Space Medicine in the Human System Integration Process

Richard A. Scheuring, DO, MS, FA
Constellation Medical Operations
NASA-Johnson Space Center
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- Michelle C. Scheuring
The HSI Knowledge Broadcast is intended to educate personnel about the importance of considering the human (health, performance and limitations) in the early stages of a project's lifecycle, thus reducing costs, increasing safety and improving overall system performance.
Historical Precedence

Lunar Surface Operations

- Metabolic expenditure: deconditioning or poor pre-flight preparation?
Historical Precedence

- **Lunar Surface Operations**
  - Recommendations\(^1\)
    - The hatch and ingress corridor should be sized appropriately for an inflated 1/6 g pressure suit

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Overview

- Evidence Base
- Medical Condition List
- Medical Technology Development

Research

How can we do better?

Requirements Development

- Space Flight Human System Stnd
  - Levels Of Care
- HSIR Medical Requirements

Operations

Lessons learned!

Verification

Were requirements met?

Requirements Integration

Negotiating project buy-in

Design

Hands-on architectural involvement

- Flight Surgeons assigned to Projects
  - Orion, LSS, EVA

- Shuttle
- ISS
- Apollo

- Human in the Loop testing
- Analog Testing of Medical Hardware
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Operations

Lessons learned!

- In-flight sleep disturbances
- Post-flight herniated discs (HNP)
- Lunar dust
- Thrust oscillations
- Risk factors for lunar surface injuries
- In-flight hypothermia
- Apollo EVA suit issues
- Landing/Recovery
- Waste management systems
Injury Prevention

Lunar Surface Operations

- Risk factors for injuries identified
  - Limit navigation into craters to < 20-26° slope
  - Rover activities
    - CDR
    - LMP
  - Falling from a height
    - Ladder
    - Rim of a crater

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Water Egress Training

- Crew experience with egress training
- Elevated heart rates (>120s) due to heat stress
- 2-4 Kg weight loss from sweating
- Elevated core body temperature (38.6-40.0°C)

Video courtesy of Serena Aunon, MD
How can we do better?

Research

Concerns based on Delphi, In-flight Medical Conditions Data Collection, Mission Operational Concepts and Occupational Medical Considerations

Expected illnesses and problems\(^2,3,4\)

- Orthopedic and musculoskeletal problems
- Infectious, hematological, and immune-related diseases
- Dermatological, ophthalmologic, and ENT problems

Acute medical emergencies

- Wounds, lacerations, and burns
- Toxic exposure and acute anaphylaxis
- Acute radiation illness
- Dental, ophthalmologic, and psychiatric conditions

Chronic diseases

- Radiation-induced problems
- Responses to dust exposure
- Presentation or acute manifestation of nascent illness


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- What conditions do we expect to see for long lunar stays?
  - Outpost Medical Condition List
    - [Lunar Outpost Conditions.xls](http://example.com)

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Health Monitoring on the Lunar Surface

- **Lab analysis**
  - Blood
    - CBC w/differential
    - Chemistries
    - Oxidative stress markers
  - Urine
    - Solutes
    - Dipstick
      - Spec G, Cells, LE, etc.
  - Saliva
    - Immune parameters, shed virus, etc.

- **Pulmonary function tests (PFT’s)**
- **Ultrasound**
- **ECG monitoring (IVA)**
- **HR monitoring (EVA)**

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5Grigoriav AI, Popatov LN, Jones JA, Sullivan TA, Scheuring RA. Medical Support for Interplanetary Space Flights, in Space Biology and Medicine, Volume V


In-vivo Real Time Imaging Cervical Spine

Ultrasound (USN) MRI

Courtesy of Dan Buckland, 2009.
Exploration Vehicles Atmospheres

Pre-launch Transition
Shuttle/Mir/ISS
Lunar Sortie CEV
LER/Outpost
Shuttle EVA Preparation
Ascent Transition
Early Apollo Design
Normoxic Equivalent
Hypoxic Boundary
Historical Designs

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♦ Medical Technology Development

- High Intensity Focused Ultrasound (HIFU)
- Non-invasive blood analyzers
- Non-contact electrodes
- Lightweight trauma module
- Oxygen concentrators
- Real-time radiation dosimetry
- Ultrasound stethoscope
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Requirements Development

NASA HQ Standard

Constellation Req’ts

Vehicle Requirements and Specifications

Levels of Care
Performance Stnds

Space Med Req’ts
Crew Function Req’ts

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R.A. Scheuring 3-9769
## Levels of Care

<table>
<thead>
<tr>
<th>Level of Care</th>
<th>Mission</th>
<th>Example Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>LEO &lt; 8 days</td>
<td>SMS, BLS, First Aid</td>
</tr>
<tr>
<td>II</td>
<td>LEO &lt;30 day; e.g. STS EDOMP</td>
<td>Level I + Clinical Diagnostics, Ambulatory Care, Private Audio, (± Video) Telemedicine</td>
</tr>
<tr>
<td>III</td>
<td>LEO &gt; 30 day (ISS or Lunar Sortie)</td>
<td>Level II+ Limited Advanced Life Support, Trauma Care, Telemedicine, Minor Surgical and Dental Care</td>
</tr>
<tr>
<td>IV</td>
<td>Lunar &gt; 30 day (Outpost)</td>
<td>Level III+ Imaging, Sustainable ALS</td>
</tr>
<tr>
<td>V</td>
<td>Mars Expedition</td>
<td>Level IV+ Autonomous ALS, Basic Surgical Care</td>
</tr>
</tbody>
</table>

**Table-1: Levels of Care is matched to mission duration and destination**  

LEO = Low Earth Orbit; STS = Shuttle Transport System; EDOMP = Extended Duration Orbiter Medical Project; SMS = Space Motion Sickness; BLS = Basic Life Support; ALS = Advanced Life Support

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## HSIR Medical Req’ts

- 3.2.1.4.4 Lunar Dust Contamination

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Requirements Integration

Negotiating project

Flight Surgeons integrated with Projects during development stages
Design

*Hands-on architectural involvement*

• Thrust Oscillations
ESR2 Config 1 suit testing

- Shoulder Bearing
- Modular Arms & Gloves
- Body Seal Closure (BSC)
- Wrist Bearing
- Hip Bearing
- Thigh Bearing
- Modular LTA
- Modular boots

EVA Suit Reference (ESR)- Configuration 1
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Instrumentation of the PMHS

Accelerometers
Results:
Post 4
Vehicle development

- Orion
- Altair
- Lunar Electric Vehicle (LEV)
- Lunar Outpost
Lunar Lander (Altair) and Ascent Stage
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Lunar Electric Rover

- Exploration range of up to 1000km (vs. 240km w/ large pressurized rover)
- Shirt-sleeve environment with visibility as good as suited EVAs
- Single-person EVA capability
- Dust control through use of suitport
- SPE protection within 20mins
- Pressurized safe-haven within 20mins
- DCS treatment within 20mins
- Expedited on-site treatment and/or medication of injured crewmember
- Reduces suit induced trauma
- Better options for nutrition, hydration, waste management
- Provides resistive and cardiovascular exercise (75% VO2 peak) during otherwise unproductive translation time
- Better background radiation shielding vs. EVA suit
- Examine rear-entry suit port in overhead and “dip” position to determine force loads on the shoulder.
Verification

Were requirements met?

• Analog testing of medical hardware, procedures, and concepts
## Analog Function Characteristics Mapped to Sites

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Haughton-Mars</th>
<th>H Remote Sci</th>
<th>Desert RATS</th>
<th>Mars Desert R</th>
<th>Flashline Arctic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical space for infrastructure setup</td>
<td>Hi</td>
<td>Lo</td>
<td>Hi</td>
<td>Hi</td>
<td>Hi</td>
</tr>
<tr>
<td>Physical space for an Outpost configuration (at least 0.5 sq km)</td>
<td>Hi</td>
<td>Lo</td>
<td>Hi</td>
<td>Hi</td>
<td>Hi</td>
</tr>
<tr>
<td>Extended physical space for long distance testing (able to traverse up to 100 km)</td>
<td>Med</td>
<td>Lo</td>
<td>Hi</td>
<td>Hi</td>
<td>Hi</td>
</tr>
<tr>
<td>Regolith Handling</td>
<td>Hi</td>
<td>Lo</td>
<td>Hi</td>
<td>Hi</td>
<td>Hi</td>
</tr>
<tr>
<td>Power source (electricity via generators or grid connection)</td>
<td>Med</td>
<td>Hi</td>
<td>Med</td>
<td>Med</td>
<td>Hi</td>
</tr>
<tr>
<td>Full Internet access to remote locations</td>
<td>Med</td>
<td>Hi</td>
<td>Med</td>
<td>Med</td>
<td>Hi</td>
</tr>
<tr>
<td>Good vista (not too many man made objects or vegetation insight, looks like the Moon or Mars)</td>
<td>Hi</td>
<td>Lo</td>
<td>Med</td>
<td>Med</td>
<td>Hi</td>
</tr>
<tr>
<td>High Temperature extremes (~100 degrees F)</td>
<td>Lo</td>
<td>Lo</td>
<td>Med</td>
<td>Hi</td>
<td>Lo</td>
</tr>
<tr>
<td>Low Temperature extremes (~32 degrees F)</td>
<td>Hi</td>
<td>Lo</td>
<td>Med</td>
<td>Lo</td>
<td>Hi</td>
</tr>
<tr>
<td>Zero-G capability</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Partial -G</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Site Diversity</td>
<td>Med</td>
<td>Lo</td>
<td>Hi</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Access for large equipment</td>
<td>Lo</td>
<td>Hi</td>
<td>Hi</td>
<td>Med</td>
<td>Lo</td>
</tr>
<tr>
<td>Access for People</td>
<td>Hi</td>
<td>Hi</td>
<td>Med</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Cost of working there</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Partnerships/Shared Costs</td>
<td>Hi</td>
<td>Med</td>
<td>Lo</td>
<td>Lo</td>
<td>Med</td>
</tr>
</tbody>
</table>

**DRAFT**

- **NEEMO**
- **Integrity**
- **Intl. Space Station**
- **Mars Yard/Chamber**
- **Antarctic/desert**
- **PISCES**
Verification
Were requirements met?

- Analog testing/training for Lunar Surface Operations
  - To ensure operational success and optimize performance of the crews
  - Allow adequate time to practice mission activities in a variety of environments including good analogs that allows preparation for off-nominal events

Apollo 16 Geological field training in New Mexico
Apollo 12 Lunar Lander Training Vehicle (LLTV) Ellington Field
Apollo 17 Lunar Surface Activity training at JSC
Analog Exploration Environments

- **Backyard/Nearby**
  - Rockpile
  - Desert RATS

- **Remote/Extreme Environments**
  - Devon Island, Haughton Crater- HMP
  - NEEMO
  - Antarctica- Coastal and Polar Stations

- **Flight**
  - Zero- and partial-g Aircraft
  - ISS

Docs are operational oriented and focused on developing experienced-based confidence in medical support system

Many are ex- or current military and/or have experience in expeditionary support
Apollo Medical Operations Recommendations

♦ Analog environments

- Remote location, not easily accessible
- Operationally focused - multiple "EVA days/week"

![Analog environments images]
3rd Party Assisted Rescue on Sloped Terrain
(haul from top)

Procedure
Benefits of the Analog Environment

- Mission Constraints
- Timeline
- Crew dynamics
- Limited resources
- Coordination w/ teams
- Collaboration w/ centers
- Simulated planetary environments
- Lack of one perfect analog
- Psychological factors
- Training
- Similar dimensions to space vehicles (NEEMO)
- Testbed for hardware and systems
- Recommendation from Apollo crewmembers
- Subsystem testing vs. system integration testing\(^{10}\)

Questions?

- **Research**
  - How can we do better?

- **Requirements Development**

- **Operations**
  - Lessons learned!

- **Verification**
  - Were requirements met?

- **Design**
  - Hands-on architectural involvement

- **Integration**
  - Negotiating project buy-in

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