate acute exposure risks
- **Gap: Accurate forecasting; Earth independence along Sun-Mars line**



Galactic Cosmic Radiation (GCR)

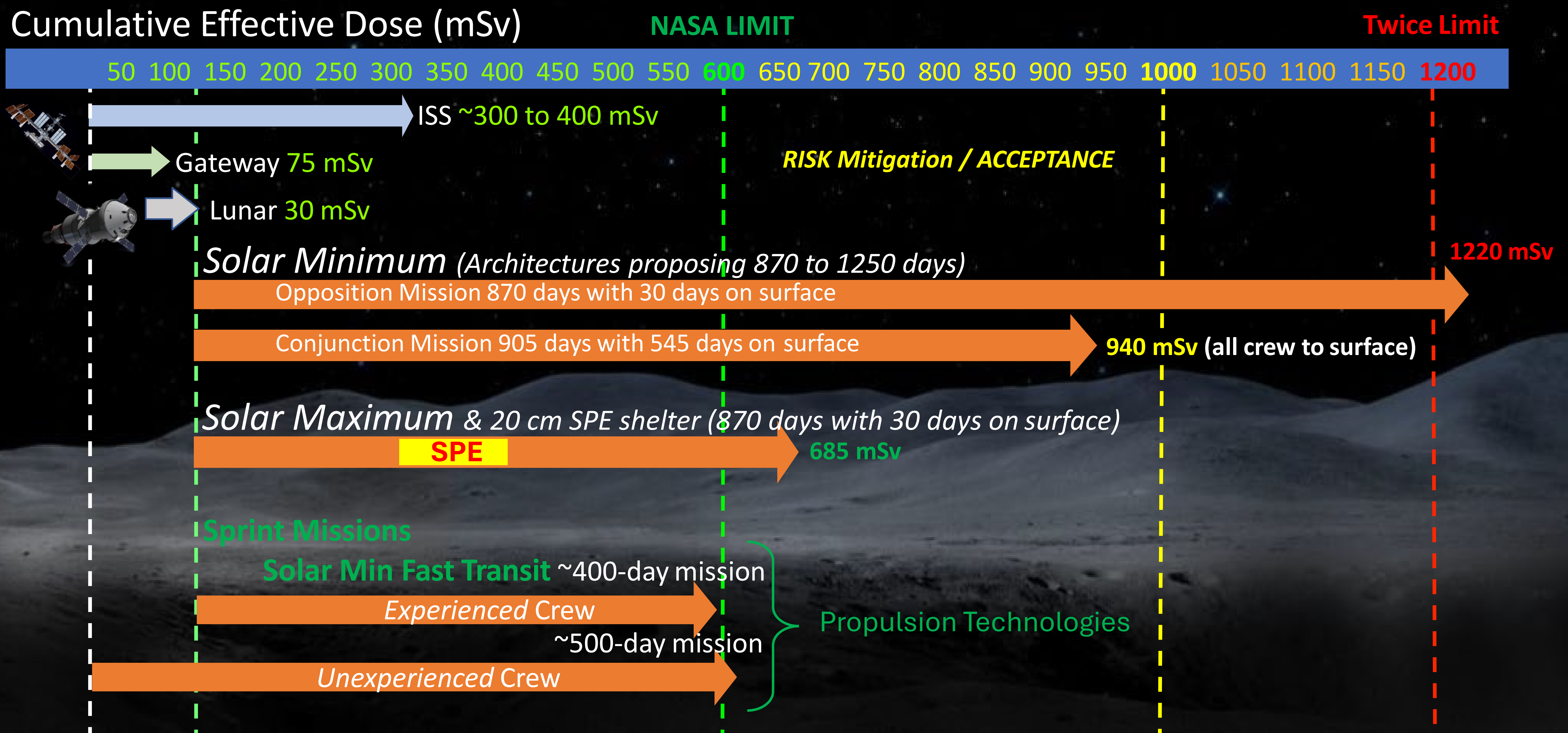
- Continuous background of low dose radiation
- ~ 89% protons, ~10% alpha particles (He), and ~1% heavier nuclei
- Broad energy spectrum from 10's of MeV/n to >100 GeV/n
- Highly penetrating and difficult to shield against
- Nuclear fragmentation into lighter, penetrating species
- **Gap: Effective shielding; Accurate quantification of biological effects & health risks, Validated biomarkers and countermeasures**

GCR intensity varies with ~9.6 to 12.4 yr solar cycle

- *Solar maximum*
  - Highest probability of SPE
  - GCR intensity at lowest levels
- *Solar minimum*
  - Lower probability of SPE
  - GCR intensities at highest levels

Gap: Accurate prediction of solar cycle duration

Mission Exposures



Integrated Mitigation Strategy: Gap Structure

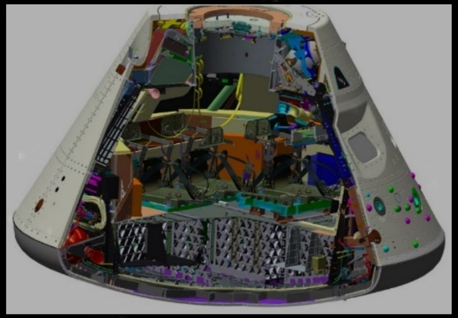
- **Space Radiation Protection**
  - **Physical Mitigation Technologies**
    - 1.1 Space weather forecasting
    - 1.2 Radiation Monitoring
      - Dosimetry Sys.
      - Environmental Measurements
    - 1.3 Effective Shielding
      - SPE shielding
      - Passive GCR Shielding
      - Active Shielding
  - **Biological Mitigation**
    - 1.4 Predictive Models of Crew Health Risks
    - 1.5 Biomedical Countermeasures and Surveillance

Effective GCR Shielding/Passive: State of the Art

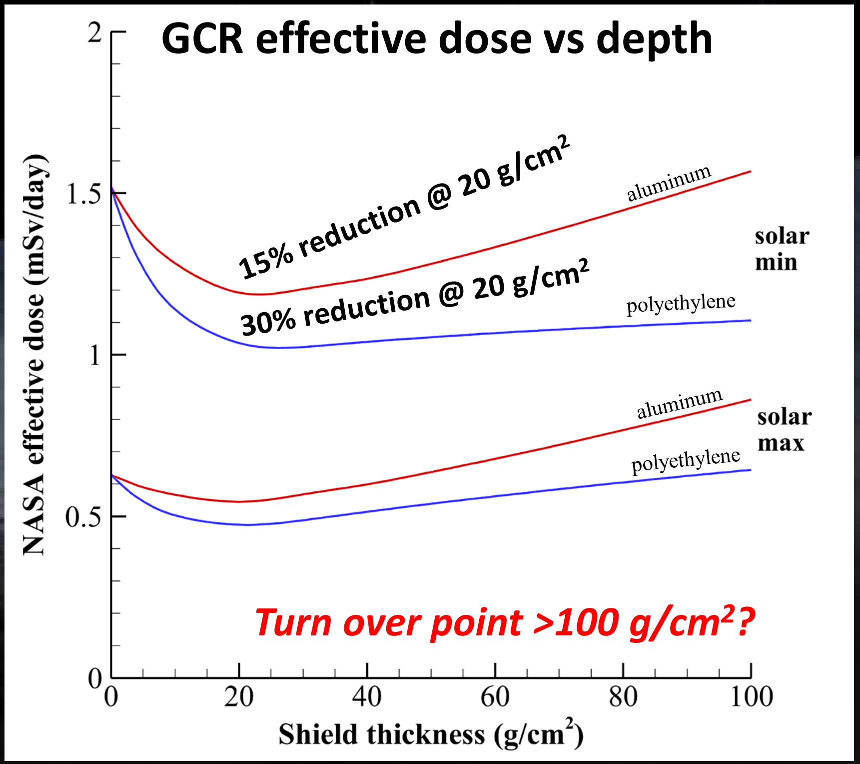
- Optimized vehicle shielding can reduce exposures by 10 - 15%
  - ➢ 10 – 30 g/cm^2 range
  - ➢ Further optimization limited by physics/transport uncertainties and lack of spaceflight measurements

- Sizing of thick shield concepts (>100 g/cm^2) not currently possible due to large uncertainty in radiation physics/transport

- Lack of mature (non-parasitic) hydrogen-rich, low-atomic-mass technology/material options for infusion



Shield Models



Effective GCR Shielding: Engineering and Technology Gaps

- Integrate hydrogen-rich, low-atomic charge materials into crewed vehicles. Identify high TRL candidates for infusion - goal of ~30% reduction

- Vehicle Shield Optimization & Thick Shield Concepts
  - Improve transport & nuclear model uncertainty by factor of 2.
  - Validate with in-space or lunar surface measurements at moderate (20 g/cm^2) to large depths (>80 to >100 g/cm^2) to within +/- 50%

- Extend neutron measurements in ≥100 MeV to 1 GeV
  - Validate with measurements on ISS and lunar surface

Metric: Increase acceptable mission durations by a factor of two

GCR Shielding Physics

Radiation field behind thick shielding is dominated by secondary particles produced from nuclear collisions

- Heavier ions (e.g. heavier than ^{4}He) suffer nuclear collisions and break-up into lighter particles
- Secondary particles: neutrons, light ions, pions, gammas, electrons, positrons

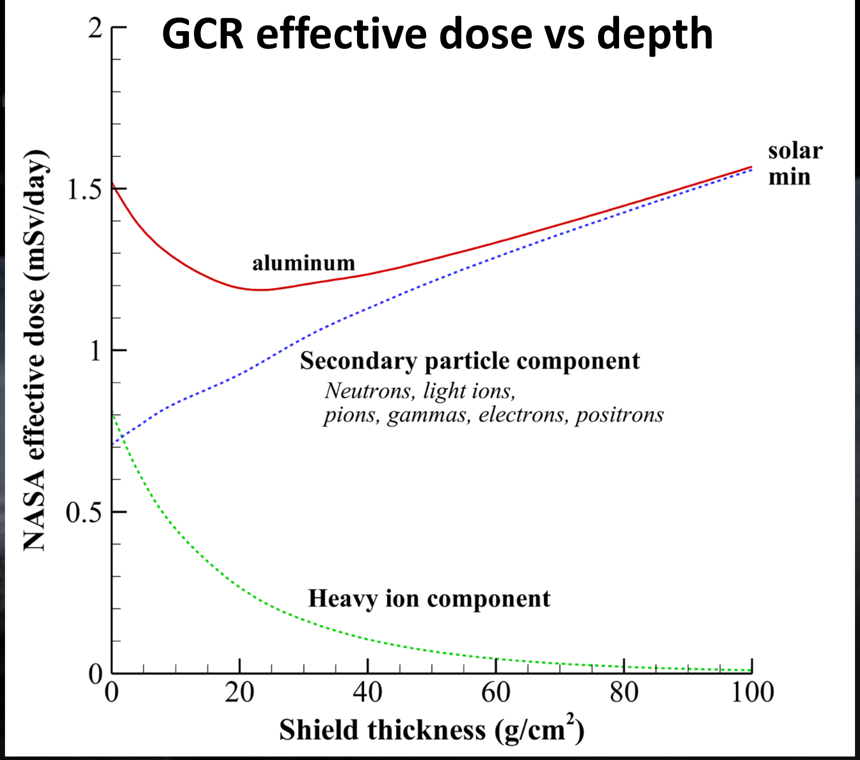
Measurements are needed to better understand the mixed radiation field behind thick shields

- Neutron energy spectrum up to ~1 GeV
- Dose-depth for GCR beyond 100 g/cm^2
- Additional ground-based nuclear interaction measurements

Lunar surface provides an opportunity to perform in situ dose-depth measurements

- Shielding mass (regolith) readily available
- Shielding characteristics of regolith similar to aluminum
- Deep-space like conditions (no magnetic field, no atmosphere)

Enables validation of dose-depth curve from moderate to thick depths for vehicle shield optimization and sizing of thick shield concepts

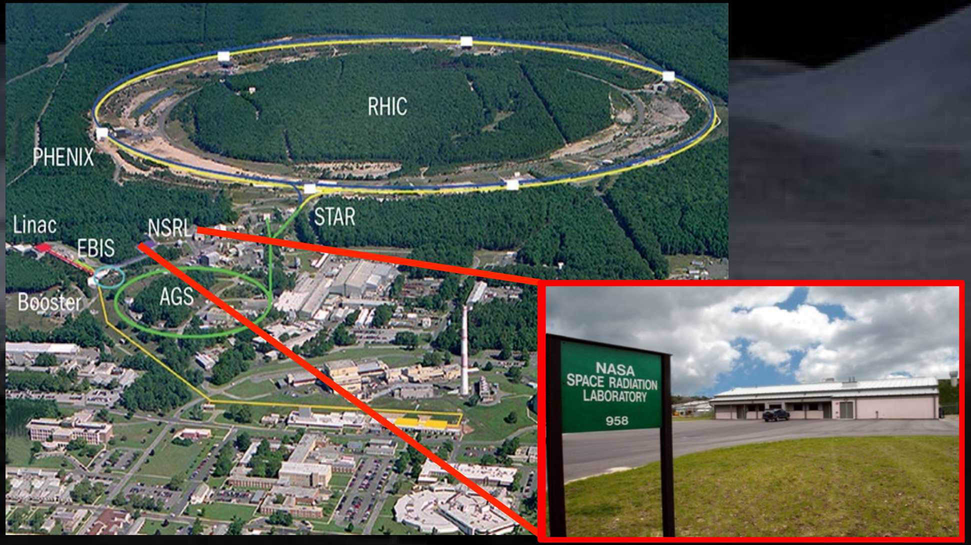


Ground-based Limitations

Ground-based measurements are constrained by facility limitations

- The NSRL "GCR simulator" was developed specifically for studying biological effects
- Higher energy beams (>4 GeV) are needed to study thick shield physics (not available at NSRL)
- Thick shields placed in beam line require large mass (~tons) and volume to ensure leakage effects are minimized (e.g. secondaries scattering from side of shield)

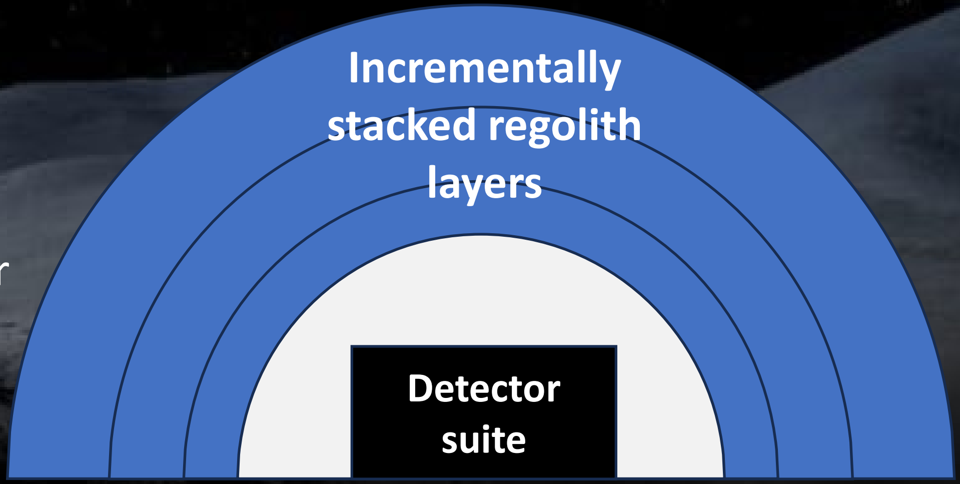
NASA Space Radiation Laboratory (NSRL)



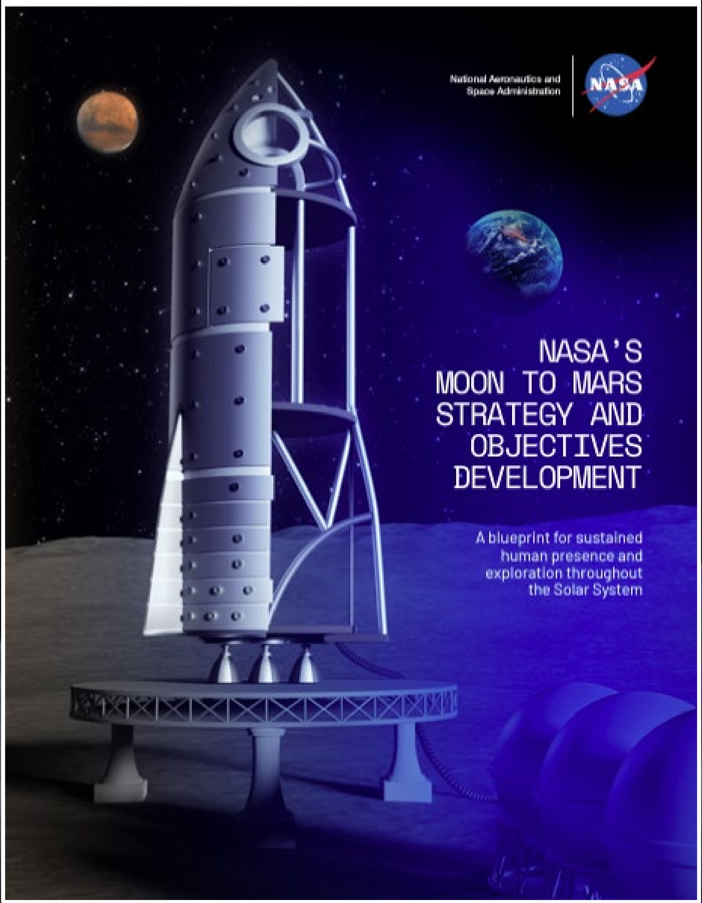
Thick Shield Measurements on Lunar Surface

Humans and Robotics needed to conduct lunar shield experiment

- **Site Survey:** Perform measurement far enough away from lander/habitat and large topographical features to avoid ambiguity in shielding and dose measurements
- **Dose measurement**: Detector system positioned under increasingly thick hemispherical layers of regolith - measure radiation attenuation as a function of thickness
- **Constructed shielding:** Regolith excavation and in-situ manufacturing/construction used to achieve uniform hemispherical thicknesses between 20 g/cm^2 to > 100 g/cm^2
- **Regolith:** Measure composition and density
- **Depth measurement**: Confirmation of uniform thicknesses: Visually or using technologies such as ground penetrating radar
- **Concept of operations:** Needed to optimize human robotic interactions, coordination with other surface ops, technologies needed



Closing GCR Shielding Gaps supports Moon2Mars Architecture Objectives



Physics and Physical Science	*Address **high priority physics** and physical science questions that are best accomplished by using **unique attributes of the lunar environment**.*
Science-Enabling	*Develop **integrated human and robotic** methods and advanced techniques that **enable high-priority scientific questions** to be addressed around and on the Moon and Mars.*
Applied Science	*Conduct science on the Moon, in cislunar space, and around and on Mars using integrated human and robotic methods and advanced techniques, **to inform design and development of exploration systems** and enable safe operations.*
Lunar Infrastructure	*Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain **continuous robotic and human presence on the lunar surface** for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.*

Summary

- **Humans to Mars: Current design reference missions have durations of 870 to >1250 days with crew exposures exceeding NASA's radiation limit by up to a factor of 1.5x - 2x**
  - ➢ Shield technologies and fast transit to reduce GCR exposures—by any significant amount—are mass prohibitive within current M2M architecture
  - ➢ Cheap mass to orbit may be a gamechanger - requires ability to size shield mass for concept trades

- **Sustained lunar economy: Thick regolith shielding of habitats can support M2M objectives for continuous human presence**

- **Effective GCR shielding can reduce crew health and performance risks - especially for long durations and multiple mission increments**
  - ➢ Requires ability to optimize designs for minimal mass impacts
  - ➢ In-space measurements required to validate of dose-depth curves

Questions?

Image Credit: NASA Artemis JM 058

Image Credit: NASA/Pat Rawlings, SAIC