National Aeronautics and Space Administration

Mars Mission and Space Radiation Risks Overview

Briefing to
NAC HEOMD/SMD Joint Committee

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Space Radiation Presentations

Overview

- Mars Mission and Space Radiation Risks — *Steve Davison, NASA-HQ, 30 min*
- Health Standards Decision Framework — *David Liskowsky, NASA-HQ, 10 min*

Space Radiation Environment

- Introduction — *Chris St. Cyr, NASA-GSFC, 5 min*
- Solar Energetic Particles — *Allan Tylka, NASA-GSFC, 30 min*
- Comparison and Validation of GCR Models — *Tony Slaba, NASA-LaRC, 30 min*
- GCR Radiation Environment Predictions — *Nathan Schwadron, Univ. of NH, 30 min*
- Emerging GCR Data from AMS-2 — *Veronica Bindi, Univ. of Hawaii, 30 min*

Radiation Health Risk Projections — *Eddie Semones, NASA-JSC, 45 min*

- NCRP Recommendations, Permissible Exposure Limits, Space Radiation Cancer Risk Model, Operations and In-Flight Solar Particle Event Mitigations

Space Radiation R&T for Risk Mitigation — *Lisa Simonsen, NASA-LaRC, 45 min*

- Radiobiology Research Portfolio (Cancer, CNS, Cardio) and Spacecraft Shielding Design, Analysis, and Optimization

Overview of Mars Mission Crew Health Risks

- **Mission And Crew Health Risks Are Associated With Any Human Space Mission**
  - Briefing is focused on space exploration crew health risks associated with space radiation
- **Exploration Health Risks Have Been Identified, And Medical Standards Are In Place To Protect Crew Health And Safety**
  - Further investigation and development is required for some areas, but this work will likely be completed well before a Mars mission launches
- **There Are No Crew Health Risks At This Time That Are Considered “mission-stoppers” for a Human Mission to Mars**
  - The Agency will accept some level of crew health risk for a Mars mission, but that risk will continue to be reduced through research and testing
- **The Most Challenging Medical Standard To Meet For A Mars Mission Is That Associated With The Risk Of Radiation-induced Cancer**
  - Research and technology development as part of NASA’s integrated radiation protection portfolio will help to minimize this long-term crew health risk

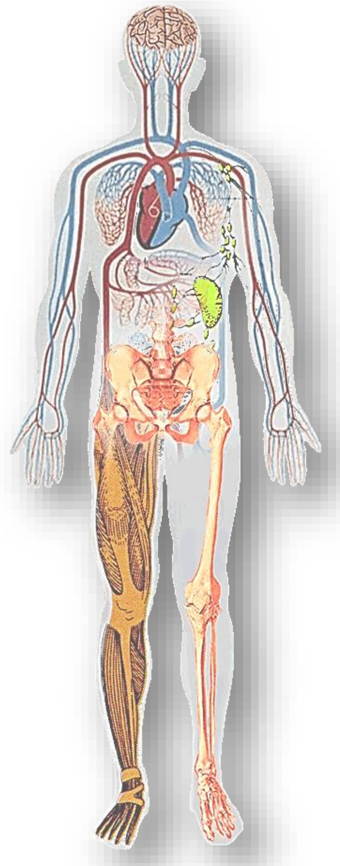
Human Spaceflight Risks are Driven by Spaceflight Hazards

Altered Gravity - Physiological Changes

Balance Disorders
Fluid Shifts
Visual Alterations
Cardiovascular Deconditioning
Decreased Immune Function
Muscle Atrophy
Bone Loss

Space Radiation

Acute In-flight effects
Long-term cancer risk
CNS and Cardiovascular



Distance from Earth

Drives the need for additional "autonomous" medical care capacity – cannot come home for treatment

Hostile/ Closed Environment

Vehicle Design
Environmental – CO_2 Levels, Toxic Exposures, Water, Food

Isolation & Confinement

Behavioral aspect of isolation
Sleep disorders

Human System Risk Board (HSRB): Human Risks of Spaceflight Summary

Altered Gravity Field

1. Spaceflight-Induced Intracranial Hypertension/Vision Alterations
2. Renal Stone Formation
3. Impaired Control of Spacecraft/Associated Systems and Decreased Mobility Due to Vestibular/Sensorimotor Alterations Associated with Space Flight
4. Bone Fracture due to spaceflight Induced changes to bone
5. Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance
6. Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity
7. Adverse Health Effects Due to Host-Microorganism Interactions
8. Urinary Retention
9. Orthostatic Intolerance During Re-Exposure to Gravity
10. Cardiac Rhythm Problems
11. Space Adaptation Back Pain

Radiation

1. Risk of Space Radiation Exposure on Human Health (cancer, acute, cardio, CNS)

Distance from Earth

1. Adverse Health Outcomes & Decrements in Performance due to inflight Medical Conditions
2. Ineffective or Toxic Medications due to Long Term Storage

Isolation

1. Adverse Cognitive or Behavioral Conditions & Psychiatric Disorders
2. Performance & Behavioral health Decrements Due to Inadequate Cooperation, Coordination, Communication, & Psychosocial Adaptation within a Team

Hostile/Closed Environment-Spacecraft Design

1. Acute & Chronic Carbon Dioxide Exposure
2. Performance decrement and crew illness due to inadequate food and nutrition
3. Reduced Crew Performance Due to Inadequate Human-System Interaction Design (HSID)
4. Injury from Dynamic Loads
5. Injury and Compromised Performance due to EVA Operations
6. Adverse Health & Performance Effects of Celestial Dust Exposure
7. Adverse Health Event Due to Altered Immune Response
8. Reduced Crew Performance Due to Hypobaric Hypoxia
9. Performance Decrements & Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, & Work Overload
10. Decompression Sickness
11. Toxic Exposure
12. Hearing Loss Related to Spaceflight
13. Injury from Sunlight Exposure
14. Electrical shock/plasma

— Each risk will be controlled by a NASA standard to protect crew health and safety—

Mars Mission Human Health Risks

Based On The On-going Human System Risk Board (HSRB) Assessment, The Following Risks Are The Most Significant For A Mars Mission:

- Adverse affect on health
  - ✧ space radiation exposure (long-term cancer risk)
  - ✧ spaceflight-induced vision alterations
  - ✧ renal stone formation
  - ✧ compromised health due to inadequate nutrition
  - ✧ bone fracture due to spaceflight induced bone changes
  - ✧ acute and chronic elevated carbon dioxide exposure
- Inability to provide in mission treatment/care
  - ✧ lack of medical capabilities
  - ✧ ineffective medications due to long term storage
- Adverse impact on performance
  - ✧ decrements in performance due to adverse behavioral conditions and training deficiencies
  - ✧ impaired performance due to reduced muscle and aerobic capacity, and sensorimotor adaptation

Post Mission Risks

In-Mission Risks

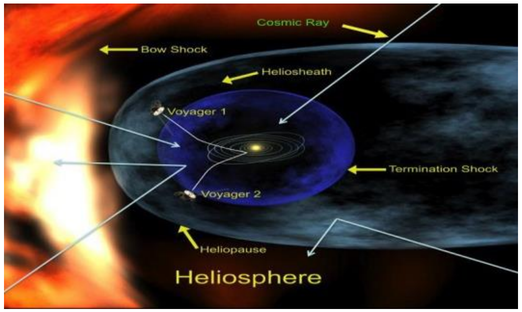
Current Space Flight Health Standards

- **NASA Should Be Able To Meet All Fitness for Duty (FFD) And Permissible Outcome Limits (POL) Standards For A Mars Mission**
  - Based on long-duration ISS flight experience and mitigation plans
- **Meeting The Current Low Earth Orbit (LEO) Space Radiation Permissible Exposure Limit (PEL) Standard Will Be Challenging For A Mars Mission**
  - NASA exposure limit is the most conservative of all space agencies

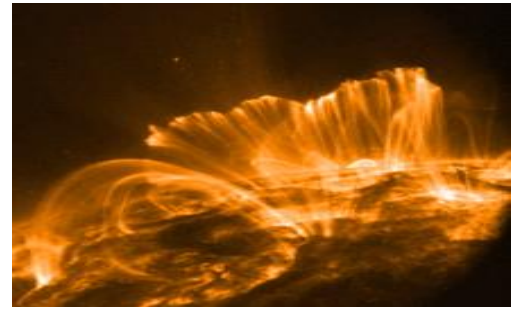
Area	Type	Standard
Bone	POL	Maintain bone mass at ≥-2SD
Cardiovascular	FFD	Maintain ≥75% of baseline VO2 max
Neurosensory	FFD	Control motion sickness, spatial disorientation, & sensorimotor deficits to allow operational tasks
Behavioral	FFD	Maintain nominal behaviors, cognitive test scores, adequate sleep
Immunology	POL	WBC > 5000/ul; CD4 + T > 2000/ul
Nutrition	POL	90% of spaceflight-modified/USDA nutrient requirements
Muscle	FFD	Maintain 80% of baseline muscle strength
Radiation	PEL	≤ 3% REID (Risk of Exposure Induced Death, 95% C.I.

Space Radiation Challenge

Galactic cosmic rays (GCR) – penetrating protons and heavy nuclei



Solar Particle Events (SPE) – low to medium energy protons



What are the levels of radiation in deep space and how does it change with time? → **How much radiation is inside the spacecraft, on Mars surface, and in the human body?** → **What are the health risks associated with radiation exposure?** → **How do we mitigate these health risks?**

SMD R&D

Helio- & Astrophysics Characterization/measurement

Modeling/Prediction & Real-time Monitoring

HEOMD R&D

Radiation Transport Code Development

Transport of radiation into body

Tissue/Organ doses

Cancer risks

Acute radiation

Non-cancer risks

NSRL research

Spacecraft Shielding

Bio-Countermeasures

Medical Standards

Space Radiation Health Risks

Health Risk Areas	Status
Carcinogenesis Space radiation exposure may cause increased cancer morbidity or mortality risk in astronauts	➢ Cancer risk model developed for mission risk assessment ➢ Model is being refined through research at NASA Space Radiation Laboratory (NSRL) ➢ Health standard established
Acute Radiation Syndromes from SPEs Acute (in-flight) radiation syndromes, which may be clinically severe, may occur due to occupational radiation exposure	➢ Acute radiation health model has been developed and is mature ➢ Health standards established ➢ Risk area is controlled with operational & shielding mitigations
Degenerative Tissue Effects Radiation exposure may result in effects to cardiovascular system, as well as cataracts **Central Nervous System Risks (CNS)** Acute and late radiation damage to the central CNS may lead to changes in cognition or neurological disorders	➢ Non-cancer risks (**Cardiovascular and CNS**) are currently being defined ➢ Research is underway at NSRL and on ISS to address these areas ➢ Appropriate animal models needed to assess clinical significance

Mars Mission Space Radiation Risks

Mars Missions May Expose Crews To Levels Of Radiation Beyond Those Permitted By The Current LEO Cancer Risk Limit (≤ 3% REID, 95% C.I.)

- May increase the probability that a crewmember develops a cancer over their lifetime and may also have undefined health effects to central nervous system and/or cardiovascular system; these areas are currently under study

Mars Missions Cancer Risk Calculations

- Calculations use 900-Day conjunction class (long-stay) trajectory option for Mars mission (500 days on Mars surface)
  - Exposure levels are about the same for 600-Day opposition-class (short-stay) trajectory option (30 days on Mars surface)

- Based on 2012 NASA Space Radiation Cancer Risk Model as recommended by the National Council on Radiation Protection and reviewed by National Academies
  - Model calculates risk of exposure induced death (REID) from space radiation-induced cancer with significant uncertainties
  - Calculations take into range of solar conditions and shielding configuration
  - Mars surface calculations include shielding by the planet, atmosphere, & lander

Post Mission Cancer Risk For A 900-day Mars Mission

Mars Mission Timing	Mission Shielding Configuration	Calculated REID, 95% C.I. (Age=45, Male-Female)	Amount Above 3% Standard
Solar Max	Good shielding like ISS (20 g/cm2) w/no exposure from SPEs	4% - 6%	1% - 3%
Solar Max	Good shielding like ISS (20 g/cm2) w/large SPE	5% - 7%	2% - 4%
Solar Min	Good shielding like ISS (20 g/cm2)	7% - 10%	4% - 7%

NASA Standards Limit The Additional Risk Of Cancer Death By Radiation Exposure, Not The Total Lifetime Risk Of Dying From Cancer

- Baseline lifetime risk of death from cancer (non-smokers)
  - 16% males, 12% females
- After Mars Mission (solar max), Astronauts lifetime risk of death from cancer ~20%

Mars Space Radiation Risk For Solar Max Can Be Explained As Follows

- If 100 astronauts were exposed to the Mars mission space radiation, in a worst case (95% confidence) 5 to 7 would die of cancer, later in life, attributable to their radiation exposure and their life expectancy would be reduced by an average on the order of 15 years
- Challenging to use a population-based risk model to estimate individual risk for the few individuals that would undertake a Mars Mission

Radiation Protection Portfolio

Optimize human radiation protection by integrating research, operations and development activities across the agency

Integrated Radiation Protection

Radiation Exposure Standard

OCHMO

Space Radiation Environment

SMD, Monitoring/Prediction Advances

External Advisory Panels

NCRP, NAS, SRP, NAC

Monitoring Devices

In flight Crew Monitoring
Dosimeter Technology Development

Shielding/Vehicle Design

Models to enable exposure assessment
Shielding Optimization

Occupational Surveillance

Pre- and In- Mission Care
Post Mission Screening/Treatment

Countermeasures

Advances in Nutrition/Pharmaceuticals

Analysis, Operations, Mission Planning

Radiation Assessment Models
Assessment & Planning, SRAG

Space Radiation Biological Effects

Radiobiology research on cancer, CNS, and cardiovascular

Reducing Mars Mission Radiation Risks

NASA Is Working Across All Phases Of The Mars Mission To Minimize The Space Radiation Health Risk

Pre - Mission

Radiation Factors

*Individual Sensitivity – Biomarkers**

Selection – age, gender

Model Projection of Risk

Space Radiation Envir. Model

In - Mission

Radiation Factors

Shielding

Mission Duration

Solar Min vs. Max

Operational Planning

Dosimetry

*Countermeasures**

- Pharmaceutical & Nutritional

Post - Mission

Radiation Factors

*Occupational Health Care for Astronauts**

- Personalized Cancer Screening, Biomarkers

- Cancer Treatment

Reduction in Total Risk Posture

**long-term development*

Reducing Radiation Health Risks

Space Radiation Research at NSRL

- Key to reducing the space radiation health effects uncertainties, refinement of cancer risk model, and understanding cardiovascular and CNS risks

Space Radiation Environment Characterization

- LRO-CRaTER measurements of radiation environment
- SEP real-time monitoring and characterization
- MSL-RAD Measurements of radiation environment during transit and on the surface of Mars

Medical Approaches Applied Pre-/Post-Mission

- Understanding the individual sensitivities and enhancing post mission care are the key areas that can significantly reduce the space radiation risk

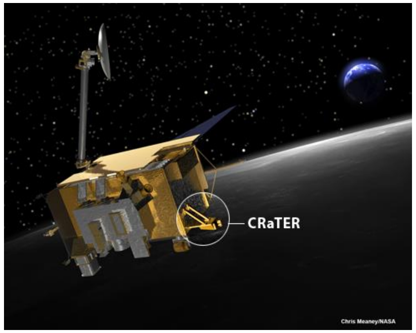
Exploration Space Radiation Storm Shelter Design and Real-time Radiation Alert System

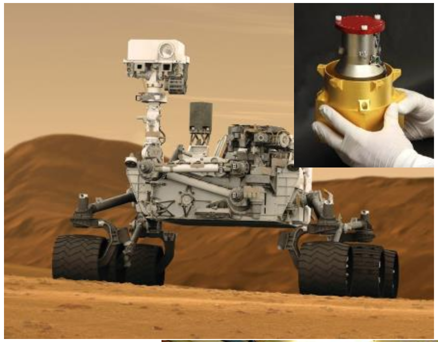
- Development of these capabilities for exploration missions can reduce crew exposure risk to SPEs to negligible levels

Mars Mission Design and Deep Space Propulsion

- Reducing deep space transit times can reduce space radiation exposure and mitigate human health risks

LRO-CRaTER *radiation measurements*





MSL-RAD radiation measurements on Mars

NSRL simulates space cosmic and solar radiation environment

Summary

Based on current mitigation plans for Crew Health and Performance Risks, NASA can support a Mars Mission

- **Mars Mission Health Risks Have Been Identified And Medical Standards Are In Place To Protect Crew Health And Safety**
  - While there is a fair amount of forward work to do, there are no crew health risks at this time that can be considered "mission-stoppers"
  - There will be a level of crew health risk that will need to be accepted by the Agency to undertake a Mars mission, but that risk will continue to be reduced through R&D

- **Based on <u>present</u> understanding of risks and standards**
  - Exercise countermeasure approaches (hardware & prescriptions) require further refinement/optimization to meet exploration mission, vehicle, and habitat designs
  - Additional data needed to fully quantify some risks (vision impairment, CO_2 exposure)
  - Renal stone risk needs new intervention/treatment approaches
  - Some risks (nutrition, inflight medical conditions) require optimization in order to support a Mars Mission
  - Pharmaceutical & food stability/shelf life needs to be improved for a Mars Mission
  - Behavioral health and human factors impacts need to be further minimized
  - **The radiation standard would not currently be met**