Mars Mission and Space Radiation Risks Overview

Briefing to
NAC HEOMD/SMD Joint Committee

April 7, 2015
## 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

- **Distance from Earth**
  - Drives the need for additional “autonomous” medical care capacity – cannot come home for treatment

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

- **Hostile/Closed Environment**
  - Vehicle Design
  - Environmental – CO₂ Levels, Toxic Exposures, Water, Food

- **Isolation & Confinement**
  - Behavioral aspect of isolation
  - Sleep disorders
### 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 & Decrement 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 Decrement 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 Decrement & 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 —
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

<table>
<thead>
<tr>
<th>Area</th>
<th>Type</th>
<th>Standard</th>
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<tbody>
<tr>
<td>Bone</td>
<td>POL</td>
<td>Maintain bone mass at $\geq-2$SD</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>FFD</td>
<td>Maintain $\geq75%$ of baseline VO2 max</td>
</tr>
<tr>
<td>Neurosensory</td>
<td>FFD</td>
<td>Control motion sickness, spatial disorientation, &amp; sensorimotor deficits to allow operational tasks</td>
</tr>
<tr>
<td>Behavioral</td>
<td>FFD</td>
<td>Maintain nominal behaviors, cognitive test scores, adequate sleep</td>
</tr>
<tr>
<td>Immunology</td>
<td>POL</td>
<td>WBC $&gt; 5000/\text{ul}; \text{CD4} + \text{T} &gt; 2000/\text{ul}$</td>
</tr>
<tr>
<td>Nutrition</td>
<td>POL</td>
<td>90% of spaceflight-modified/USDA nutrient requirements</td>
</tr>
<tr>
<td>Muscle</td>
<td>FFD</td>
<td>Maintain 80% of baseline muscle strength</td>
</tr>
<tr>
<td>Radiation</td>
<td>PEL</td>
<td>$\leq 3%$ REID (Risk of Exposure Induced Death, 95% C.I.)</td>
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</table>
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

<table>
<thead>
<tr>
<th>Health Risk Areas</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carcinogenesis</strong></td>
<td>➢ Cancer risk model developed for mission risk assessment</td>
</tr>
<tr>
<td>Space radiation exposure may cause increased cancer morbidity or mortality risk in astronauts</td>
<td>➢ Model is being refined through research at NASA Space Radiation Laboratory (NSRL)</td>
</tr>
<tr>
<td></td>
<td>➢ Health standard established</td>
</tr>
<tr>
<td><strong>Acute Radiation Syndromes from SPEs</strong></td>
<td>➢ Acute radiation health model has been developed and is mature</td>
</tr>
<tr>
<td>Acute (in-flight) radiation syndromes, which may be clinically severe, may occur due to occupational radiation exposure</td>
<td>➢ Health standards established</td>
</tr>
<tr>
<td></td>
<td>➢ Risk area is controlled with operational &amp; shielding mitigations</td>
</tr>
<tr>
<td><strong>Degenerative Tissue Effects</strong></td>
<td>➢ Non-cancer risks (<strong>Cardiovascular and CNS</strong>) are currently being defined</td>
</tr>
<tr>
<td>Radiation exposure may result in effects to cardiovascular system, as well as cataracts</td>
<td>➢ Research is underway at NSRL and on ISS to address these areas</td>
</tr>
<tr>
<td></td>
<td>➢ Appropriate animal models needed to assess clinical significance</td>
</tr>
<tr>
<td><strong>Central Nervous System Risks (CNS)</strong></td>
<td></td>
</tr>
<tr>
<td>Acute and late radiation damage to the central CNS may lead to changes in cognition or neurological disorders</td>
<td></td>
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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
Mars Mission Cancer Risk For A 900-day Mars Mission

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

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

Integrated Radiation Protection

- **Space Radiation Biological Effects**
  - Radiobiology research on cancer, CNS, and cardiovascular

- **Analysis, Operations, Mission Planning**
  - Radiation Assessment Models Assessment & Planning, SRAG

- **Countermeasures**
  - Advances in Nutrition/Pharmaceuticals

- **Occupational Surveillance**
  - Pre- and In- Mission Care
  - Post Mission Screening/Treatment

- **Shielding/Vehicle Design**
  - Models to enable exposure assessment
  - Shielding Optimization

- **Space Radiation Environment**
  - OCHMO
  - SMD, Monitoring/Prediction Advances

- **External Advisory Panels**
  - NCRP, NAS, SRP, NAC

- **Monitoring Devices**
  - In flight Crew Monitoring
  - Dosimeter Technology Development
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

*long-term development

Reduction in Total Risk Posture
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
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 present 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, CO₂ 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