Planning for Mars: An Exploration Medicine Overview

UTMB USRA Grand Rounds
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Conflicts of Interest Disclosure

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6. Co-owner and Executive Officer ADE Medical PLLC

I have financial interests in the above entities.
The opinions shared here are my own and not necessarily reflective of the above institutions.
Outline

• Defining the challenge
• History of Spaceflight Medical Systems
• Mars is different
• Principles of Approach
• Scoping a Medical System
• Where are we now?
What is the challenge?

• When we say “Mission to Mars" what do we really mean?

• What implications does that have for how you provide medical care?

• Is this really so different from what we do on the ISS or when we went to the moon?
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.
To minimize mission medical risk through medical system design and integration into the overall mission and vehicle design.
SOME HISTORY
2001, Conclusion 6:

NASA, because of its mission and history, has tended to be an insular organization dominated by traditional engineering. Because of the engineering problems associated with early space endeavors, the historical approach to solving problems has been that of engineering. Long duration space travel will require a different approach, one requiring wider participation of those with expertise in divergent, emerging, and evolving fields. NASA has only recently begun to recognize this insufficiency and to reach out to communities, both domestic and international, to gain expertise on how to remedy it.
Project Mercury

**Figure 4.1.** Mercury medical kits containing items such as antibiotics, decongestants, stimulants, electrode paste, and medications to treat nausea and diarrhea. (Photo courtesy of NASA)

**Figure 4.2.** Mercury medical kit containing items such as saline solution, bandages, stimulants, and decongestants (Photo courtesy of NASA)

Principles of Clinical Medicine for Spaceflight
Eds. Barratt, Pool, 2008
Gemini and Apollo

Table 4.1. Contents of the Gemini VII medical kit [10].

<table>
<thead>
<tr>
<th>Medication</th>
<th>Indication</th>
<th>Dose</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Amphetamine sulfate</td>
<td>Stimulant</td>
<td>5 mg tablets</td>
<td>8</td>
</tr>
<tr>
<td>Aspirin-phenacetin-caffeine</td>
<td>Pain</td>
<td>Tablets</td>
<td>16</td>
</tr>
<tr>
<td>Cyclazine HCl</td>
<td>Motion sickness</td>
<td>50 mg tablets</td>
<td>8</td>
</tr>
<tr>
<td>Diphenoxylic HCl</td>
<td>Diarrhea</td>
<td>2.5 mg tablets</td>
<td>16</td>
</tr>
<tr>
<td>Meperidine HCl</td>
<td>Pain</td>
<td>100 mg tablets</td>
<td>1</td>
</tr>
<tr>
<td>Methyl cellulose solution</td>
<td>Lubricant</td>
<td>15 ml bottle</td>
<td>1</td>
</tr>
<tr>
<td>Parenteral cyclazine</td>
<td>Motion sickness</td>
<td>45 mg</td>
<td>2</td>
</tr>
<tr>
<td>Parenteral meperidine HCl</td>
<td>Pain</td>
<td>90 mg (0.9 ml)</td>
<td>2</td>
</tr>
<tr>
<td>Pseudoephedrine HCl</td>
<td>Decongestant</td>
<td>60 mg tablets</td>
<td>16</td>
</tr>
<tr>
<td>Tetracycline HCl</td>
<td>Antibiotic</td>
<td>250 mg coated tablets</td>
<td>16</td>
</tr>
<tr>
<td>Triprolidine HCl</td>
<td>Decongestant</td>
<td>2.5 mg tablets</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 4.3. Apollo medical kit containing items such as skin cream, antibiotic ointment, nasal spray, band-aids, and stimulants (Photo courtesy of NASA)

Figure 4.4. Apollo Command Module medical kit (Photo courtesy of NASA)

Figure 4.5. Apollo clinical physiological monitoring kit and emergency medical kit (Photo courtesy of NASA)

Figure 4.6. Apollo emergency medical kit (Photo courtesy of NASA)

Principles of Clinical Medicine for Spaceflight
Eds. Barratt, Pool, 2008
And more, but it is still a kit.
International Space Station

Start of a medical-vehicle system

6 month – 1 year
Less emergency
More health maintenance

CHeCS

CMS
EHS
HMS
HUMAN EXPLORATION
NASA’s Path to Mars

EARTH RELIANT
MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

PROVING GROUND
MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY
MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

Developing planetary independence by exploring Mars, its moons and other deep space destinations

www.nasa.gov
What about Mars?
Going there

Trans-Mars Cruise  About 9 months

Mars at start
Earth at start
Spacecraft at start

Mars at landing
Spacecraft at landing
Earth at landing

Being there

Wait on Mars

About 16 months

Coming Home

Trans-Earth Cruise

About 9 months

Health and Human Performance System

- Keep the crew safe
- Making sure they can get to Mars safely
- Make sure they come home from Mars safely
All is well until the methods legitimated by the paradigm cannot cope with a cluster of anomalies; crisis results and persists until a new achievement redirects research and serves as a new paradigm.

- Thomas S. Kuhn 1962
What are the anomalies?

• NO real-time communications
  – What does it mean to have a medically autonomous crew?
  – Cannot provide real time guidance
  – How do we train for medical needs?
  – How do we keep skills fresh?
  – What is the role of the flight surgeon?
  – Do we transition from real time guidance to a store-and-forward consult model?
  – What does it mean to provide situation awareness to earth-based support?
More Anomalies

• NO regular resupply of materials
  – How do we provide a safe and effective pharmacy when medications will expire?
  – How do we plan to limit medical consumable usage when a crew is autonomous?
  – How do we track that usage so the crew understands their risk posture throughout a mission?
Does ISS prepare us?

• NO potential for evacuation if serious medical concerns arise.
  – How do we plan for serious illness and injury?
  – How long do we treat severe injury or illness?
  – How do we decide what consumables to expend on an injured crew member such that we don’t increase the risk to the rest of the crew?
  – How do we make ethical decisions in our plans for supplying a crew and recommendations to an autonomous crew on how to implement medical care?
PRINCIPLES OF APPROACH
• From Conclusion 2:
  • “Currently, there is no comprehensive and inclusive strategy to provide optimum health care for astronauts in support of long-duration missions beyond low Earth orbit, nor is there sufficient coordination of health care needs with the engineering aspects of such missions.”

• From Conclusion 6:
  • “The human being must be integrated into the space mission in the same way in which all other aspects of the mission are integrated.”
The Medical Engineering Challenge

What you end up with.

MEDICINE

What is needed?

SYSTEM

Research

ENGINEERING

What is possible?

How can you get more of what is needed?
Fundamental Content Drivers

• Concept of Operations – The user’s experience of the system?

• Risk Assessment and Trade Capability – How do we value and prioritize medical capabilities?

• System Design
  – Medical Data Architecture
  – Medical Appliances
  – Vehicle Integration

• Programmatics – What drives successful execution?

• Ethics – What level of care do we provide?
Concept of Operations

Planned medical events
• Private Medical Conferences
• Self exams
• Private psychiatric conferences
• Scheduled Exercise
• Etc.

Unplanned medical events
• Exploration Medical Condition List

• Three categories:
  – Self Care
  – CMO Directed Care
  – Emergency Care
Concept of Operations

Planned medical events

• Private Medical Conferences
• Self exams
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• Scheduled Exercise
• Etc.

Unplanned medical events

• Exploration Medical Condition List

• Three categories:
  – Self Care
  – CMO Directed Care
  – Emergency Care
What is needed

• Medical care includes:
  – Prevention/Screening
  – Diagnostic capability
  – Treatment capability
  – Rehabilitation capability
  – Prognosis

Getting to Possible

• 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
QUANTIFYING MEDICAL RISK

Well, what are you trying to treat?
Exploration Medical Conditions

SKIN
- Burns secondary to Fire
- Skin Abrasion
- Skin Laceration

EYES
- Acute Glaucoma
- Eye Corneal Ulcer
- Eye Infection
- Retinal Detachment
- Eye Abrasion
- Eye Chemical Burn
- Eye Penetration

EARS, NOSE, THROAT
- Barotrauma (sinus block)
- Nasal Congestion (SA)
- Nosebleed (SA)
- Acute Sinusitis
- Hearing Loss
- Otitis Externa
- Otitis Media
- Pharyngitis

DENTAL
- Abscess
- Caries
- Exposed Pulp
- Tooth Loss
- Crown Loss
- Filling Loss

CARDIOVASCULAR
- Angina/Myocardial Infarction
- Atrial Fibrillation / Atrial Flutter
- Cardiogenic Shock secondary to Myocardial Infarction
- Hypertension
- Sudden Cardiac Arrest
- Traumatic Hypovolemic Shock

GASTROINTESTINAL
- Constipation (SA)
- Abdominal Injury
- Acute Cholecystitis
- Acute Diverticulitis
- Acute Pancreatitis
- Appendicitis
- Diarrhea
- Gastroenteritis
- Hemorrhoids
- Indigestion
- Small Bowel Obstruction

Pulmonary
- Choking/Obstructed Airway
- Respiratory Infection
- Toxic Exposure: Ammonia
- Smoke Inhalation
- Chest Injury

NEUROLOGIC
- Space Motion Sickness (SA)
- Head Injury
- Seizures
- Headache
- Stroke
- Paresthesia
- Headache (SA)
- Neurogenic Shock
- VIIIP (SA)

MUSKULOSKELETAL
- Back Pain (SA)
- Abdominal Wall Hernia
- Acute Arthritis
- Back Injury
- Ankle Sprain/Strain
- Elbow Dislocation
- Elbow Sprain/Strain
- Finger Dislocation
- Fingernail Delamination (EVA)
- Hip Sprain/Strain
- Hip/Proximal Femur Fracture
- Knee Sprain/Strain
- Lower Extremity Stress fracture
- Lumbar Spine Fracture
- Shoulder Dislocation
- Shoulder Sprain/Strain
- Acute Compartment Syndrome
- Neck Injury
- Wrist Sprain/Strain
- Wrist Fracture

PSYCHIATRIC
- Insomnia (Space Adaptation)
- Late Insomnia
- Anxiety
- Behavioral Emergency
- Depression

GENITOURINARY
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (SA)
- Urinary Retention (SA)
- Vaginal Yeast Infection

INFECTION
- Herpes Zoster (shingles)
- Influenza
- Mouth Ulcer
- Sepsis
- Skin Infection
- Urinary Tract Infection

IMMUNE
- Allergic Reaction
- Anaphylaxis
- Skin Rash
- Medication Reaction

ENVIRONMENT
- Acute Radiation Syndrome
- Altitude Sickness
- Decompression Sickness (EVA)
- Headache (CO2)
Spaceflight Medical Risk

~100 Medical Events

Medical Conditions for which we have not planned.
Three tools are highlighted which currently describe the medical trade space:

1. **The Exploration Medical Condition List (EMCL)** - Identifies ~100 conditions of interest for medical system development

2. **The Integrated Medical Model (IMM)**

3. **The Medical Optimization Network for Space Telemedicine Resources (MONSTR)**
Quantitative Risk - Integrated Medical Model

**Mission Specific Inputs**

- Mission Duration
- Size/Gender of Crew
- # EVAs
- Other crew attributes
- **iMED**
  - Information for 100 Medical Conditions
  - Clinical Phase 1,2,3

**Quantified Outputs**

- Evacuation
- Loss of Crew Life
- Quality Time Lost
- Type of Medical Events
- Number of Medical Events
- Resources Used (i.e. Medications)
Quantitative Risk - MONSTR

Most useful medication categories for Mars DRM

Draft Data – Internal ExMC use only
Uses data from: IMM RunD-20150730-327RevA
Pre-decisional
Relative Importance of Labs for Mars DRM

Draft Data – Internal ExMC use only
Uses data from: IMM RunD-20150730-327RevA
Pre-decisional
What does it take to scope a medical system?

• How do we envision doing medicine?
  – Planned medical operations
  – Unplanned medical operations
  – Performance
  – Research

• How do we value and prioritize medical capability?
  – What is likely to happen and how often?
  – What would a physician want to have with them if it happened?
  – A repeatable way of prioritizing medical capability to invest research $$ in.

• How do we enable system operations that support crew autonomy?
  – Information handling from lots of sources
  – Command and control of devices (ultrasound, lab analysis, etc.)
  – Proving System-Vehicle and Ground-Vehicle Interfacing
SCOPING A MEDICAL SYSTEM

A medical system is judged by its ability to provide a crew fit for duty when called
Ground Based and Vehicle Data Architectures:
- Clinical Care
- Operational Needs
- Occupational Surveillance
- Research

Medical System Augments Crew Autonomy

- Flight Surgeon/BME
- External Consults

Occupational Health and Mission Support

Vehicle Exploration Medical System
- Crew Medical Officer
- Crew Medical Support

Real-Time Data Processing for Crew
Medical System Capture Diagram

- **Sensors**: Biomonitors, Environmental, EVA, Exercise, Behavioral
- **Tracking**: Consumables, Food, Medications, Fluids, Medical Eq.
- **Data Streaming**: Displays / Conferencing
- **Medical Equipment**: Imaging, 3-D Printing, Devices, Medications, Rehab
- **Performance**: Behavioral Monitor, Exercise Monitor
- **Training**: Medical Procedures, Imaging Techniques, Behavioral Intervention
- **EMS**: EMR, AMP
  - EMR: Tracking, Consumables, Food, Medications, Fluids, Medical Eq.
  - AMP: Tracking, Consumables, Food, Medications, Fluids, Medical Eq.
- **Intelligence Augmentation**
- **Models**: IMM, MONSTeR, Digital Astronaut, Radiation
- **Medical Decision Support**: Telemedicine, Semi-autonomy
- **References**: Pharmacologic, Toxicologic, Medical Imaging, Training Modules, Up-To-Date™
Programmatics and Ethics

• Must have a target to design towards
• Must have a way to make hard decisions
• This is not “sometime” in the distant future

Today 9 years

2016 2025 2030s

End of ISS

2025

9 years

ISS
WHERE ARE WE NOW?
ExMC Work Decomposition

Operational Needs

Information Resources

Technology and Hardware
<table>
<thead>
<tr>
<th>Med01</th>
<th>We do not have a concept of operations for medical care during exploration missions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med02</td>
<td>We do not have the capability to provide a safe and effective pharmacy for exploration missions.</td>
</tr>
<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>
</tr>
<tr>
<td>Med04</td>
<td>We do not have a defined rehabilitation capability for injured or de-conditioned crew members during exploration missions.</td>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td>Med08</td>
<td>We do not have quantified knowledge bases and modeling to estimate medical risk incurred on exploration missions.</td>
</tr>
<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>
</tr>
<tr>
<td>Med10</td>
<td>We do not have the capability to provide computed medical decision support during exploration missions.</td>
</tr>
<tr>
<td>Med11</td>
<td>We do not have the capability to minimize medical system resource utilization during exploration missions.</td>
</tr>
<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>
</tr>
</tbody>
</table>
ExMC Current Status

- ExMC Research Pathway Changed 2015
- IMM external review finishing
- MONSTR phase 2 completed for evaluation
- Concept of Operations started, delivery of Mars transit ConOps expected February
- Pharmacy research plan expected in November
- Medical Data Architecture underway
- Medical Device Projects Continue
- Clinician’s Working Group created
- Systems Engineering and Operations Group created
ExMC Data Architecture (ARC)

**Data Sources Layer**
- **Structured**
  - Health Records
  - Medical Records
  - Clinical Trials
  - Other
- **Unstructured**
  - Medical devices
  - Monitoring System
  - Images
  - Logs & Notes
  - Exercise Machine
  - Other
- **Streams**
  - Bio Sensors
  - Env. Sensors
  - Other

**Data Storage Layer**
- **Data Assets**
  - Knowledge Models
    - EHR
    - Documents
    - Sensor
    - Vitals
  - Other
- **Data Services**
  - Annotate
  - Correlate
  - Classify
- **Integrated Data Platform**

**Analytical Layer**
- **Clinical Decision Support System**
- **Analytics Data Mart**
- **Knowledge Base**
- **API, Information Services**

**Discovery & Analytics**
- **Reports**
  - Dashboard
- **Data Mining**
  - Text Classification
  - Computational Statistics
- **Modeling & Analytics**
  - Diagnostic
  - Predictive
- **Discovery**
  - Ontological Search
- **Real Time Apps**
  - Alerts
- **Cognitive Computing**
  - Adaptive, Interactive, Contextual

**User Interface**
- **Applications & Prototypes**
- **User Interface & Visualization**

**Data Virtualization**
- **Metadata & Data Standards**
- **Federated Access & Delivery Infrastructure (FADI)**
• CHS already investing
• Creating a governance model
• Data Reservoir
• Analytics Platform
• Phase 1 integrates LSAH, MMR, EMR

POCs: Andy Carnell
    Ram Pisipati
Appliance Examples

• FUS – Flexible Ultrasound
  – Kidney stone diagnostics and therapies
  – Bone healing

• RTA – Measure the degradation of pharmaceuticals non-invasively

• Dose Tracker – Track pharmaceutical usage, efficacy, and side effects

• Medical Consumables Tracker – RFID tagging to track pharmaceuticals usage

• EKG Cardiax device delivered to Space Station

• Laboratory Analysis devices in development and evaluation
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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</thead>
<tbody>
<tr>
<td><strong>Capability</strong></td>
<td>MDA System Definition</td>
<td>MDA System Enhancements</td>
<td>Multi-agent Data Mining</td>
<td>Computed Clinical Diagnosis</td>
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<tr>
<td></td>
<td>Biomedical Device Integration Definition</td>
<td>Biomedical Device Provisioning</td>
<td>Computed Problem Solving</td>
<td>Augmented Intelligence</td>
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<td></td>
<td>Image Analysis</td>
<td>Knowledge Base</td>
<td>Semantic Relations Network</td>
<td>Remote Data Asset Synchronization</td>
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<tr>
<td></td>
<td>Data Mining</td>
<td>Improved UI</td>
<td>Optimized UI</td>
<td>FDIR</td>
</tr>
<tr>
<td></td>
<td>Basic UI</td>
<td>Interface Engine</td>
<td>Ground System Int.</td>
<td>Analog Test Prep</td>
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<tr>
<td><strong>Medical Resources</strong></td>
<td>Astroskin</td>
<td>Medical Consumables Tracking</td>
<td>BHP appliances, apps and data</td>
<td>Vehicle Resources</td>
</tr>
<tr>
<td></td>
<td>EKG</td>
<td>Flexible Ultrasound</td>
<td>HHC appliance apps and data</td>
<td>Oxygen, Medical Suction</td>
</tr>
<tr>
<td></td>
<td>Dose Tracker</td>
<td>ELA</td>
<td>Ground System Data Analytics Platform</td>
<td>Vehicle subsystem integration (ECLSS, Avionics, Power, Thermal)</td>
</tr>
<tr>
<td></td>
<td>Flexible Ultrasound</td>
<td>Raman Analyzer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Notional System Block Diagram

Human Health and Performance System Block Diagram

Flight System
- In-Flight Health Data System
  - Data Repository
  - Data Analytics & Decision Support
- 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

Ground System
- Ground Health Data System
- Pre- and Post-Flight Medical Appliances
- Ground Health Maintenance System
- Ground Health and Performance Monitoring Data System

Emergency Medical Care (ExMC) scope
- Interfaces within HH&P
- Interfaces external to HH&P

Crew as Caregiver
Crew as Explorer or Patient

Researchers, Analysts, MCC, ASCR, FOD Trainer, Flight Surgeon
Integrated System Testing

Iterate

Benchtop

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

Iterate

Integrated System

IPAS
Integrated Sims
Ground System

Iterate

Analog

Hestia
HERA
Aquarius

Proving Ground Vehicle

NASA Internal

External

Smart Pods

DOD

Antarctica

Independent Evaluation of System
(Likely tied to IPAS)
Risk Mitigation Strategy
- Planning: Concept of Operations Development
- Characterization of Risk
- Active Risk Reduction (system to support crews)
- Engineering Testing Pathway
- Integration of Medical with Vehicle Designers and ECLSS SMTs
QUESTIONS?
**HUMAN EXPLORATION**
*NASA’s Path to Mars*

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[www.nasa.gov](http://www.nasa.gov)
BACKUP SLIDES
In 2001 *Safe Passage: Astronaut Care for Exploration Missions* prompted National Aeronautics and Space Administration (NASA) to improve the integration of the vehicle and human systems through a very intentional and evidence based design of medical systems to support human spaceflight for exploration missions.

The Human Research Program was established in 2005 to focus NASA’s research on the highest risks to human health and performance during exploration missions.

- Perform research necessary to understand and reduce spaceflight human health and performance risks in support of exploration
- Develop technologies to reduce medical risks
- Develop NASA spaceflight human system standards

Providing health care capabilities for exploration class missions will necessitate the definition of new medical requirements and development of technologies to ensure the safety and success of exploration missions.

A Medical System should maximize flexibility to enable a care provider to address conditions that were not considered in the initial design.
Mars Design Context

- Current architectures for exploration call for long duration missions of 1-3 years
- Mars will not have a capability for medical evacuation.
- Mars missions cannot expect resupply although some prepositioning of resources may be available.
- There will be periods of limited communications and extended transit times.
  - Comm rates: kilobits per second, like dial-up internet.
  - The one-way flight time for radio signals can be more than 20 minutes.
  - Comm will not be continuous.
- Mars Mission will require multiple launches
  - Launch one or more durable unpiloted ships with non-perishable supplies and equipment to Mars 78 or 52 or 26 months before the crew departs.
  - Construct the crew transit ship in high Earth or Moon orbit with several SLS payloads launched
  - Crew launch.

With low margins available on these missions, we can expect increasing scrutiny and competition for resources across mission systems.
Astronaut Long Term Health

- Understanding Long Term Health effects is challenging
- Occupational Surveillance to follow lifetime challenges
- Human Research Program to identify emerging issues

2013 Mortality Multiple Cause Micro-data Files
http://www.cdc.gov/nchs/data_access/Vitalstatsonline.htm
The ConOps captures the planned operational use of the exploration medical system.

• Provides guidance on medical capabilities required for prevention, diagnosis, treatment, and rehabilitation as envisioned for a Mars Mission to enable crew medical autonomy.

• Individuals will need to be sufficiently trained as medical officers

• The exploration medical system must be operable at the skill level of those selected to serve as medical officers.

• ConOps envisions and documents both planned and unplanned medical activities so that capabilities required to enable those activities can be identified.
Risk Characterization

But what if it happens?

- Secondary Prevention
- Diagnosis
- Treatment
- Chronic Management
- Rehabilitation

Medical Capability

For known risks:
How do we decrease this?

Keep it from happening?

- Selection
- Screening
- Primary Prevention
- Vehicle Design Standards
- Mission Architecture
2. IMM cont. - informs decision making

Mission Specific Inputs
- Crew Member Attributes
- Crew Composition
- Mission Duration and Profile

Monte Carlo Simulations
- Adaptive Medical Model
- CliFFs

Quantified Outputs
- Type and Quantity of all Medical Events
- Risk of EVAC
- Risk of Loss of Crew
- Quality Time Lost
- Medical Resources Used
- Optimized Medical System within Vehicle Constraints

Informed Analysis
- Flight Surgeon

ISS Medical System Resources
- Diagnosis and Treatment of Medical Conditions
- Medical Condition Incidence Data
- Risks due to EVAs

IMM Relational Database

13,500+ data elements
Forward Plan

- Risk Mitigation Strategy
  - Planning
    - Concept of Operations Development (Ops Risk Reduction)
    - Long Term Health Planning
  - Characterization of Risk
    - Models – Integrated Medical Model (IMM), MONSTR prototype
    - Active Data Gathering – Medical Consumables Tracker (MCT), Biosensors, Flexible Ultrasound
    - Medical Support – Exploration Medical System Demonstrator, Data Architecture
    - Long Term Health data collection
  - Active Risk Reduction
    - Technology Development – Oxygen Concentrator Module, Medical Suction, IVGen…
    - Training
    - Decision Support
    - Long Term Health interventions
    - Integration of Medical with Vehicle Designers and ECLSS SMTs

Medical System Development

ExMC Responsibilities and Interfaces
IMPALA Phasing

**Phase 1a**
- Analytics Platform
  - Project Management
  - Procure, Install & Configure
  - Establish Data Governance
  - Plan, Analyze & Design
  - Required Capabilities
  - Validate & Operationalize

**Phase 1b**
- System Integration (3 data sources)
  - Data source Identification & Migration
  - Project Management
  - Data Preparation
  - Collect & Manage Requirements
  - Build use cases
  - Dataset creation & management

**Phase 1c**
- Operations & Maintenance
  - Maintain Software Currency
  - Maintain Hardware Currency
  - Storage Management
  - Technical Operations
  - Takeover Platform Operations

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**Notes**
- Awarded to Lockheed Martin
- Delivery date Sep 30, 2016
- Planned delivery date – Dec 2016
- Platform Sustainment and O&M
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