Humans Back on the Moon

Research, Technology Development, and Validation for Bioastronautics

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National Vision for Space Exploration

THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM

Implement a sustained and affordable human and robotic program to explore the solar system and beyond

Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.
VSE & ESAS lunar mission progression

1. Sortie Missions (2016+)
   - 4 crewmembers
   - 4-14 days on Moon

2. Establish and Occupy a Base (2020+)
   - 4-8 crewmembers
   - Up to 6 months

3. Mars and beyond
   - Moon as stage for solar system exploration (2030+)
Risk Mitigation and Performance Optimization

• Pre-2004: NASA planned that all needed Bioastronautics research for Mars missions would be done on ISS or on Earth

• 2004: Announcement of the Vision for Space Exploration, with shift of emphasis to goals beyond Earth orbit
  – ISS & ground-based research to re-focus specifically to support exploration, rather than a broader science program
  – Opportunities for research on ISS (crew & hardware availability) inadequate to retire large number of risks
    • Unlikely to fully quantify and retire medical risks
  – Additional risk reduction via lunar mission research
Bioastronautics preparation for VSE

- SEI/FLO (1989)
- ESAS support (2005)
- Continuing data mining and generalization during STS and ISS eras
Some bioastronautically-relevant lunar environmental factors

- **Earth**
  - 1 g
  - 1 atm.
  - Temperature
  - 24 hr. solar day at equator

- **Moon**
  - 1/6 g
  - 0 atm. (byo)
  - +120C / -150C (byo)
  - 708 hr. solar day at equator
    - Circadian rhythms
    - Mission activity planning
  - Dust (abrasive, possibly biologically reactive)
  - Intense ionizing radiation (byo)
How does human physiological capacity vary with gravity?
How does human physiological capacity vary with gravity?

Gravity (x Earth)

1/20 10

0-g normal

1-g normal

0-g normal

0 1/6 1/4 3/8 Mars 1/2 3/4 1 Earth

ISS, etc. Moon Mars

Your favorite parameter

Gravity (x Earth)
How does human physiological capacity vary with gravity?
How does human physiological capacity vary with gravity?
How does human physiological capacity vary with gravity?

Gravity (x Earth)

1/20
1/4
1/6
3/8
Moon
Mars
ISS, etc.
Earth

0-g normal
1-g normal

Your favorite parameter

Gravity (x Earth)
How does human physiological capacity vary with gravity?

Pick your favorite curve—none has been disproven!
Protective effect of lunar gravity?

• If lunar gravity is adequate countermeasure for adaptation, then expected benefit from Mars gravity is greater
  – Generally considered unlikely (esp., lunar)
• If lunar g levels not adequate, additional countermeasures will be necessary
• Note: Even at 1 g, we use daily countermeasures
# Environmental characteristics of DRMs analyzed by BR

<table>
<thead>
<tr>
<th></th>
<th>1-year ISS</th>
<th>Lunar</th>
<th>Mars DRM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Launch Date</strong></td>
<td>~2005 - 2016</td>
<td>2015 - 2020</td>
<td>NET 2025 - 2030 Oct.2024; Nov.2026; Jan.2029; Feb.2031</td>
</tr>
<tr>
<td><strong>Mission Duration</strong></td>
<td>1 year</td>
<td>10-44 days</td>
<td>30 months</td>
</tr>
<tr>
<td><strong>Outbound Transit &amp; Return Transit (each)</strong></td>
<td>2 days</td>
<td>3-7 days</td>
<td>4-6 months</td>
</tr>
<tr>
<td><strong>On-site Duration</strong></td>
<td>1 year</td>
<td>4 - 30 days</td>
<td>18 months</td>
</tr>
<tr>
<td><strong>One-way Comm. Lag</strong></td>
<td>0+</td>
<td>1.3 seconds+</td>
<td>3 - 20 minutes</td>
</tr>
<tr>
<td><strong>“G” Transitions (assume no artificial gravity)</strong></td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td><strong>Hypogravity</strong></td>
<td>0 g</td>
<td>1/6 g on Moon</td>
<td>1/3 g on Mars</td>
</tr>
<tr>
<td><strong>Spacecraft Internal Environment</strong></td>
<td>14.7 p.s.i, 21% O₂</td>
<td>TBD (maybe 10.2 p.s.i, 30% O₂)</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Equivalent Deep Space Radiation Exposure</strong></td>
<td>33% per year plus trapped electrons (SAA)</td>
<td>100% while in transit plus 50% while on or near Moon (due to solid angle shielding)</td>
<td>100% while in transit plus 40% while on Mars (due to solid angle &amp; atmosphere shielding) plus TBD neutron backscatter</td>
</tr>
</tbody>
</table>
## Operational characteristics of DRMs analyzed by BR

<table>
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<th>1-year ISS</th>
<th>Lunar</th>
<th>Mars DRM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crew Size</strong></td>
<td>2+</td>
<td>4-6</td>
<td>6</td>
</tr>
<tr>
<td><strong>EVA opportunities</strong></td>
<td>0 - 4 per LDM</td>
<td>2 - 3 per week ~ 4 - 15 EVAs per person</td>
<td>2 - 3 per week ~ 180 EVAs per person</td>
</tr>
<tr>
<td><strong>Destination Planet</strong></td>
<td>N/A</td>
<td>Piloting (or monitoring autoland) aboard LSAM</td>
<td>Monitor autoland aboard MSAM</td>
</tr>
<tr>
<td><strong>Landing Responsibilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Destination Planet</strong></td>
<td>N/A</td>
<td>Upright</td>
<td>Recumbent (atmosphere entry); upright (landing)</td>
</tr>
<tr>
<td><strong>Landing Posture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Earth Landing</strong></td>
<td>Passenger aboard STS; supervisory autoland aboard Soyuz, CEV</td>
<td>Monitoring autoland aboard CEV</td>
<td>Monitoring autoland aboard CEV</td>
</tr>
<tr>
<td><strong>Responsibilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Earth Landing Posture</strong></td>
<td>Recumbent</td>
<td>Recumbent</td>
<td>Recumbent</td>
</tr>
</tbody>
</table>
BR risks for “Moon 30”

• Human health risks
  – Priority 1
    • Major illness & trauma
    • Carcinogenesis from radiation exposure
  – Priority 2
    • Injury to joints and intervertebral structures; serious cardiac dysrhythmias; diminished cardiac and vascular function; Impaired sensory motor capability during piloting and post-landing
    • Clinical monitoring and prevention; pharmacology; informatics; skill maintenance
    • Psychosocial and neurobehavioral problems; cognitive task mismatch
    • Acute and chronic effects of radiation on CNS and tissue degeneration
    • Define acceptable limits for air and water contaminants
BR risks for “Moon 30”

• System performance/efficiency risks
  – Priority 1
    • Air quality; water quality; internal surfaces, food and soil; external environment
  – Priority 2
    • Integrated autonomous control of LSS
    • Space suits and PLSS
    • Acceptable atmosphere; acceptable thermal balance; waste management; provide and recover potable water; bioregenerative LSS
    • Mismatch between crew physical capabilities and task demands; poorly integrated ground, crew and automation functions
New capabilities needed for human exploration of Moon and Mars

- **Moon**
  - Improved radiation event detection and protection
  - Efficient and effective medical monitoring and medical care
  - Efficient and effective environmental monitoring
  - Efficient trash management (e.g., food packaging)
  - Means of stabilizing pharmaceuticals for long durations
  - Efficient and effective exercise countermeasures (hardware and protocols)
  - Enhanced human performance monitoring and prediction for physical and mental performance
  - Understanding of lunar dust toxicity

- **Mars**
  - Physiological, psychological, and pharmacological countermeasures, including exercise, nutrition, performance training, and skill maintenance
  - Efficient and effective remote medical care systems, including some level of autonomous health care
  - Enhanced capability for preserving nutritional value of food during long duration missions
  - Behavioral health tools and training
  - Efficient and effective radiation shielding capabilities
New technologies needed for human exploration of Moon and Mars

- Improved exercise countermeasure hardware
- Improved food packaging
- Improved autonomous health care systems, including detection, diagnosis, and treatment
- Improved pharmaceutical preservation techniques
- Improved personal radiation dosimetry
ISS research/activities to enable development of needed technologies

• Verification of integrated physiological countermeasures in an operational environment
• Human system monitoring using Clinical Status Evaluation approach (e.g., Holter monitoring to obtain comprehensive database on human physiology during six month long missions)
• Evaluation of prototype autonomous medical systems
• Environmental monitoring evaluation and validation
• Confirmation of biological effects of space flight radiation environment
Bioastronautics research for, about and on the Moon

<table>
<thead>
<tr>
<th>Beneficiary</th>
<th>Venue for research</th>
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<tbody>
<tr>
<td></td>
<td>Earth</td>
</tr>
<tr>
<td>Lunar sortie</td>
<td>X</td>
</tr>
<tr>
<td>Lunar Base</td>
<td>X</td>
</tr>
<tr>
<td>Mars</td>
<td>X</td>
</tr>
</tbody>
</table>
Medical strategies for lunar missions

• Human is most complex, most adaptable system in human space operations.
  – Failure catastrophic, to individual and to mission.

• Cannot prevent all medical contingencies
  – Pre-flight screening and attention to safety to minimize frequency, severity of injury or illness
  – Majority of medical events likely to be minor
    • Headaches, minor cuts, short-lived viral infection, etc.
  – Analogs, experience foretell more serious events
  – Crew must handle wide range of medical procedures

• Routine monitoring of astronaut health
  – Document continued fitness for duty
  – Document adaptation to lunar environment for Mars program (closest thing to “research” on Moon)
Medical strategy for lunar sorties

• Build upon STS/CEV/ISS model
• Preventive medicine as prime risk mitigation
• Low-overhead exercise capability in CEV during transit to/from Moon
  – May not have exercise capability in LSAM
• Two crew medical officers
  – Not necessarily MD
  – MD astronauts likely to be multi-qualified (e.g., also engineers, pilots, geologists, etc.)
• Immediate life-saving measures available
  – critical care after serious event will be limited by consumables, training, and LSAM constraints
• Stabilization of ill or injured crew, transport to Earth are TBD
Medical strategy for lunar outpost

• Build upon ISS/Sortie model
• Preventive medicine as prime risk mitigation
• Low-overhead exercise capability
  – CEV during transit to/from Moon
  – Habitat during surface
• Increased exposure risk on lunar surface plus increased Earth return time requires advanced and ambulatory care at outpost
  – Crew medical officers should include EMT or MD
  – Immediate life-saving measures to be available
    • greater amount of equipment in habitat
    • critical care needed after serious event still limited by consumables, training, and habitat constraints
• Stabilization of ill or injured crew, transport to Earth are TBD
Billica et al. (1997) surveyed US and Russian aviation, space, submarine and Antarctic operational experience, then estimated requirement for hospital-like care:
- ER-equivalent: 6% per person per year
- ICU-equivalent: 2% per person per year
For 4-person crews on 6-month lunar outpost expeditions:
- ER-equivalent: 1 in 8 missions
- ICU-equivalent: 1 in 25 missions
Behavioral health strategy for lunar outpost

• Behavioral health strategies and equipment to be important
  – As on Mir and ISS
  – Allow for adequate rest, communication with loved ones, adequate recreation, and a workload that is interesting, challenging, not excessive
Fitness strategy for lunar outpost

• Reasons for exercise in lunar habitat
  1. Daily exercise, as on ISS, on non-EVA days
     • Reduce risk of injury due to weakening bones and muscles
  2. Quantitative health monitoring purposes
     • Requires calibrated and well characterized equipment.
  3. Rehabilitation after injury

• Include aerobic and resistance exercise

• Creative approaches for multipurpose equipment to reduce overall mass delivered to the lunar surface

• Vibration-dampening as appropriate to limit structural stress on habitat
Hardware strategy for lunar outpost

• All medical care and countermeasure equipment
  – Testing and demonstration in advance of Mars missions
  – First and foremost for crew health support at the outpost

• Hardware must be certified for primary mission, recertified for each subsequent crew

• Long-term goal for countermeasure and crew health equipment is verification of hardware capability
  – Beyond requirements for six month Moon mission
  – Fulfill additional or more rigorous requirements of Mars mission

• Design goal should be equivalent to long-term stay on Mars: at least 18 months

• Repairs and replacement are feasible, even if undesirable
  – Develop the spares and repair strategy for Mars
Countermeasures strategy for lunar outpost

- ISS countermeasures initially used in lunar habitat
  - Transition to program to evaluate the effects of partial gravity and determine countermeasure requirements under lunar conditions
- Probably conservative requirements (mass, power, crew time)
- With Moon experience, revised requirements might significantly reduce overhead to support a human mission on Mars
  - Conservative approach to obtaining data on Moon will be paid back during Mars missions
Return to the Moon…

…Enabled by Bioastronautics