Medical Risks and Capabilities for Human Exploration Spaceflight

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Risk of Human Spaceflight

O’Campo RP, Klaus DM. Applying regression analysis to model the risk of space flight and terrestrial activities. Journal of Space Safety Engineering. Sep-Dec 2018;5(3-4): 135-139.
Outline

• Historical spaceflight medical kits/systems
• Historical occurrence of medical conditions
• Upcoming missions and medical challenges
• Medical risk and spaceflight events
• Medical system and technology integration

Objectives

• Describe the key principles of extreme environmental medicine
• Identify the challenges with telemedicine and remote medical support
• Analyze the steps necessary to increase clinical autonomy
• Outline how using systems engineering principles can improve medical system design
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)
## 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</td>
<td>8</td>
</tr>
<tr>
<td>Aspirin-phenacetin-caffeine</td>
<td>Pain</td>
<td>Tablets</td>
<td>16</td>
</tr>
<tr>
<td>Cyclizine HCI</td>
<td>Motion sickness</td>
<td>50 mg</td>
<td>8</td>
</tr>
<tr>
<td>Diphenoxylate HCl</td>
<td>Diarrhea</td>
<td>2.5 mg</td>
<td>16</td>
</tr>
<tr>
<td>Meperidine HCl</td>
<td>Pain</td>
<td>100 mg</td>
<td>4</td>
</tr>
<tr>
<td>Methyl cellulose solution</td>
<td>Eye lubricant</td>
<td>15 ml</td>
<td>1</td>
</tr>
<tr>
<td>Parenteral cyclizine</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</td>
<td>2</td>
</tr>
<tr>
<td>Pseudoephedrine HCl</td>
<td>Decongestant</td>
<td>60 mg</td>
<td>16</td>
</tr>
<tr>
<td>Tetracycline HCl</td>
<td>Antibiotic</td>
<td>250 mg</td>
<td>16</td>
</tr>
<tr>
<td>Triprolidine HCl</td>
<td>Decongestant</td>
<td>2.5 mg</td>
<td>16</td>
</tr>
</tbody>
</table>

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**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)
FIGURE 4.7. Shuttle Orbiter Medical System. Following redesign in 2000, components include Saline Supply Bag, EENT Subpack, IV Administration Subpack, Trauma Subpack, Sharps Container, Drug Subpack, and Airway Subpack (Photo courtesy of NASA)
Figure 4.8. ISS Health Maintenance System. Components include (from left) defibrillator, Advanced Life Support Pack, Respiratory Support Pack, and Crew Medical Restraint System (Photo courtesy of NASA).
Do we need medicine in spaceflight?

<table>
<thead>
<tr>
<th>Medical Condition</th>
<th>Events</th>
<th>Medical Condition</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allergic reaction (mild to moderate)</td>
<td>11</td>
<td>Mouth ulcer</td>
<td>9</td>
</tr>
<tr>
<td>Ankle sprain/strain</td>
<td>11</td>
<td>Nasal congestion (space adaptation)</td>
<td>389</td>
</tr>
<tr>
<td>Back injury</td>
<td>31</td>
<td>Neck injury</td>
<td>9</td>
</tr>
<tr>
<td>Back pain (space adaptation)</td>
<td>382</td>
<td>Nose bleed (space adaptation)</td>
<td>6</td>
</tr>
<tr>
<td>Barotrauma (ear/sinus block)</td>
<td>31</td>
<td>Otitis externa</td>
<td>3</td>
</tr>
<tr>
<td>Choking/obstructed airway</td>
<td>3</td>
<td>Otitis media</td>
<td>3</td>
</tr>
<tr>
<td>Constipation (space adaptation)</td>
<td>113</td>
<td>Paresthesias</td>
<td>26</td>
</tr>
<tr>
<td>Diarrhea</td>
<td>33</td>
<td>Pharyngitis</td>
<td>11</td>
</tr>
<tr>
<td>Elbow sprain/strain</td>
<td>12</td>
<td>Respiratory infection</td>
<td>33</td>
</tr>
<tr>
<td>Eye abrasion (foreign body)</td>
<td>70</td>
<td>Shoulder sprain/strain</td>
<td>22</td>
</tr>
<tr>
<td>Eye chemical burn</td>
<td>6</td>
<td>Sinusitis</td>
<td>6</td>
</tr>
<tr>
<td>Eye infection</td>
<td>5</td>
<td>Skin abrasion</td>
<td>94</td>
</tr>
<tr>
<td>Finger dislocation</td>
<td>1</td>
<td>Skin infection</td>
<td>13</td>
</tr>
<tr>
<td>Fingernail delamination (EVA)</td>
<td>16</td>
<td>Skin laceration</td>
<td>1</td>
</tr>
<tr>
<td>Gastroenteritis</td>
<td>4</td>
<td>Skin rash</td>
<td>94</td>
</tr>
<tr>
<td>Headache (CO2 induced)</td>
<td>20</td>
<td>Smoke inhalation</td>
<td>3</td>
</tr>
<tr>
<td>Headache (late)</td>
<td>49</td>
<td>Space motion sickness (space adaptation)</td>
<td>325</td>
</tr>
<tr>
<td>Headache (space adaptation)</td>
<td>233</td>
<td>Urinary incontinence (space adaptation)</td>
<td>5</td>
</tr>
<tr>
<td>Hemorrhoids</td>
<td>2</td>
<td>Urinary retention (space adaptation) – female</td>
<td>5</td>
</tr>
<tr>
<td>Herpes Zoster reactivation (shingles)</td>
<td>1</td>
<td>Urinary retention (space adaptation) – male</td>
<td>4</td>
</tr>
<tr>
<td>Indigestion</td>
<td>6</td>
<td>Urinary tract infection – female</td>
<td>5</td>
</tr>
<tr>
<td>Influenza</td>
<td>1</td>
<td>Urinary tract infection – male</td>
<td>4</td>
</tr>
<tr>
<td>Insomnia (space adaptation)</td>
<td>299</td>
<td>Visual impairment/increased intracranial pressure (space adaptation)</td>
<td>15</td>
</tr>
<tr>
<td>Insomnia (late)</td>
<td>133</td>
<td>Wrist sprain/strain</td>
<td>5</td>
</tr>
<tr>
<td>Knee sprain/strain</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How is medical care provided in mission?

- Live remote guidance
- Live monitoring
- Store and forward
EXPLORATION SPACEFLIGHT
NASA Human Spaceflight Missions

- Soyuz Launch and Landings
- International Space Station
- Commercial Crew Program
- Multi-Purpose Crew Vehicle
- Gateway Habitat
- Deep Space Transport
- Mars Missions

Near Term (Current - 5 yrs)
Medium Term (within 10 yrs)
Long Term (10 – 20 yrs)
Phase 1: Gateway
What about Mars?
1. Radiation
2. Isolation and Confinement
3. Altered Gravity Fields
4. Hostile/closed environments
5. Distance from Earth
A Mars mission cannot use the current operational medical approach because that approach is dependent on evacuation for delivery of definitive care.
Access to the Deep Space Network for the vehicle may be as limited as 1 hour in a 24 hour period.

A Mars mission cannot use the current operational medical approach because that approach is totally dependent on real-time communication with the ground.
A Mars mission cannot use the current operational medical approach because that approach requires frequent resupply.
A Mars mission cannot use the current operational medical approach because that approach requires significant, continuous ground support.
How do we scope a medical system to meet the needs of a planetary mission that is:

- 2-3 times as long as any prior mission
- >500 times as far as any prior mission

Vehicle is committed after trans-Martian injection?
MEDICAL PROBABILISTIC RISK ANALYSIS
**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

**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

**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

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

**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

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

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

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

~100 Medical Conditions

Medical Conditions for which we have not planned.
Extrapolating Medical Risk

• Lack of single source for data
• Flight data- high internal validity, small volume
• Analog data- Lower validity, higher volume
• Expert opinion
Probabilistic Risk Assessment

IMM Framework: Event Simulation

Best-case resources available?

Treated Case:
Decrement medical resources

Untreated Case
Decrement medical resources

Worst-case resources available?

Untreated Worst-Case
Decrement medical resources

Treated case:
Decrement medical resources

Calculate End States:
• Evacuation (EVAC)
• Loss of Crew Life (LOCL)
• Crew Health Index (CHI)
• Resource Utilization
• Type and Number of Medical Events

Medical Event

Best-case Scenario

Yes

No

Worst-case Scenario

Yes

No

Worst-case resources available?

Slide courtesy of E Kerstman
Proportion of Mission Risk attributable to Medical

Mission Risk (LOC)

- Launch: 730 days
  - Transit Hardware
  - Transit Medical - LOCL
- Mars Transit: 365 days
  - Deep Space Transport
- Shuttle/ISS: 128 days
- Gateway: 42 days
- EM2: 21 days
- Space Shuttle: 14 days
Some IMM Assumptions…

1. All diagnoses are 100% accurate.
2. All events receive appropriate treatment.
3. All meds and equipment are 100% reliable and effective.
4. All events respond as they would terrestrially.
5. No mistakes in medical procedures (regardless of training)
6. Power, water, oxygen unlimited
PRA Estimates of Loss of Crew Life

- Perfect
- Physician - No Detraining
- Non-Physician - No Detraining

21 Day Lunar 6 Month ISS 1 Year ISS 2.5 Years Mars Design Reference Mission

Slide courtesy of E Kerstman
Proportion of Mission Risk attributable to Medical

Mission Risk (LOC)
“…[The] assumption has been that risk of vehicle system malfunction far outweighs the risk of human system failure…NASA buys down the risk of failure of the human system through rigorous selection of individuals designed to minimize medical issues and optimize available capability in flight.”

NASA SP-2017-0633
CREW HEALTH AND PERFORMANCE SYSTEM
Vehicle/Mission Architecture Integration

Habitat System

Crew Health and Performance
- Natural and Induced Environments Protection
- Medical
- Mission Task Performance
- Health and Wellness

Structures
Command & Data Handling
Guidance, Navigation and Control
Comm & Tracking
Power
etc.

Ground System

MedOps

Crew as Physician
Crew as Explorer or Patient
Crew Health and Performance System Must…

- Protect from environmental hazards
  - Radiation protection
  - Noise, vibration, CO\(_2\), etc.

- **Keep healthy crew well**
  - Exercise
  - Other physiological countermeasures
  - Food
  - Behavioral health

- **Prevent, diagnose, treat, manage long-term health care**
  - Data system
    - Medical Data Capture
    - Medical Training
  - Medical devices
  - Medical supplies

- **Support crew to accomplish mission tasks**
  - Procedures
  - Training
  - User interfaces
System Performance Threatened by Sleep Deficit

- Cognition
- Ground Support
- Biomonitoring
- Emergency response
- Medical Equipment
- Medical Skills Maintenance
- Pharmacy
- Food and Nutrition
- Waste Management
- Radiation Monitoring
- Air Quality
- Water Quality
- Team Cohesion
- Team Dynamics
- Training Capabilities
- Mood
- Physical Strength
- Stamina
- Exercise Equipment
- CO2 Levels
- Oxygen
- E.E. / Exercise equipment
- CO2 Levels
Sleep Deficit Affects Other System Aspects

- Ground Support
- Biomonitoring
- Emergency response
- Medical Equipment
- Medical Skills Maintenance
- Pharmacy
- Food and Nutrition
- Waste Management
- Radiation Monitoring
- Air Quality
- Water Quality
- CO2 Levels
- Oxygen
- Exercise Equipment
- Team Cohesion
- Team Dynamics
- Training Capabilities
- Mood
- Physical Strength
- Stamina
- Cognition
- Sleep
Translate Medicine to Engineering

Stakeholder needs, goals

NASA Standards

Program requirements & architecture

System functions & behaviors

System requirements & architecture

Subsystem requirements & architecture

Characterize system

Analyze & trade

Design & Build

Do we have the capabilities to meet the needs?
What allocations are necessary?
The ground medical system shall…

The XYZ device shall…

The habitat medical system shall…

The DSG habitat shall…

The DSG shall…

The CH&P system shall…

The habitat medical system shall…

The ground medical system shall…

NOT Official – best guess on requirements context
Medical and Non-medical Risk

Mission Risk

Total Risk

Non-Medical Risk

Medical Risk

Mass/Volume of Medical System

Ideal Mission Risk

Notional
Medical Systems Engineering

From “System Engineering at JPL” training course material, June 1991.

Crew Health and Performance System
MEDICAL DATA ARCHITECTURE
We’re not bringing an Intensive Care Unit but…

Crew Health and Performance System

These technologies exist today

Medical

- EMR
- Dashboard
- Diagnosis
- Procedures
- References
- Laboratory
- Inventory
- Equipment
- Imaging

Notional
Where are we today? MDA

Data Sources Layer
- Structured
  - Health Records
  - Med 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
    - Other
  - Vitals

Analytical Layer
- Clinical Decision Support System
- Analytics Data Mart
  - Knowledge Base
  - Data Service
    - Data Models
      - Annotate
      - Correlate
      - Classify

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)
Areostationary Satellite Mission: Primary – Comm Relay; secondary – Science/Exploration
Continuous relay availability for surface assets
High availability for low-altitude orbiters and CubeSats
High-performance directional proximity links
High-performance Earth link

Low-Altitude Science Orbiter
Mission: Prime – Science/Exploration; secondary – Comm Relay
High-performance Earth link for science data return
Intermittent relay services (~20 min/sol to Surface Asset)

Surface Asset (Fixed or Mobile)
Low-rate command and telemetry on Earth link
Continuously available high-rate relay link via Areostationary Relay Satellite
Intermittent high-rate relay to science orbiter(s)

Communication Technologies
New! Deep space optical communications: smaller, lighter, lower power flight terminals combined with large aperture ground telescopes offer 10-100x higher data rates
Advanced deep space RF communications: higher power and frequency, larger aperture, and sophisticated processing offer 10-20x higher data rates

Figure 1. Advanced RF and optical communications technologies combined with using the areostationary orbit offer 100-1000x greater data return from Mars and nearly continuous availability.

Table 1. High-Performance Mars-Earth Trunk Line Capability

<table>
<thead>
<tr>
<th>Current State-of-the-Art (MRO)</th>
<th>Frequency Band</th>
<th>Maturity</th>
<th>S/C Aperture</th>
<th>S/C Txmt Power</th>
<th>Ground Receiver</th>
<th>Data Rate (@ 2 AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X-band</td>
<td>Operational</td>
<td>3 m</td>
<td>100 W</td>
<td>34 m DSN BWG antenna</td>
<td>1 Mb/s</td>
</tr>
<tr>
<td></td>
<td>Ka-band (MRO)</td>
<td>TRL 6</td>
<td>3 m</td>
<td>200 W</td>
<td>34 m DSN BWG antenna</td>
<td>5 Mb/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRL 3-4</td>
<td>5 m</td>
<td>1 kW</td>
<td>34 m DSN BWG antenna</td>
<td>70 Mb/s</td>
</tr>
<tr>
<td></td>
<td>Optical (1550 nm)</td>
<td>TRL 6 (DSOC; to fly on 2023 Psyche Discovery Mission)</td>
<td>22 cm</td>
<td>4 W</td>
<td>5 m ground telescope</td>
<td>1 Mb/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRL 3</td>
<td>50 cm</td>
<td>50 W</td>
<td>12 m ground telescope</td>
<td>100 Mb/s</td>
</tr>
</tbody>
</table>
Can we replace the doctor?

- Full Artificial Intelligence
- Integrative Health and Performance Prediction
- Condition Specific Guidance
- Differential Diagnosis Generation
- Automated Image/Data Analysis
- Knowledge Support/Known Algorithm Provision
- Preventive Care Strategies
Perform physical exam, and collect vitals.

- Blood pressure
- Heart rate
- Respiratory rate
- Temperature
- Oxygen saturation
- Skin condition
- Limb symmetry
- Ocular examination
- Urine output
- Vital signs monitoring

Abdomen:
- Assess abdominal symmetry
- Check for tenderness
- Palpate for masses or tenderness
- Auscultate for bowel sounds
- Percuss for liver span

Differential Diagnosis:
- Appendicitis
- Cholecystitis
- Diverticulitis
- Pancreatitis
- Gastritis
- Meckel's Diverticulum

Abdominal examination:
- Assess for muscle guarding
- Palpate for tenderness or masses
- Percuss for liver span
- Auscultate for bowel sounds

Next steps:
- Order relevant laboratory tests
- Consider imaging studies
- Manage pain and hydration

Ultrasound Imaging:
- Renal ultrasound for kidney and bladder assessment
- Abdominal ultrasound for diagnostic purposes

Fundoscopy – Retinal Imaging:
- Examine retina for signs of diabetes or hypertension
- Evaluate for abnormalities such as detachment or macular degeneration

Intubation Emergency:
- Airway management in critical care situations
- Perform proper intubation techniques
- Monitor patient's oxygenation and ventilation
**Taking a Good Image: Composition**

**Tips for good composition:**

To move the optic disc down the subject needs to look up.

To move the optic disc right the subject needs to look right.

In a good composition the optic disc is centered.

**Bad composition**

In poor composition, the optic disc is not centered or not visible.

- Bad composition: Optic disc is too far right
- Bad composition: Optic disc is too low

**Good composition**
Medical Technology Development

SEEQ Mobile Cardiac Telemetry System: Medtronic

FUS moving stone in ER patient
PHARMACY
Stability Evidence: Flown Studies

Altered Medication

Du et al. 2011
Chuong et al. 2011
Wotring 2016
Unpublished: Cory 2017
Wu 2016

* Drug tested only for Vit B API
** Drug would fail by today’s API standard
† drug had unidentified degradant product

Ground Control Available

Acyclovir
Amoxicillin/Clavulanate
Atorvastatin
Azithromycin
Cefadroxil
Ciprofloxacin
Clotrimazole
Dextromethorphan
Epinephrine
Fluconazole
Furosemide
Ibuprofen
Imipenem/Cilastin
Levofoxacin
Levotyroxine
Lidocaine
Metoprolol
Metronidazole
Mupirocin
Nasal Cobolamine
Phenytoin
Progestin/Estrogen
Promethazine
Risedronate
Sertraline
Silver Sulfadiazine
Sulfamethoxazole/Trimethoprim
Temazepam
Triamcinolone

API and Physical Characteristics

API (B Vitamin only)

Unpublished Results

Centrum Silver® Multivitamin*
Women’s Once-A-Day® Multivitamin*

Aspirin
Acetaminophen**
Ibuprofen
Loratadine**†
Loperamide†
Pseudoephedrine
Melatonin
Modafinil†
Zolpidem†

* Drug tested only for Vit B API
** Drug would fail by today’s API standard
† drug had unidentified degradant product

Ibuprofen
Levofloxacin
Phenytoin
Sertraline
Valacyclovir

Altered Medication

Unaltered Medication
Other Topics within In-Flight Medical Conditions

• Imaging
• Rehabilitation
• Lab Analysis
• Biomonitoring and Wearables
• Personalized Medicine
• Renal Stones
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.”

Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit, Board on Health Sciences Policy and I. O. Medicine, Safe Passage: Astronaut Care for Exploration Missions, Institute of Medicine of the National Academies Press, 2001.
Rosetta Stone

ENGINEERING, LIFE SCIENCES, AND HEALTH/MEDICINE SYNERGY IN AEROSPACE HUMAN SYSTEMS INTEGRATION

THE ROSETTA STONE PROJECT

Edited by Richard S. Williams and Charles R. Doarn
Questions?

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