Human Health and Performance System

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Element Scientist
What is the goal?

- HRP – provide a systematic countermeasure to the known risks of exploration spaceflight.
- Start with gaining scientific understanding of the challenges.
- End with solutions and countermeasures that are delivered in the form of a vehicle subsystem and mission architecture focused on optimizing human health and performance.
Start with the Medical Risk?

Why? Because it becomes an integrating risk for Human Health and Performance.
ExMC Responsibilities

**Risk Title:** Risk of Adverse Health Outcomes & Decrements in Performance due to Inflight Medical Conditions

**Description:** Given that medical conditions will occur during human spaceflight missions, there is a possibility of adverse health outcomes and decrements in performance during these missions and for long term health.

**Other ExMC Risks:**

1. Risk of bone fracture due to spaceflight induced changes in bone.
2. Risk of ineffective or toxic medications due to long term storage.
<table>
<thead>
<tr>
<th>Risk or Concern</th>
<th>Current ExMC Ownership</th>
<th>Likely Future ExMC Ownership</th>
<th>Color</th>
<th>Meaning</th>
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<td>Concern of Interventions Disc Damage upon and immediately after re-exposure to Gravity</td>
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<td>Risk Factor of Inadequate Nutrition</td>
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<td>Risk of Acute and Late Central Nervous System Effects from Radiation Exposure</td>
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<td>Performance Decrement with possible Medical Treatment</td>
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<td>Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders</td>
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<td>Risk of Cardiac Rhythm Problems</td>
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<td>Risk Of Cardiovascular Disease and Other Degenerative Tissue Effects</td>
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<td>From Radiation Exposure</td>
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<td>Risk of Decompression Sickness</td>
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<td>Risk Of Early Onset Osteoporosis Due To Spaceflight</td>
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<td>Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance</td>
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<td>Risk of Ineffective or Toxic Medications Due to Long Term Storage</td>
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<td>Risk of Injury and Compromised Performance Due to EVA Operations</td>
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<td>Risk of Injury from Dynamic Loads</td>
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<td>Risk of Orthostatic Intolerance During Re-Exposure to Gravity</td>
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<td>Risk of Performance and Behavioral Health Decrement Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team</td>
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<td>Risk of Performance Errors Due to Training Deficiencies</td>
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<td>Risk of Radiation Carcinogenesis</td>
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<td>Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity</td>
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<td>Risk of Renal Stone Formation</td>
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<td>Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations</td>
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<td>Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities</td>
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Forward Plan

• Risk Mitigation Strategy
  – Planning
    • Concept of Operations Development (Ops Risk Reduction)
  – Characterization of Risk
    • Models and Metrics – Integrated Medical Model (IMM), MONSTR prototype
    • Active Data Gathering – Medical Consumables Tracker (MCT), biosensors, Flexible Ultrasound
  – Active Risk Reduction
    • Medical Support – Exploration Medical System Demonstrator (EMSD), Data Architecture
    • Technology Development – Oxygen Concentrator Module, Medical Suction, IVGen...
    • Training
    • Medical Decision Support
    • Integration of Medical with Vehicle Designers and ECLSS SMTs
The Medical System Goal

Provide the crew with the best chance to accomplish mission and get home healthy

Medical Operations
- Nominal Operations
- Contingency Operations
  - Routine
  - Urgent
  - Emergent
Background

- Exploration Medicine is unique:
  - NO regular resupply of materials
  - NO real-time communications
  - NO potential for evacuation if serious medical concerns arise.

- Medical care includes:
  - Screening
  - Prevention
  - diagnostic capability
  - treatment capability
  - follow up care
  - prognosis

- Characterize the likely medical risks
- Identify medical needs to address those risks
- Create a medical system to optimize crew response to those risks
- Engage in a testing pathway to validate and improve that system
- Work with vehicle engineers and flight surgeons to ensure useful implementation of that system

Exploration requires Stay and Fight Medicine, not Retreat Medicine.
Goal: develop a system

Gap restructuring to enable that system

Earliest Gap Needs:

- Risk Assessment (Med08)
- Concept of operations needs to guide system development (Med01)
- Data Architecture development (Med07)
- Early incremental testing of the system concepts (Med 01)
- Vehicle Integration strategy (Med 01)
## Medical Risk

### New Gaps

<table>
<thead>
<tr>
<th>Med01</th>
<th>We do not have a concept of operations for medical care during exploration missions.</th>
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</thead>
<tbody>
<tr>
<td>Med02</td>
<td>We do not have the capability to provide a safe and effective pharmacy for exploration missions.</td>
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<tr>
<td>Med03</td>
<td>We do not know how we are going to apply personalized medicine to reduce health risk for a selected crew.</td>
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<td>Med04</td>
<td>We do not have a defined rehabilitation capability for injured or de-conditioned crew members during exploration missions.</td>
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<tr>
<td>Med05</td>
<td>We do not know how to train crew for medical decision making or to perform diagnostic and therapeutic medical procedures to enable extended mission or autonomous operations.</td>
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<tr>
<td>Med06</td>
<td>We do not know how to define medical planning or operational needs for ethical issues that may arise during exploration missions.</td>
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<tr>
<td>Med07</td>
<td>We do not have the capability to comprehensively process medically-relevant information to support medical operations during exploration missions.</td>
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<tr>
<td>Med08</td>
<td>We do not have quantified knowledge bases and modeling to estimate medical risk incurred on exploration missions.</td>
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<tr>
<td>Med09</td>
<td>We do not have the capability to predict estimated medical risk posture during exploration missions based on current crew health and resources.</td>
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<tr>
<td>Med10</td>
<td>We do not have the capability to provide computed medical decision support during exploration missions.</td>
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<tr>
<td>Med11</td>
<td>We do not have the capability to minimize medical system resource utilization during exploration missions.</td>
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<tr>
<td>Med12</td>
<td>We do not have the capability to mitigate select medical conditions</td>
</tr>
<tr>
<td>Med13</td>
<td>We do not have the capability to implement medical resources that enhance operational innovation for medical needs</td>
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</table>
Gap Restructuring Enables System Creation

- Safe and Effective Pharmacy
- Oxygen Delivery
- Medical Suction
- Ultrasound Imaging
- Laboratory Analysis
- Biosensors/EKG

Concept of operations
- Pharmacy recommendation
- Select technologies
- Integrated medical system
- Optimized medical system

Risk

1 2 3 4 5

Capability
How to decompose the work

Incremental and Iterative Approach

Pedigree: DoDAF

Operations Research
- Identify Medical Needs
- Conceptualize Operations
- Analog Testing

- Technology Options
  - Optimization
  - Drawbacks/Risks

Information Resources
- Medical Systems
- Data Architecture
- Intelligence Augmentation
- Environmental Data

- Functional Requirements
  - Non-Functional Requirements
  - Medical Capabilities

Technology Development
- Medical Appliances
- Element Collaboration
- Environmental Data API Integration

- System Resource Interfaces
  - Communication Standards
  - Contingency Plans

Vehicle Interface Standards
- Medical Appliance Standards
- Technology Constraints
- Guidance on Optimal User-Interfaces

System Performance
- Integrated System Added Value
- Domain Knowledge

Relationships between research divisions in the Exploration Medical Capability Element.
The HHP Goal

HHP System Operations

- Risk monitoring
  - Vehicle
  - Environment
  - Crew
  - SYSTEM
- Countermeasure readiness and deployment
- Maximize mission objective attainment while minimizing crew casualty
Medical Data Architecture

Ground Based and Vehicle Data Architectures:

- Clinical Operational Needs
- Research Data Capture
- Long Term Health Information

- Flight Surgeon/BME
- External Consults

Mirrored Delayed Data Presentation for situational awareness/support

Vehicle Exploration Medical System

- Crew Medical Officer
- Crew Medical Support

Real-Time Data Processing for Crew
ExMC Data Architecture (ARC)
# Ground-based Data Architecture (JSC)

<table>
<thead>
<tr>
<th>IDENTIFY</th>
<th>ACQUIRE</th>
<th>ORGANIZE</th>
<th>ANALYZE</th>
<th>DECIDE</th>
<th>APPLICATIONS</th>
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</thead>
<tbody>
<tr>
<td>EMR</td>
<td>Extract, Transform &amp; Load Data</td>
<td>Processed Data sources</td>
<td>Querying, Mining &amp; Exploration</td>
<td>Ad-hoc Datasets</td>
<td>MASH Report</td>
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<tr>
<td>LSAH</td>
<td>Cleanse Data</td>
<td>EMR -&gt; LSAH</td>
<td>Controlled Data Modification</td>
<td>Datasets T2</td>
<td>Reports &amp; Dashboards</td>
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<tr>
<td>SMOT</td>
<td>Data Profile &amp; Verification</td>
<td>LSAH -&gt; SMOT</td>
<td>Analytics &amp; Visualization</td>
<td>Other</td>
<td>Content Analytics</td>
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<tr>
<td>PMC</td>
<td>Exception Handling</td>
<td>PMC -&gt; LSDA</td>
<td>Exploration &amp; Discovery</td>
<td>Scheduled Data sources</td>
<td>Machine Learning</td>
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<tr>
<td>LSDA</td>
<td>Workflow &amp; Rules Management</td>
<td>LSDA -&gt; Other</td>
<td>Analytics</td>
<td>VIP</td>
<td>Data Catalog &amp; Search</td>
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<tr>
<td>Other</td>
<td>Batch Processing</td>
<td>Other</td>
<td>Machine Learning</td>
<td>CO2</td>
<td>Portfolio Analytics</td>
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<td></td>
<td>Realtime Stream Processing</td>
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**Contextual Datasets**
- Operational & Transactional Data
- Historical & Trend Data
- Reference & Meta Data
- Audit & Exception Data

**Data Granularity**
- Operational & Transactional Data
- Historical & Trend Data
- Reference & Meta Data
- Audit & Exception Data

**Current Processes & Protocols**
- Data Governance & Stewardship
- Security & Access Control
Long Term Health Directions

Long Term Health

1. R + 1yr: come back to preflight baseline?
   a. Effects post flight?
   b. Back to Pre-flight baseline?

2. Astronaut Career: come back to pre-selection baseline?
   a. Effects on career?
   b. Can they fly again?

3. Lifetime
   a. Effects on lifetime risk?
   b. Will they have problems later in life?

2013 Mortality Multiple Cause Micro-data Files
http://www.cdc.gov/nchs/data_access/Vitalstatsonline.htm
Long Term Health Recommendations

We do not understand LTH effects sufficiently to advise interventions

Long Term Health Definitions

1. R + 1yr
2. Astronaut Career
3. Lifetime

- Generate a list of conditions with potential LTH consequences
- LSAH/HRP joint project to define relevant clinical and research data collection to monitor through program evolution
- Construct a Medical Data Architecture to support data collection and analysis
- Occupational Health to set triggers for intervening on data trends that are concerning
- Periodic re-evaluation of data collected to narrow or expand scope as more is learned about long term health effects
Three Sources of Information

- Clinical Medical
- Human Performance
- Research
HHP System Development

Science Focus  Engineering Focus  System Integration

SHFH  BHP  HHC  ExMC  SR

ISS Testing  Orion  Proving Ground  Mars
Systems Testing and Development

Exploration Medical System Analog Testing and Evaluation

EMSD

Analog 1

Version 1

Analog 2

Version 2

Analog 3

Version 3

Flight

Time

Feedback and Improvement

Notional
MDA Test Bed Roadmap

<table>
<thead>
<tr>
<th>Phase</th>
<th>Test Bed 1</th>
<th>Test Bed 2</th>
<th>Test Bed 3</th>
<th>Test Bed 4</th>
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<td>MDA System Definition</td>
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<td>Biomedical Device Provisioning</td>
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<td>Knowledge Base</td>
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<td>Improved UI</td>
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<td>Ground System Data Analytics Platform</td>
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<td>Vehicle Resources Oxygen, Medical Suction</td>
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<td>Vehicle subsystem integration (ECLSS, Avionics, Power, Thermal)</td>
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Integrated System Testing

Iterate

Benchttop

Medical Appliances
(H/W and S/W products)

NASA Internal

External

Iterate

Integrated System

IPAS
Integrated Sims
Ground System

Hestia
HERA
Aquarius

Iterate

Analog

Smart Pods
DOD
Antarctica

Independent Evaluation of System
(Likely tied to IPAS)
Backup
Human Health and Performance System Block Diagram

Flight System
- In-Flight Health Data System
  - Data Repository
  - Data Analytics & Decision Support
- Medical Appliances System
  - FUS
  - EKG
  - ...
- In-Flight Health Maintenance System
  - Exercise System
  - Behavioral Health System
  - Food System
- In-Flight Health and Performance Monitoring Data System
  - Biomarkers System
  - Physiological Data Stream System
  - Vehicle & Habitat Environment Management System
- Mission Task Performance Support System
- Pre- and Post-Flight Medical Appliances
  - Ground Health Data System
  - Ground Health Maintenance System
  - Ground Health and Performance Monitoring Data System

Ground System
- FSW
- Telecom
- Avionics
- Power
- Structures
- ECLSS
- EVA Systems
- Robotic Assets
- GNC
- Researcher
- Analyst
- MCC
- ASCR
- FOD Trainer
- Flight Surgeon

Crew as Caregiver
Crew as Explorer or Patient

ExMC scope
Interfaces within HH&P
Interfaces external to HH&P

Work in Progress
4/19/16
Medical Decision Support System (MDSS)

A knowledge system designed to use patient medical data and medical knowledge to generate case-specific assessment and recommendations to help medical staff make medical decisions.
Hybrid Approach for Implementation

- Knowledge based
  - Use of knowledge bases
  - Inference engine
  - Decisions based on rules

- Non-knowledge based
  - Machine learning
  - Neural Networks (ANN/CNN) and algorithms
  - Derive knowledge from patient data
  - Learn from decision trees
Medical Decision Support Module

Knowledge base & Inference engine

Data Integration and Transformation

Information Interpretation

Machine learning & Patterns

Medical & health records

Bio & Env. sensors

Images

Test results

Training

References

Health Assessment & Predictions