Human System Risk in Exploration and the Human Research Program
Presentation contents:

- Human System Risks in Exploration Missions
  - Pedigree of Human System Risks
  - Nature and Diversity of Human System Risks
- Exploration Risks: How they are baselined and changed
  - Human System Risk Board
  - Relationship to Other Risk Boards
NASA’s (Ex-)Exploration Roadmap

Mars
- Many medical risks (known, unknown, unanticipated)
- Communications difficult (latency delays)
- 30 months mission – no contingency return
- Autonomous medical care absolutely required

Moon (Long duration)
- Many known medical risks, others unknown but anticipated
- Communication
- 2-3 day to access Earth facilities
- Greater autonomy necessary

Moon (Short duration)
- Mostly known medical risks
- Communication
- 2-3 day to access Earth facilities
- Greater autonomy necessary

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- Known medical risks
- Communications
- Access to Earth
- Minimum autonomy
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- Many medical risks (known, unknown, unanticipated)
- Crew of 2 (or 3)
- 6 - 12 months mission – contingency return problematic
- Autonomous medical care absolutely required
Human Space Flight Experience

904 person-missions (86%)

143 person-missions (14%)

Flight Duration

Number of individual exposures

1 day or less
1-2 weeks
2-3 weeks
3 wk-1 mo.
1-2 months
2-3 months
3-4 months
4-5 months
5-6 months
6-7 months
7-8 months
8-9 months
9-10 months
10-11 months
11-12 months
12-13 months
13-14 months
14-15 months
Flights longer than 28 days

Most long-duration flights are 4-7 months long

Mars missions may last up to 30 months

Space Flight Experience (continuous)
The risks to Human Health and Performance in exploration missions have been developed over 13 years (since 1997).

In 2004, NASA published the “Bioastronautics Roadmap” a framework to identify and assess the risks of crew exposure to the hazardous environments of space.

The risks were reviewed by the Institute of Medicine (NRC) with a published report in 2006 – “A Risk Reduction Strategy for Human Exploration of Space”

In 2008, NASA had updated the risks and mapped them to the missions of space exploration under the Constellation program. NASA published the compiled evidence that supports the risks and requested review by the Institute of Medicine.

In 2008 the IOM published a letter report “Review of NASA’s Human Research Program Evidence Books”
In 2008, NASA established the Human System Risk Board (HSRB) to systematically apply continuous risk management methodology to human system risks for exploration.

HSRB is a multidisciplinary Board with representatives from all aspects of Space Life Sciences/Human Research Program:

- Chief Medical Officer at JSC
- Human Research Program Manager
- Space Medicine
- Human Adaptation & Countermeasures
- Human Factors
- Astronaut representative

As an international adjunct to the HSRB, in 2009, the Collaborative Human System Risk Forum was established to be a venue that will offer all participants the opportunity to hold open discussions concerning the human health and performance risks associated with human space flight. The forum provides a broad-based opportunity for integration to address gaps in knowledge, technology, and other issues.
Overall Human System Risk Management

IDENTIFY

- Identify Human Health & Performance Risks by Mission
- Exploration Mission Operations Concepts

ANALYZE

- Analyze Human Health & Performance Risks by Mission
  - Validated Risk Acceptable Level
- SFHS Standards (V1, V2,)
  - Invalidated Risk or Risk Factors needing research
  - Validated Risk Unacceptable Mitigation
  - Validated Risk Acceptable Mitigation

PLAN

- Research Requirements (Quantify/Substantiate)
- Research Requirements (CM/Technology Development)
- Cx Vehicle Requirements
- Operational Program Requirements (MORD, Fit Rules)

Research Data
Med Ops Data
Env. Data

TRACK/CONTROL

- Research Reviews
- Evidence Base Analysis
  - Data Collection: Performance, Medical, Research, Terrestrial
- Exploration Mission Operations Concepts

Human Research Program

Validated Risk Acceptable Mitigation
Invalidated Risk or Risk Factors needing research
Validated Risk Unacceptable Mitigation
SFHS Standards (V1, V2,)
Research Requirements (Quantify/Substantiate)
Research Requirements (CM/Technology Development)
Cx Vehicle Requirements
Operational Program Requirements (MORD, Fit Rules)
The Human System Risk Board (HSRB) has accepted 42 risks. Of those 42 risks, 28 have been determined to need research either to quantify or substantiate the risks or need countermeasure/technology development to achieve acceptable mitigation. The remainder have adequate operational controls for the missions analyzed.

The risks vary considerably in depth of complexity and analysis. A risk may be described by evidence comparable to terrestrial health risks or may require extensive research data and modeling (such as space radiation, probability of medical events, Decompression Sickness likelihood).
### Risk Scorecard

#### Consequence Criteria

<table>
<thead>
<tr>
<th>Consequence Criteria</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical Health:</strong> Injury or illness that is self-limiting</td>
<td>PH: Injury or illness requiring treatment</td>
<td>PH: Injury, illness, or incapacitation, may affect personal safety or health</td>
<td>PH: Injury, illness, incapacitation or impairment, could be serious enough to lead to evacuation</td>
<td>PH: Injury, illness, incapacitation or impairment, could be serious enough to lead to evacuation</td>
<td>PH: Death (LOC) or permanent disabling injury</td>
</tr>
<tr>
<td><strong>Operational Performance:</strong> Negligible impact to mission operations/objectives</td>
<td>OP: Minor impact to operations, workarounds available</td>
<td>OP: Moderate impact to operations, workarounds available</td>
<td>OP: Failure to achieve major mission objectives. Significant risk of inability to CoFR, limited mitigation options or operational workarounds</td>
<td>OP: Failure to achieve major mission objectives. Significant risk of inability to CoFR, limited mitigation options or operational workarounds</td>
<td>OP: Contingency abort (LOM)</td>
</tr>
<tr>
<td><strong>Long Term Health:</strong> Disability is short term</td>
<td>LTH: Disability or occupational illness, can be corrected with terrestrial advances in treatment and/or surgery to approximate pre-flight condition</td>
<td>LTH: Disability or occupational illness, partially corrected, able to compensate</td>
<td>LTH: Disability or occupational illness, partially corrected, able to compensate</td>
<td>LTH: Disability or occupational illness, partially corrected, able to compensate</td>
<td>LTH: Permanently disabling injury or illness, unable to correct or compensate; premature death</td>
</tr>
</tbody>
</table>

#### Likelihood

- **5 -Highly Likely** Nearly certain to occur. Controls have little or no effect. >50%
- **4 -Likely** Highly likely to occur. Controls have significant uncertainties. 10-50%
- **3 -Possible** May occur. Controls exist with some uncertainties. 1-10%
- **2 -Unlikely** Not likely to occur. Controls have minor limitations/uncertainties. 0.1-1.0%
- **1 -Highly Unlikely** Very unlikely to occur. Strong controls in place. <0.1%
Status of HRP risks for Exploration Missions

Criticality Metric

• Describes current state of data and information on the risk and its mitigation and countermeasures

  ✓ Degree of uncertainty in understanding likelihood, consequence, or timeframe

  ✓ Ability to mitigate risk to an acceptable level

• Criticality metric established for Lunar and Mars missions

U unacceptable risk that would keep a mission from proceeding

A acceptable as is, but with a high uncertainty in risk; additional mitigation recommended, and

C acceptable through use of known controls.
## Human System Risks in Exploration Missions – Scoreboard
### For Risks Requiring Research

<table>
<thead>
<tr>
<th>Risk</th>
<th>Element</th>
<th>Criticality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload</td>
<td>BHP</td>
<td>C  C</td>
</tr>
<tr>
<td>Risk of Performance Decrement Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team</td>
<td>BHP</td>
<td>C  A</td>
</tr>
<tr>
<td>Risk of Adverse Behavioral Conditions and Psychiatric Disorders</td>
<td>BHP</td>
<td>C  U</td>
</tr>
<tr>
<td>Risk of Inability to Adequately Recognize or Treat an Ill or Injured Crewmember</td>
<td>ExMC</td>
<td>A  U</td>
</tr>
<tr>
<td>Risk Factor of Inadequate Nutrition</td>
<td>HHC</td>
<td>C  U</td>
</tr>
<tr>
<td>Risk of Bone Fracture</td>
<td>HHC</td>
<td>C  C</td>
</tr>
<tr>
<td>Risk of Intervertebral Disk Damage</td>
<td>HHC</td>
<td>C  A</td>
</tr>
<tr>
<td>Risk of Cardiac Rhythm Problems</td>
<td>HHC</td>
<td>C  A</td>
</tr>
<tr>
<td>Risk of Renal Stone Formation</td>
<td>HHC</td>
<td>C  C</td>
</tr>
<tr>
<td>Risk of Therapeutic Failure Due to Ineffectiveness of Medication</td>
<td>HHC</td>
<td>C  A</td>
</tr>
<tr>
<td>Risk of Compromised EVA Crew Health and Performance to Inadequate EVA Suit Systems</td>
<td>HHC</td>
<td>A  A</td>
</tr>
<tr>
<td>Risk of Crew Adverse Health Event Due to Altered Response</td>
<td>HHC</td>
<td>C  A</td>
</tr>
<tr>
<td>Risk of Orthostatic Intolerance During Re-Exposure to</td>
<td>HHC</td>
<td>C  A</td>
</tr>
<tr>
<td>Risk of Impaired Control of Spacecraft, Associated Immediate Vehicle Egress Due to Alterations Associated with Space Flight</td>
<td>HHC</td>
<td>C  A</td>
</tr>
</tbody>
</table>
### Human System Risks in Exploration Missions – Scoreboard

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<table>
<thead>
<tr>
<th>Risk Description</th>
<th>Criticality</th>
<th>Priority</th>
<th>Urgency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Of Early Onset Osteoporosis Due To Spaceflight</td>
<td>HHC</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>Risk Of Impaired Performance Due to Reduced Muscle Strength and Endurance</td>
<td>HHC</td>
<td>A</td>
<td>U</td>
</tr>
<tr>
<td>Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity</td>
<td>HHC</td>
<td>A</td>
<td>U</td>
</tr>
<tr>
<td>Risk of Adverse Health Effects from Lunar Dust Exposure</td>
<td>SHFH</td>
<td>A</td>
<td>n/a</td>
</tr>
<tr>
<td>Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions</td>
<td>SHFH</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>Risk of Performance Decrement and Crew Illness Due to Inadequate Food System</td>
<td>SHFH</td>
<td>C</td>
<td>U</td>
</tr>
<tr>
<td>Risk of Error Due to Inadequate Information</td>
<td>SHFH</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>Risk of Errors Due to Poor Task Design</td>
<td>SHFH</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>Risk of Reduced Safety and Efficiency Due to a Designed Vehicle, Environment, Tools or Equipment</td>
<td>SHFH</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>Risk of Acute and Late Central Nervous System Effects Radiation Exposure</td>
<td>SR</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Risk of Radiation Carcinogenesis</td>
<td>SR</td>
<td>A</td>
<td>U</td>
</tr>
<tr>
<td>Risk of Acute Radiation Syndromes Due to Solar Particle (SPES)</td>
<td>SR</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Risk Of Degenerative Tissue Or Other Health Effects From Radiation Exposure</td>
<td>SR</td>
<td>A</td>
<td>U</td>
</tr>
</tbody>
</table>
Evidence/Risk-based Management Approach:
Continuous Evaluation of Priorities

Evidence Base – Flight and Ground
- Science
- Clinical
- Operational experience

Reviewed by NRC/IOM

Risks

Define Requirements

Perform Gap Analysis

Prioritization & Implementation Approach
- Cx need dates
- Budgets
- Research platform availability

Integrated Research Plan

Exploration Missions & Architectures

NASA Spaceflight Human System Standards

Results and Deliverables (>300)
- Retire or Transfer Risks
- Update standards
- Countermeasures
- Medical Technologies
- Results \( \Rightarrow \) New Gaps

Evaluate - **ANNUALLY**

Update Evidence Base/Book

Solicit research

Define activities
Re-evaluating Vision Changes Risk Based on New Evidence

• Original Risk Statement: Given that visual changes have been observed in flight, there is a probability that crew could experience impaired vision during and post flight

• First Presentation given to HSRB on December 9, 2008
  – Tom Mader, M.D.: Spaceflight-induced alterations in intraocular pressure and visual acuity

• HSRB concluded it was a risk that required research and it was to come back to the Board at a later date
The Visual Changes risk was brought back to HSRB twice in 2010, and revised in definition, likelihood and consequence. The risk was elevated to a top risk requiring research.

- Given that all astronauts are exposed to microgravity and cephalad fluid shift, and given that both symptomatic and asymptomatic patients have both exhibited optic nerve sheath edema on MRI, there is a high probability that all astronauts have idiopathic intracranial hypertension to some degree, and that those susceptible (via eye architecture, anatomy, narrow disc) have a high likelihood of developing either choroidal folds or papilledema, and that the degree of that edema will determine long-term or permanent vision loss, sequelae, or impairment.
The framework of the Risk Management Analysis Tool provides for assessment of the risk and contributing factors for several missions and operational concepts. Currently (ISS, Lunar Sortie, Lunar Long, and Mars) The risk assessment for an asteroid mission will fit into this system without difficulty.
Relationship to Other Risk Systems:

The Human Risk System considers other consequences than those typically considered by Spaceflight Programs (such as ISS). Where the risks overlap in Loss of Crew or Loss of Mission (ISS, Constellation), the risk is carried in both systems, cross referenced, and monitored for activity.

ISS Top Program Risk
6169 On-Orbit Intracranial Hypertension
Given that all on-orbit astronauts are exposed to a microgravity-induced cephalad fluid shift......................

Likelihood 4 X Consequences; Cost 3, Schedule 1, Technical 4, Safety 4
Human System Risks in Exploration Missions

• Human system risks for Exploration have been developed systematically, and have been applied to exploration mission reviewed through the IOM.
• The risks are being managed continuously by NASA’s Human System Risk Board.
• The Risks and their criticality rating are the basis for establishing the research program content and its priorities.
• The risk framework is enduring and can be adapted to new human exploration missions without problem.