Human Research Program

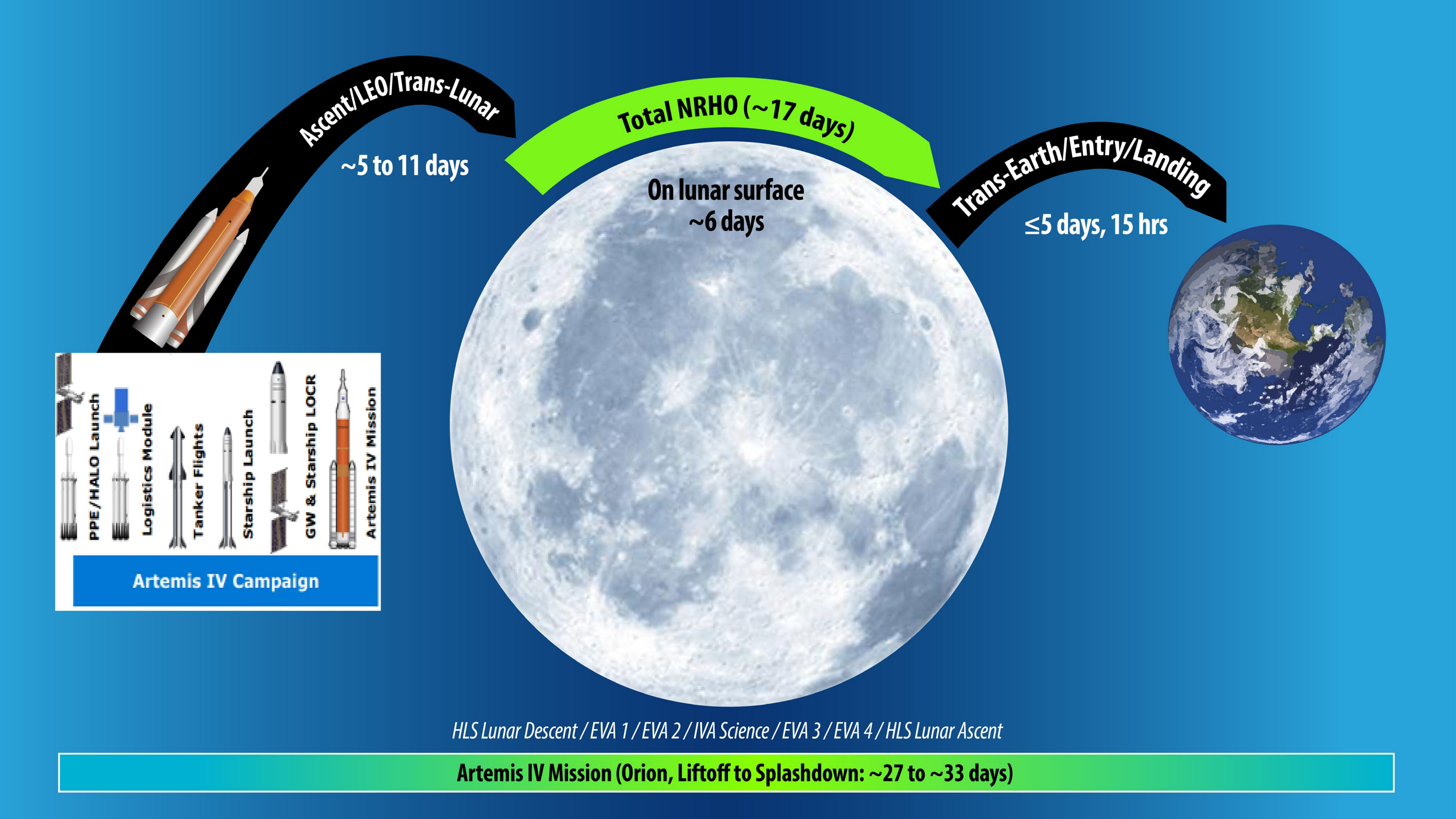
David Baumann, Program Director
Lisa Simonsen, Sr. Scientist

September 17, 2024
@ NASA Advisory Council

AGENDA

- HRP Products for Early Artemis Missions
- NASA Radiation Protection Strategy
- Backup: Recent HRP Research Findings

HRP Products for Early Artemis Missions


Ascent/LEO/Trans-Lunar
~5 to 11 days
Total NRHO (~17 days)
On lunar surface
~6 days
Trans-Earth/Entry/Landing
≤5 days, 15 hrs
PPE/HALO Launch
Logistics Module
Tanker Flights
Starship Launch
GW & Starship LOCR
Artemis IV Mission
Artemis IV Campaign
HLS Lunar Descent / EVA 1 / EVA 2 / IVA Science / EVA 3 / EVA 4 / HLS Lunar Ascent
Artemis IV Mission (Orion, Liftoff to Splashdown: ~27 to ~33 days)

HRP Products Informing Artemis Vehicle/Mission Development

Artemis Challenge	HRP Deliverable
Virtual Human-in-the-loop testing across multiple Artemis vehicles	Best practices for using tools (virtual reality) and methods (human in the loop testing) to verify requirements and assess human-system performance during the development, verification, and validation of vehicle and mission.
Food/Medication Safety	Food and Medication acceptability testing after exposure to new environments (temperature/pressure).
New Medical Conditions	Computational tools that better predict Loss of Crew risk metrics.
Hardware in Radiation Environment	Coordinating with commercial partners to help qualify flight systems by exposing hardware to simulated Galactic Cosmic Radiation (GCR) in the NASA Space Radiation Laboratory (NSRL).

HRP Products Informing Artemis Vehicle/Mission Development

Artemis Challenge	HRP Deliverable
High Tempo EVA	Improving Decompression Sickness (DCS) risk prediction tools to better respond to various vehicle, habitat and suit atmospheres that may be encountered in upcoming Artemis missions.
	Food Acceptability testing in Lunar-like conditions (high caloric demands, compressed mealtimes, no food warmer, and no fresh food).
	Evidence-based recommendations for the timing and implementation of countermeasures (caffeine, lighting) to help offset fatigue.

HRP Products Informing Artemis Dynamic Operations

Artemis Challenge	HRP Deliverable
Launch/Landing Loads	Computational tools to predict injury risks in spaceflight resulting from new launch/landing loads (seated vs standing).
Gravitational Transitions	Developing piloting and sensory motor training plans to better prepare our crew by using the KRAKEN spatial disorientation training device, provided by the United States Military.

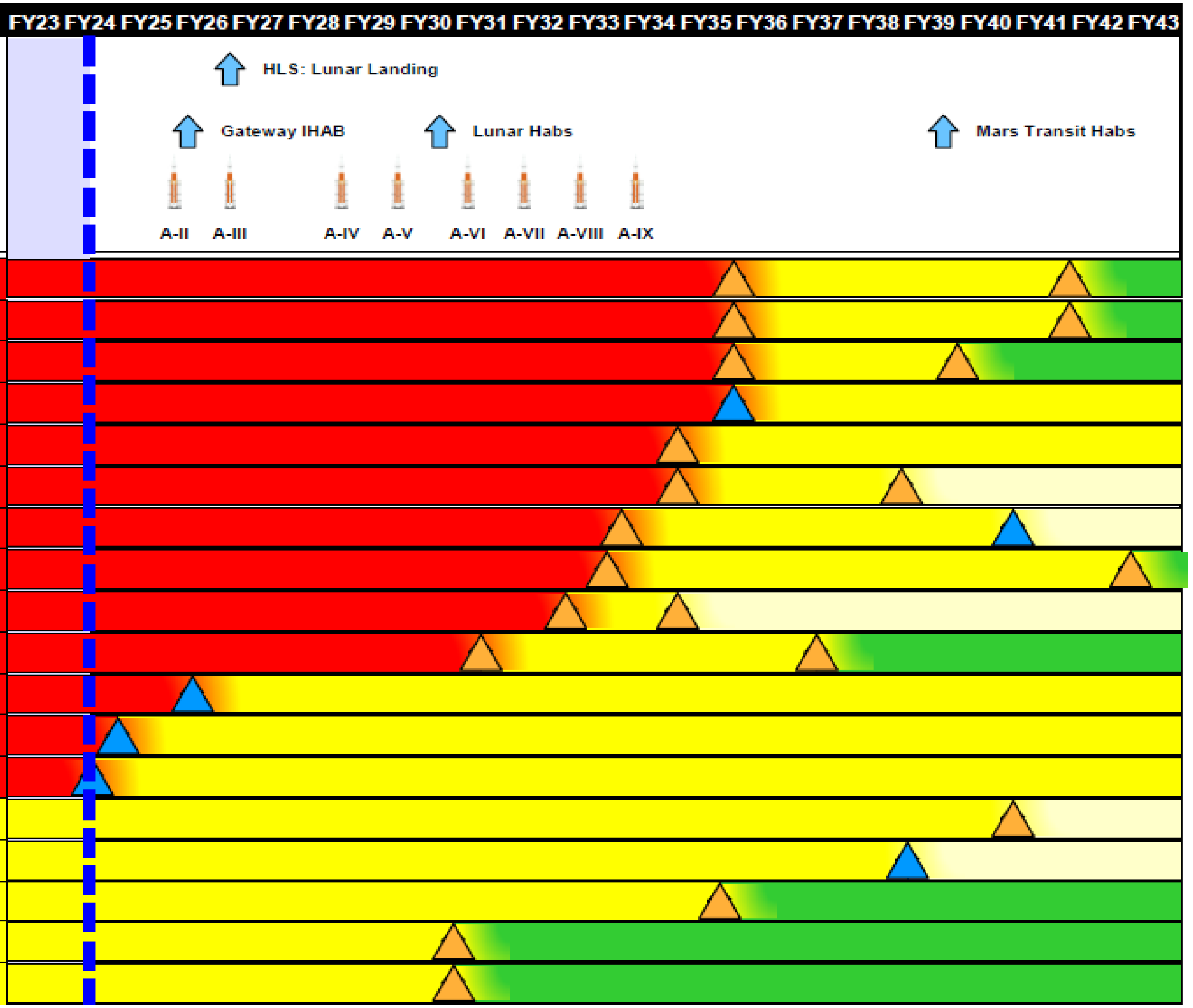
HRP Support to ESDMD
Mars Path to Risk Reduction

High Priority
Medium Priority
Low Priority

Status Date As Of: 3/29/24 - FY24Q2

HRP Mars iPRR PPBE26 PMR Content

Row ID	Exploration DRMs Exploration Mission Milestones (HRP Delivery Dates) RISKS	HSRB LxC (Below)
1	Injury Due to EVA Operations (HHC-EVA)	5x4
2	Cardiovascular Adaptations (HHC-Cardiovascular)	4x4
3	Spaceflight Associated Neuro-ocular Syndrome (HHC-SANS)	4x5 LTH
4	Celestial Dust Exposure (ExMC-Dust)	4x4
5	Cognitive or Behavioral Conditions (HFBP-Behavorial Med.)	5x3
6	Team Performance Decrements (HFBP-Team)	5x5
7	Human Systems Integration Architecture (HFBP-HSIA)	5x3
8	Spaceflight Induced Changes to Bone (HHC-Bone Fracture)	4x4
9	Injury from Dynamic Loads (HFBP-Dynamic Loads)	5x4
10	Inadequate Food and Nutrition (HHC-Food and Nutition)	5x5
11	Medical Conditions In-Mission Long Term Health (ExMC-Medical Conditions)	5x4
12	Ineffective or Toxic Medications (ExMC-Pharm)	5x3
13	Renal Stone Formation (ExMC-Renal Stone)	4x4
14	Sleep Loss and Circadian Misalignment (HFBP-Sleep)	5x2
15	Space Radiation Carcinogenesis (SR-Carcinogenesis)	* 3x3 LTH
16	Vestibular Sensorimotor Impacts (HHC-Sensorimotor)	4x2
17	Altered Immune Response (HHC-Immune)	4x3
18	Host-Microorganism Interactions (HHC-Microhost)	4x3



Risk Class: ISS Required
Completed (PRR-Color Change) Shift
Optimized
* (Asterisk) Risk Using HSRB LxC (3x4) Scale
Risk Class: ISS Not Required
High LxC
Insufficent Data
Milestone: Requires LEO Platform
Mid LxC: Requires Mitigation
Exploration Mission Milestone
Ground Based: Milestone
Mid LxC: Accepted
Mission Date
Anticipated (PRR-Color Change) Shift
Low LxC

HRP Support to ESDMD Highlighting Space Radiation Associated Risks

High Priority
Medium Priority
Low Priority

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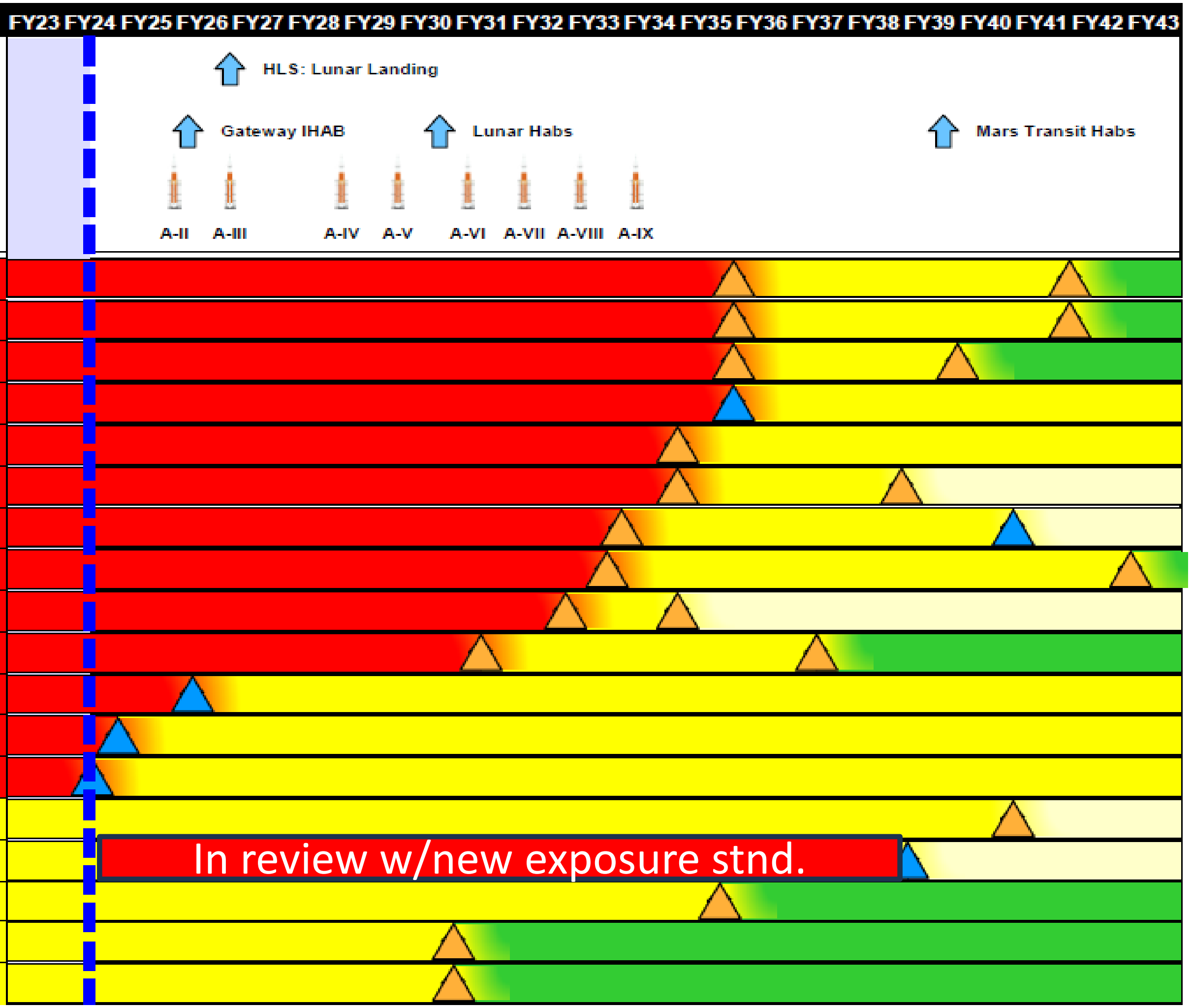

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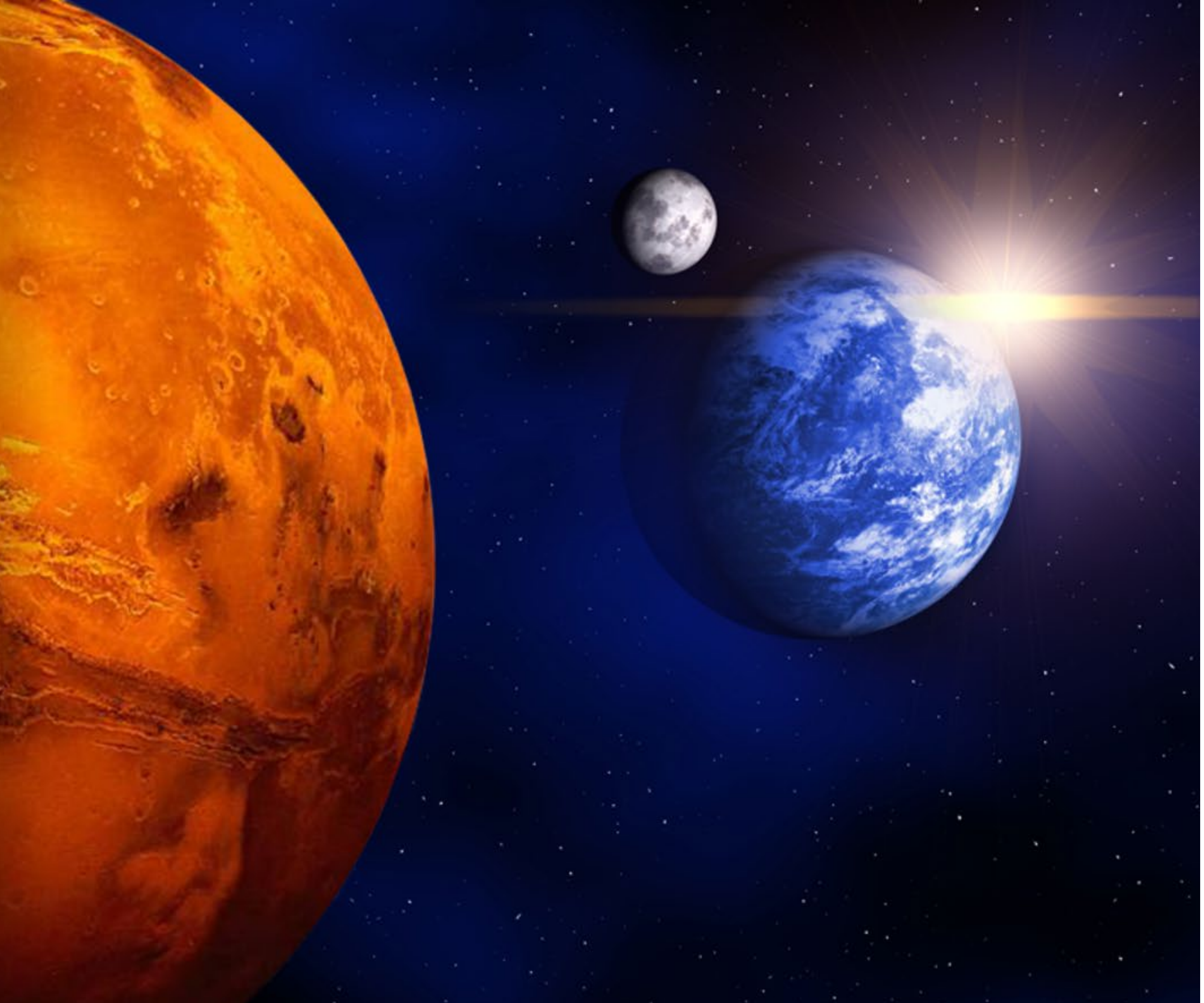
Space Radiation Protection for Human Mars Mission



NASA ADVISORY COUNCIL
Human Exploration and Operation Committee

September 17, 2024

Dr. Lisa C Simonsen
NASA HQ SOMD Human Spaceflight Capabilities Division, Senior Scientist
NASA Manager, NASA Space Radiation Laboratory @ Brookhaven National Laboratory

Key Points

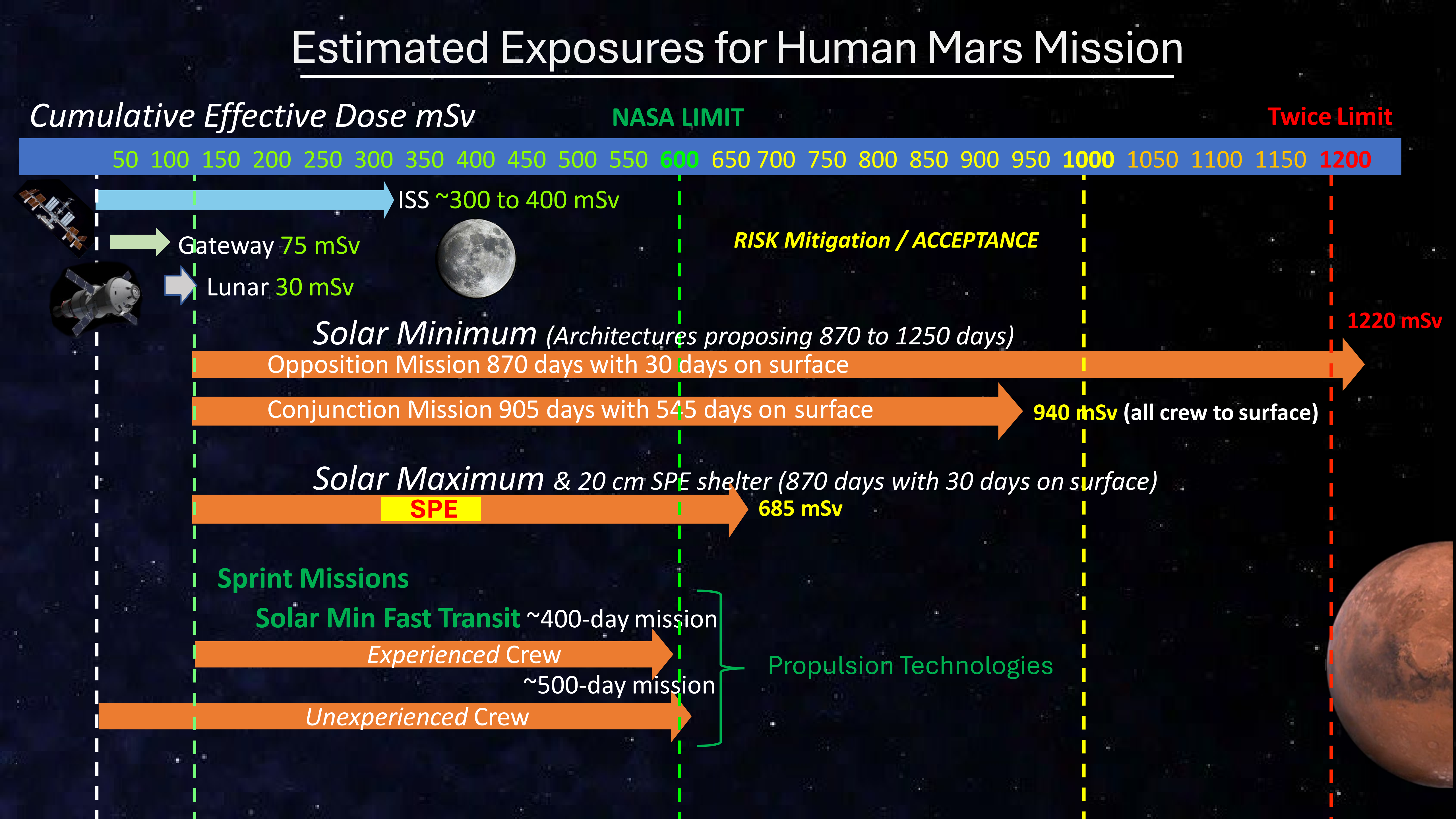
Mars Mission Duration: 870 to 1250 days; 30 days on surface;
Exposure: ~685 mSv to >1700 mSv

- Exposure levels outside spaceflight experience (~300-400 mSv) and exceed career limit of 600 mSv

- Mars mission will have potential long-term health risks
  - Cancer
  - Cardiac, vascular, cerebrovascular, neurocognitive diseases

- Potential exists for CNS performance impairments during return transit
  - Strategies identified to ensure achievable mission objectives

- Research continues to improve understanding of performance/health risks to crew & countermeasure strategies


Estimated Exposures for Human Mars Mission
Cumulative Effective Dose mSv
NASA LIMIT
Twice Limit
50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150 1200
ISS ~300 to 400 mSv
Gateway 75 mSv
Lunar 30 mSv
RISK Mitigation / ACCEPTANCE
Solar Minimum (Architectures proposing 870 to 1250 days)
1220 mSv
Opposition Mission 870 days with 30 days on surface
Conjunction Mission 905 days with 545 days on surface
940 mSv (all crew to surface)
Solar Maximum & 20 cm SPE shelter (870 days with 30 days on surface)
SPE
685 mSv
Sprint Missions
Solar Min Fast Transit ~400-day mission
Experienced Crew
~500-day mission
Unexperienced Crew
Propulsion Technologies

Advanced Habitation Systems

Space Radiation Protection

- Physical Mitigation Technologies
  - 1.1 Space Weather Forecasting
  - 1.2 Radiation Monitoring
  - 1.3 Effective Shielding
- Biological Mitigation
  - 1.4 Predictive Models of Crew Health Risks
  - 1.5 Biomedical Countermeasures and Surveillance

Solar Particle Events – Development Gaps

What we know:

- Storm shelters & dosimetry: Technology exists; Mass optimization through design
- Space Weather: Forecasting with Earth-centric observations and real time ops communication
- In case of accidental exposure, terrestrial MCMs exist (BARDA)

Research and Technology needs:

- Accurate real-time operational forecasting for SPE
  - Develop suite forecasting models utilizing current Sun-Earth observation assets (e.g., GOES, SOHO)
  - Increase accuracy of: warning times, event evolution, all-clear periods
  - Demonstrate during cis-lunar and lunar surface operations
  - Advance to use with onboard observation data in prep for Mars

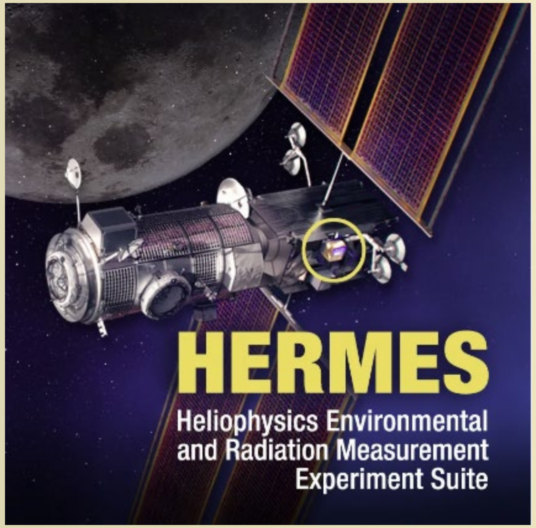
Solar Particle Events – Development Gaps

Research and Technology needs:

Earth-independent monitoring and forecasting

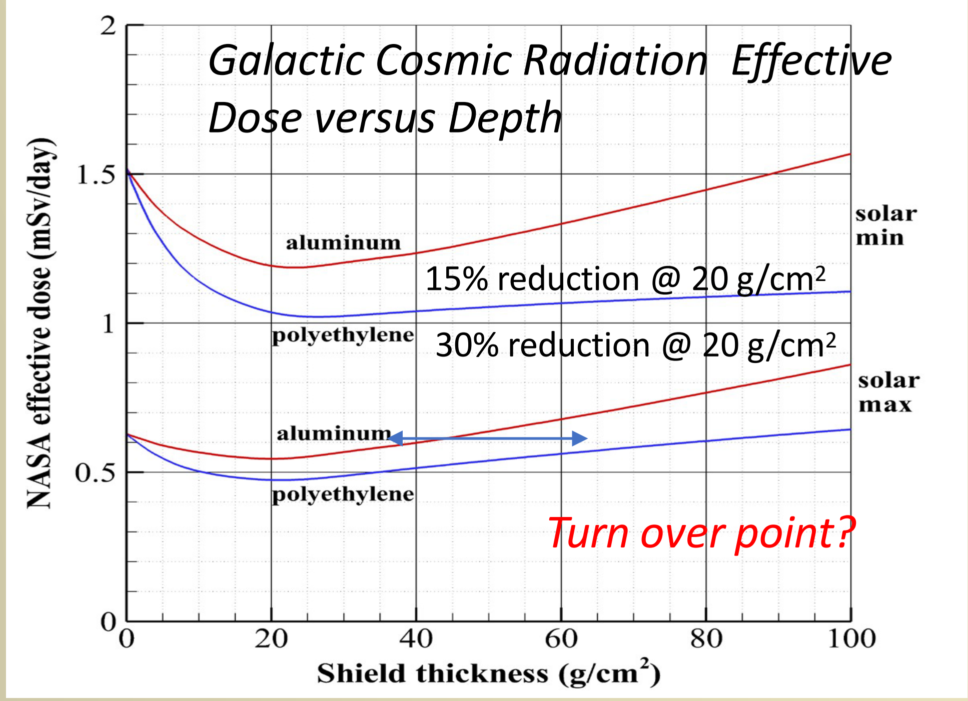
- Miniaturized onboard instrument suite for space weather observation
- Possibility of new space weather architecture platforms along Sun-Mars Line
- Autonomous forecasting & warning software

Major Asset – Space Weather Architecture



GCR: What we know

- In M2M architecture, shield technologies and fast Mars transit to reduce GCR exposures—by any significant amount—are mass prohibitive
- Optimized aluminum shielding can reduce GCR by ~15%
- Integration of H-rich materials can reduce GCR by up to 30%
- Active shielding concepts
  - Do not offer dramatic improvement over passive shielding
  - Introduce new risks in the case of system failures
- Missions at solar max can reduce exposures by ~50%
  - Current models are focused on intensity rather than duration



GCR: Technology & Knowledge Gaps

To build effective shielding/thick shield (cheap mass to orbit)

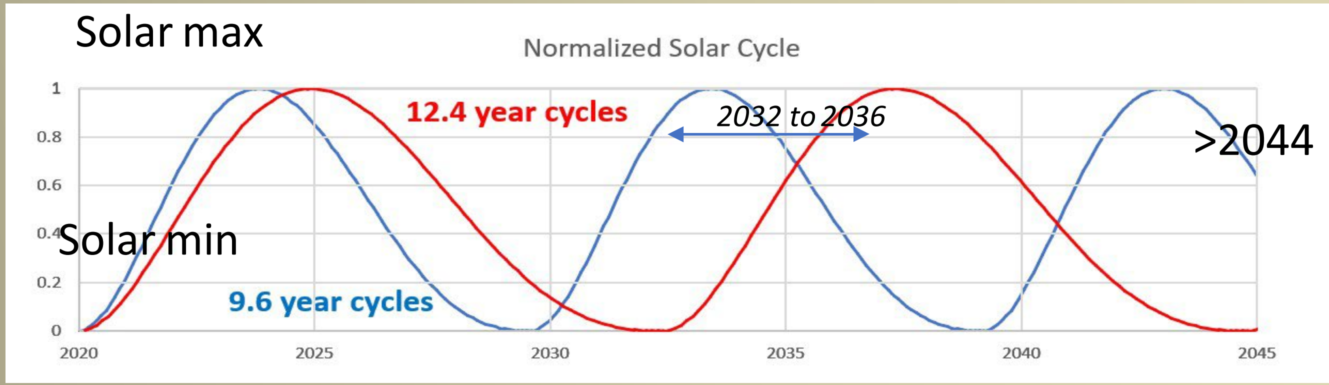
We need to…

- Reduce uncertainties of light ion production cross sections
- Extend neutron measurements in $\geq$100 MeV to 1 GeV
- Validate with in-space or lunar surface measurements at large depths

To plan mission during solar max

We need to…

- Develop models supporting predictions of solar cycle durations >10 years in advance
  - Identify data and measurements needed
- Align mission departure dates with solar max



Biological Perspective: Research Challenges

- Understanding radiation quality effects on biological damage
- Quantifying low dose and dose rate dependencies
- Translating experimental data to humans
- Understanding individual radiation sensitivity
- Quantifying synergistic modifiers of risk from other spaceflight stressors

GCR Protection: Biological Mitigation Strategies

ALARA & Risk Acceptance

- Understand & quantify risks
- Provide tools to ensure crew informed consent/NASA acceptance of risk

Personalized protection

- Understand the biology of individual sensitivity/susceptibility
- Increase protection for crew most susceptible to radiogenic health risks
    - Select most resilient crew for the longest durations (Mars demo)?

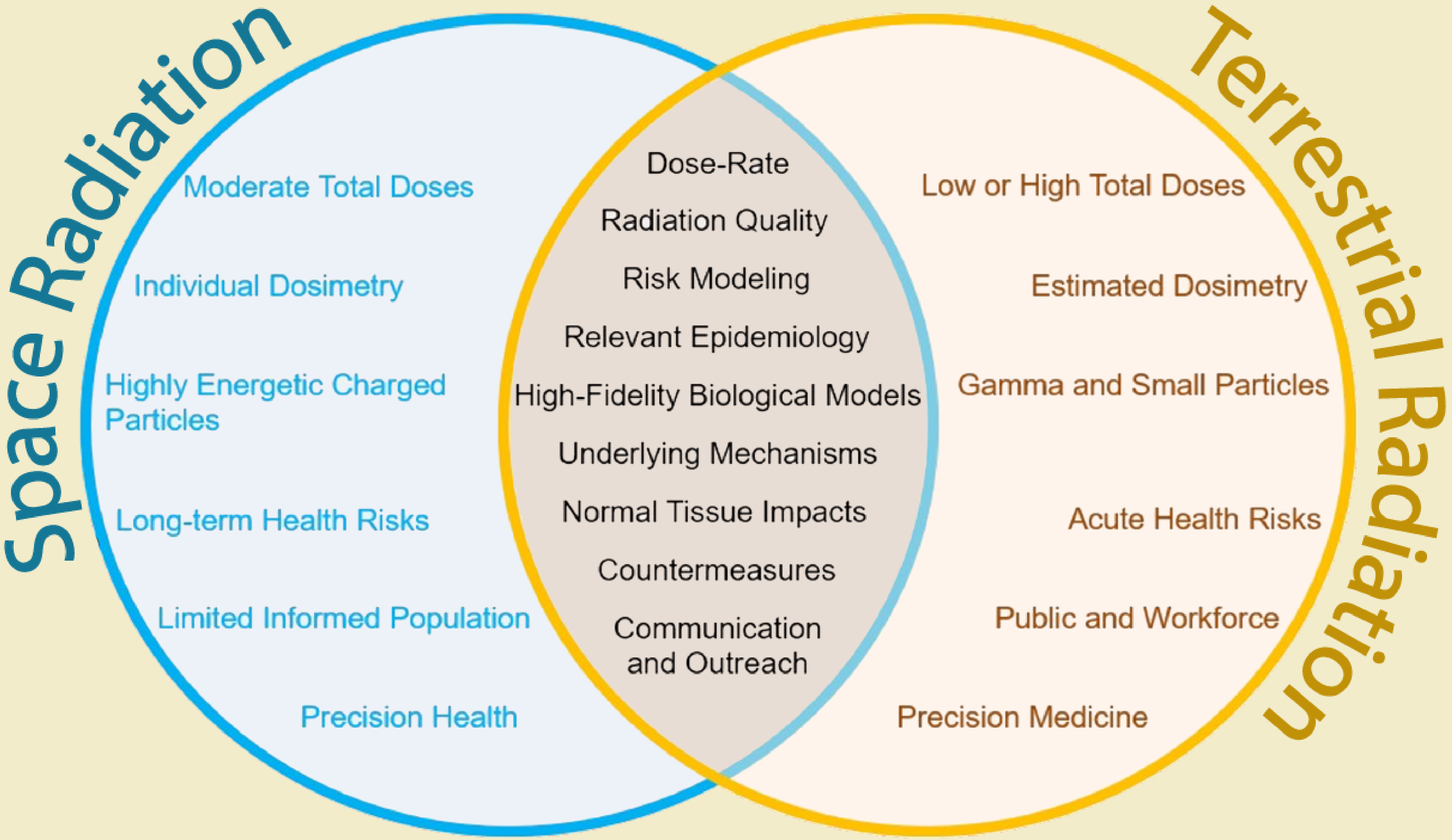
Inflight monitoring/preventative medical countermeasures

- Identify biomarkers of tissue injury & behavioral health
- Develop compact diagnostics
- Validate countermeasures focused on disease prevention

Monitor long-term health of crew

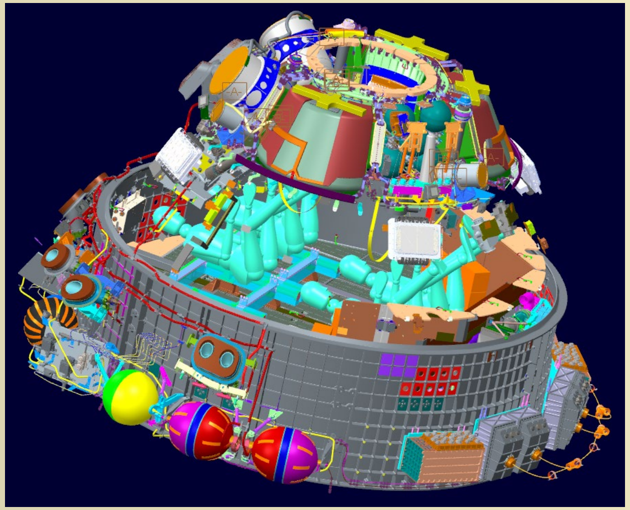
- Enable return to flight for multiple missions
- Maintain high quality of life

Leverage Advances in Terrestrial Research & Medicine

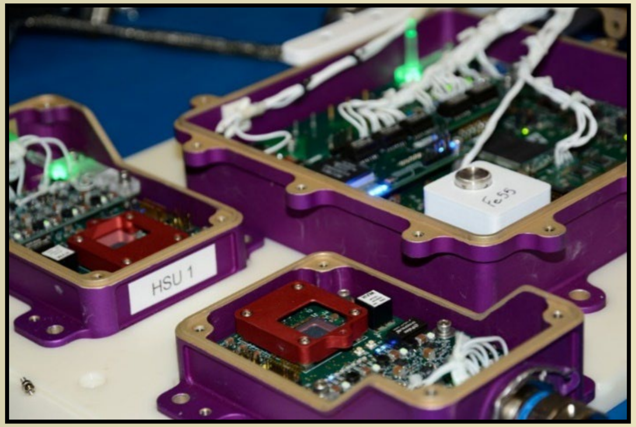


M2M Progress: Radiation Protection

- Updated health standards:
  - All crew have same career limit
  - Long-duration habitats must factor GCR
- Developed zero-mass impact solution for radiation protection in Orion storm shelter (OLTARIS)
- Characterized Mars radiation surface environment over a solar cycle
- Tested next gen dosimetry systems (ARES, HERA) on ISS, Artemis I
- Built integrated SPE scoreboard models to inform Artemis operations
- Developed compact on-board space weather observation packages for launch to Gateway (HERMES/ERSA)



Orion Shield Design



Artemis-I HERA

M2M Progress: Radiation Protection

NASA GCR Simulator: New contract with DOE signed

- Mixed field results verify NASA's operational cancer model
- Standardized exposures, large tissue sharing efforts = increased return on investment

New research on individual sensitivity, combined CNS stressors, and translation to humans

Collaborations

- DOE: Million Person Study
- NCI: Meta-analysis of cardiovascular disease
- NIH: Advances in treatments
- ICRP: State of the science on individual sensitivity
- ICRP: Risk, dose assessment for protecting astronauts
- International partners
- DOE Low Dose Program

Summary

HRP is responsive to the evolving needs to reduce risks for early Artemis missions

HRP is making progress on reducing risks for Mars missions, including those associated with deep space radiation

BACKUP

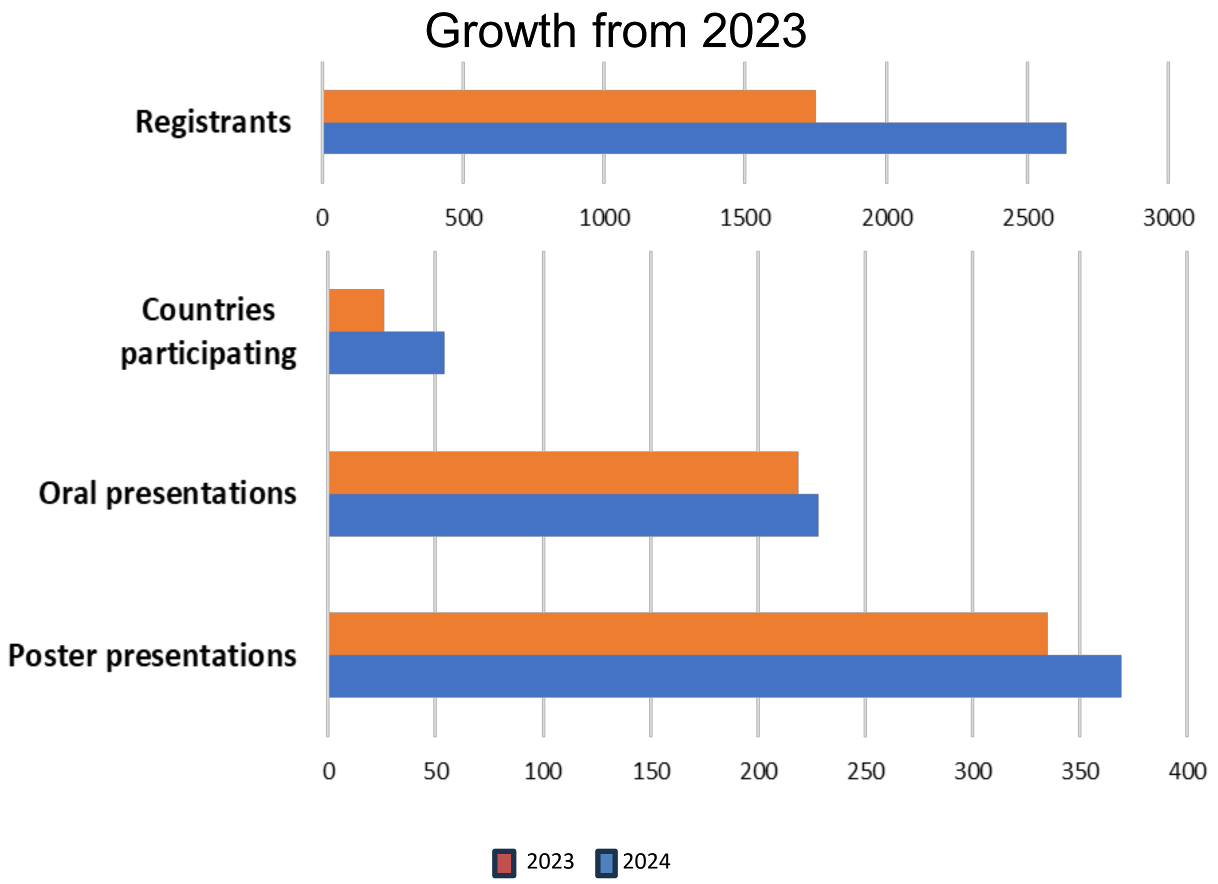
Recent HRP Research Findings

2024 HRP Investigators Workshop

13-16 February 2024 – Galveston, Texas

By the numbers:

- 2639 registrants
- 54 countries represented
- 228 oral presentations
- 369 poster presentations
- 55 sessions live-streamed
- 875 virtual attendees



Key HRP Findings Since Last NAC Report

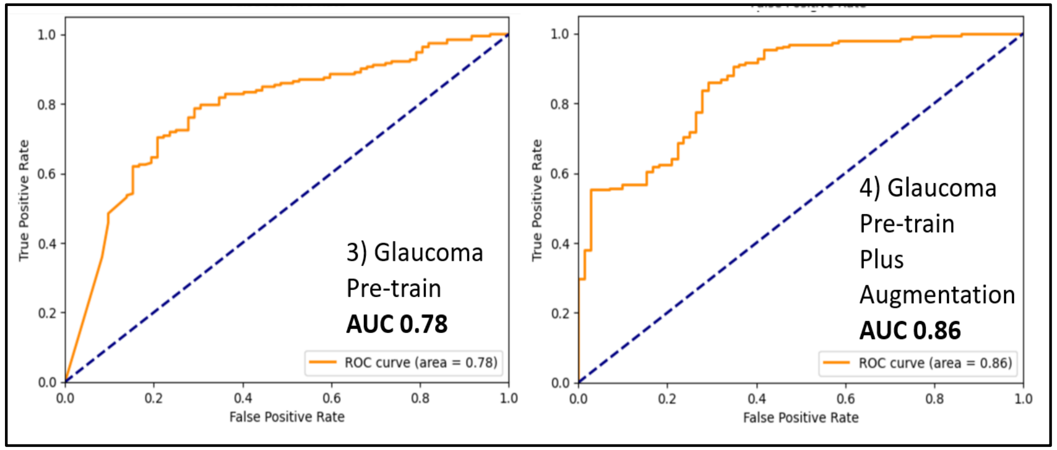
Parabolic flight investigating: Concern of Venous Thrombosis Embolism (VTE)

- Demonstrated that stagnant blood flow can occur with only brief periods of weightlessness.
- Thus, clotting risk may exist in Lunar/Martian gravity.
- HRP released a solicitation this summer to investigate further

Parabolic flight campaign attempting to replicate VTE seen on ISS

Artificial Intelligence may be able to predict who is at risk for developing Spaceflight Associated Neuro-ocular Syndrome (SANS).

- Trained on a terrestrial glaucoma model, AI can identify key anatomical regions relevant to changes seen in SANS cases
- Model could predict pre-flight those that did and did not develop SANS



Overall model performance is 0.86, a perfect model would be 1.0

Key HRP Findings Since Last NAC Report

Validation of a Portable Sensorimotor Disorientation Ground Analog

- Targets the vestibular and proprioceptive systems concurrently through galvanic vestibular stimulation and a weighted suit
- This analog can mimic postflight recovery responses and replicate a large range of postflight performance
- Can be used to test countermeasures

Technology replicated astronauts postflight sensorimotor disturbances

Mars Missions will require refrigeration for food system

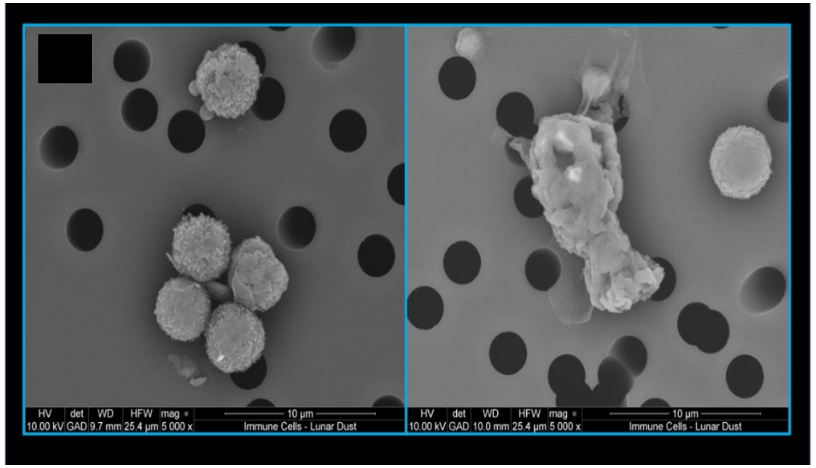
- Evaluated nutrition, acceptability, & quality of 33 foods under various combinations to test for a 5-7 year
- Not all foods will require refrigeration
- Results will inform future strategies to deliver a viable food system (e.g. need for crop growth)

An ISS crew sharing a Thanksgiving meal aboard the space station

Key HRP Findings Since Last NAC Report

Lunar dust exposure likely causes irritation but not inflammation or allergy

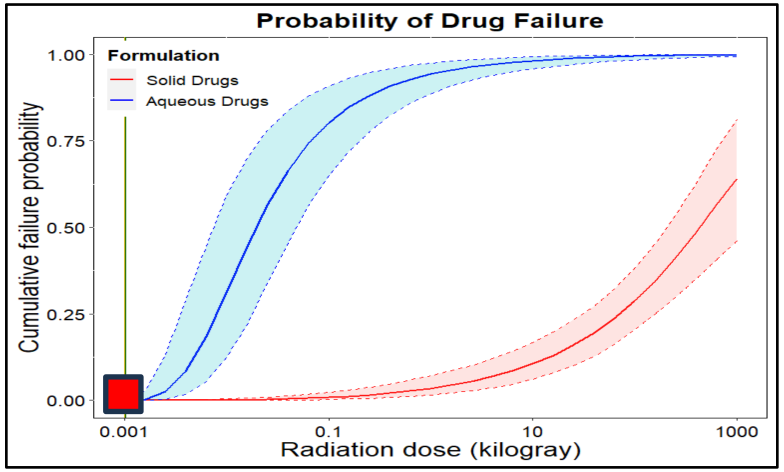
- Assessments in human subject blood immune cells indicated NO evidence for cellular responsiveness, nor ‘allergy’ to lunar dust.



Immune cell co-cultured (gray) with lunar dust (black), imaged with a backscatter detector.

Low risk of drug degradation due to ionizing radiation for Mars missions

- At Mars-relevant doses, adverse effects were not seen for solid medications
- NASA will focus on packaging solutions to reduce risk



Mars dose (~0.0005 [kGy]) at bottom, lefthand side of plot