Human System Risk in Spaceflight

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Conflicts of Interest Disclosure

1. Assistant Professor of Emergency Medicine, Baylor College of Medicine
2. Assistant Professor of Space Medicine, Center for Space Medicine
3. Attending Physician, Ben Taub General Hospital
4. Assistant Director, Human Health and Performance, NASA Johnson Space Center

I have financial interests in the above entities.

Today I am speaking in my capacity as an Assistant Director for NASA
• Historical Spaceflight Medical Systems

• Upcoming Missions and Medical Challenges

• Medical Risk and Spaceflight Events

• Medical System and Technology Integration
Space Medicine History

1961

2019

NASA centric – there is more insight to be gained from Russian experiences
What about Mars?
No comparable human experience for Mars

The entire experience of our species fits into that blue dot.

Will not get you here!

Trans-Mars Cruise – 9 mos
Full Mission - ~34 mos

What got you here…

Adapted from S. Love, E. Nelson, Mars Mission Concept of Operations, Aug 2016
Hazards of Spaceflight
Hazards Drive Human Spaceflight Risks

- Altered Gravity - Physiological Changes
- Distance from earth
- Hostile/Closed Environment
- Isolation & Confinement
- Space Radiation
Why does performance matter?

Humans in Extreme Environments

Mitigating Impacts on Human Health & Performance

Exposure Sources
• Carbon dioxide
• Celestial dust
• Toxic
• Sunlight
• Radiation

Isolation
• Cognitive, behavioral, psychiatric disorders
• Cooperation, coordination, psychosocial adaptation

Work
• Sleep loss
• Circadian desynchronization
• Work overload

Preparedness
• Food and nutrition
• Inflight medical conditions
• Medication

Injury sources
• Dynamic loads
• EVA
• Electrical shock

Altered body function
• Immune response
• Hypobaric hypoxia
• Decompression
• Renal stone
• Bone fracture
• Host-microorganism interactions
• Urinary retention
• Orthostatic intolerance
• Cardiac rhythm
• Back pain

Reduced capacities
• Hearing loss
• Intracranial hypertension/vision alteration
• Vestibular/sensorimotor alteration
• Muscle mass, strength, endurance
• Aerobic capacity

Enabling Unique Human Capabilities for Earth-Independent Ops

Anomaly Response

Causal Diagnostics

Next Worst Outcome Analysis

Contingency Planning

Risk Assessment / Time to Criticality

Knowledge Integration

Complex Procedure Execution

How Crew Is Impacted by Mission

How Crew Is Impacting Mission

Why does performance matter?
Progressive Earth Independence

- Real Time Communications
- Evacuation Capability (1.5 – 36 hrs)
- Strong Consumables Resupply

- Near Real Time Communications
- Evacuation Capability (72 – 144 hrs)
- Limited Consumables Resupply

- No Real Time Communications
- No Evacuation Capability
- No Consumables Resupply

Increasing exposure to Hazards
Provide a crew that is fit for duty when the mission calls.
Do we need medicine in Spaceflight?

Table 2. Number of occurrences of medical conditions that have affected NASA astronauts during previous space missions (NASA 2017b). Data are obtained from LSAH records for medical conditions that occurred among US astronauts during the Space Shuttle Program, Mir, and ISS (through Expedition 13 in 2006) missions. EVA: extravehicular activity.

<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 (otitis media)</td>
<td>3</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>
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<tr>
<td>Eye abrasion (foreign body)</td>
<td>79</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>23</td>
<td>Urinary incontinence (space adaptation)</td>
<td>5</td>
</tr>
<tr>
<td>Hemorrhoids</td>
<td>2</td>
<td>Urinary retention (space adaptation)</td>
<td>5</td>
</tr>
<tr>
<td>Herpes Zoster reactivation (shingles)</td>
<td>1</td>
<td>Urinary retention (space adaptation)</td>
<td>4</td>
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<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>
What about between flights?

- Kidney stone x 14
- Clostridium difficile infection
- Gastroenteritis/ colitis
- Inguinal hernia x 4
- Olecranon bursitis r/o septic joint
- Hand bacterial tenosynovitis
- Pneumonia x 2
- Corneal ulcer
- Severe epistaxis
- Right ovarian cyst
- Dysmenorrhea
- Sudden hearing loss x 2
- V-tach, exercise induced
- Angina
- Allergic reaction - severe
- Retinal detachment x 2
- Appendicitis x 2
- Diverticulitis

- Prostate Cancer x 5
- Stroke with Patent Foramen Ovale
- TIA from A. Fib
- Bladder Outlet Obstruction
- Ulcerative Colitis
- Flexor Digitorum Synovitis
- Bowel Resection
- Fatty Liver Disease
- Bulging Disc with Radiculopathy x 44 (Cervical 18 and Lumbar 26)
- Hypercholesterolemia
- Hypertension (essential)
- Atrial Fibrillation with ablation x 5
- Brain (Pituitary) Tumor x 2
- Choledocholithiasis x 4
- Pancreatitis x 2
- Hemorrhagic cyst
- Lower GI bleeding
- Duodenal ulcer with upper GI bleeding
- Malignant Melanoma
- Total Knee replacement x 2
- Total Hip Replacement x 2
- Shoulder surgical repair x 22
- Coronary Disease (Asymptomatic x 12)
- SANS
How is medical care provided in mission?

- Live remote guidance
- Live monitoring
- Store and forward
- Autonomous
What does autonomous mean?

Can be up to 150 people working the first 1 hour of a critical situation

MCC Staffing

Early 2000s

2019
MEDICAL RISK
**Exploration Medical Conditions**

<table>
<thead>
<tr>
<th>Category</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SKIN</strong></td>
<td>Burns secondary to Fire, Skin Abrasion, Skin Laceration</td>
</tr>
<tr>
<td><strong>EYES</strong></td>
<td>Acute Glaucoma, Eye Corneal Ulcer, Eye Infection, Retinal Detachment, Eye Abrasion, Eye Chemical Burn</td>
</tr>
<tr>
<td><strong>EARS, NOSE, THROAT</strong></td>
<td>Barotrauma (sinus block), Nasal Congestion (SA), Nosebleed (SA), Acute Sinusitis, Hearing Loss, Otitis Externa, Otitis Media, Pharyngitis, Acute Ear Pain, Toxin Exposure, Smoke Inhalation</td>
</tr>
<tr>
<td><strong>DENTAL</strong></td>
<td>Abscess, Caries, Exposed Pulp, Tooth Loss, Crown Loss, Filling Loss</td>
</tr>
<tr>
<td><strong>CARDIOVASCULAR</strong></td>
<td>Angina/Myocardial Infarction, Atrial Flutter, Cardiogenic Shock, Hypotension, Sudden Cardiac Arrest, Traumatic Hypovolemic Shock</td>
</tr>
<tr>
<td><strong>GASTROINTESTINAL</strong></td>
<td>Constipation (SA), Abdominal Injury, Acute Cholecystitis, Acute Diverticulitis, Acute Pancreatitis, Appendicitis, Diarrhea, Gastroenteritis, Hemorrhoids, Indigestion, Small Bowel Obstruction</td>
</tr>
<tr>
<td><strong>PSYCHIATRIC</strong></td>
<td>Insomnia (Space Adaptation), Late Insomnia, Anxiety, Behavioral Emergency, Depression</td>
</tr>
<tr>
<td><strong>GENITOURINARY</strong></td>
<td>Abnormal Uterine Bleeding, Acute Prostatitis, Nephrolithiasis, Urinary Incontinence (SA), Urinary Retention (SA), Vaginal Yeast Infection</td>
</tr>
<tr>
<td><strong>INFECTION</strong></td>
<td>Herpes Zoster (shingles), Influenza, Mouth Ulcer, Sepsis, Skin Infection, Urinary Tract Infection</td>
</tr>
<tr>
<td><strong>IMMUNE</strong></td>
<td>Allergic Reaction, Anaphylaxis, Skin Rash, Medication Reaction</td>
</tr>
<tr>
<td><strong>ENVIRONMENT</strong></td>
<td>Acute Radiation Syndrome, Altitude Sickness, Decompression Sickness (EVA), Headache (CO2)</td>
</tr>
</tbody>
</table>

*SA – Space Adaptation*
Medical Condition Diagnosis and Treatment Data
Risks due to Extravehicular Activities (EVAs)
Medical Condition Incidence Data
Crew Composition and Attributes
ISS Medical System Resources
Medical Condition Impairment and Outcomes Data
Mission Duration and Profile

What medications should be supplied?
What is the likelihood of a medical evacuation?
What medical devices should we have on ISS?
What is the risk of Loss of Crew Life due to illness on ISS?
What medications should be supplied?

Integrated Medical Model

What need does it fill?
These results include all factors.

Figure. Results on Retrospective Analysis on Shuttle Risk

STS-1 estimate includes crew escape with ejection seats (risk is 1:9 ratio without ejection seats). STS-1 risk may have been higher because of unquantified risks.

The vertical lines indicate individual flights. Adapted from the National Aeronautics and Space Administration Aerospace Safety Advisory Panel.4

Bagian, JAMA Neurology January, 2019
Evacuation

EVAC is baselined to ISS
EVAC if any criteria are met:
- potential LOCL
- potential significant permanent impairment
- potential intractable pain
- No other assumptions are made

What happens when evacuation takes longer? Or there is no evacuation option?

No Medical Capability

Unlimited ISS Medical Capability

Single ISS Medical Capability (No Resupply)

Estimate difference between having unlimited ISS medical capability and no medical capability

Probability of EVAC

IMM 4.1 Run S-20180531-405, 100,000 simulations
Loss of Crew Life

These results are medical event only

1/90 is where the Space Shuttle total LOC risk fell at the end of the program.

Remember we flew with risk as high as 1/10 in early shuttle.

IMM Run S-20180531-405, 100,000 simulations
Quantifying Performance Deficits

CHI Definition: Proportion of mission time not lost to medical events

\[ 1 - \frac{\sum QTL}{L \times n} = CHI \]

N = # crew, 
L = mission length, 
QTL = quality time lost; is a function of functional impairment and duration

Small differences between treated and untreated reflect the benefits of selecting very healthy individuals

No Medical Capability

Unlimited ISS Medical Capability

Single ISS Medical Capability (No Resupply)

Crew Health Index

Expected Performance deficit between Unlimited ISS Medical Capability and No Medical Capability.

IMM Run S-20180531-405, 100,000 simulations
Spaceflight Medical Risk

~100 Medical Conditions

Medical Conditions for which we have not planned.
How do models compare to real life?

**IMM Simulation Data**

- Medical Illness
  - VIIP/SANS
  - Dental Abscess
  - Kidney Stone
  - Sepsis
  - Stroke
  - Angina/MI
  - Afib/Aflutter

- Environmental
  - Smoke/Toxic Exposure

- Injury/Trauma
  - Hypovolemic Shock
  - Wrist Fracture
  - Back Injury

**Actual Russian Flight Data**

- EVAC
  - Urosepsis
  - Cardiac Arrhythmia
  - Smoke Inhalation

- Close Call EVAC
  - Kidney Stone
  - Dental Abscess
  - Toxic Exposure

* Russian medical data not used in IMM
Fire and Toxic Exposure
Near Drowning in EVA
SANS – adaptation or pathology?
Urinary Tract Infections and Sepsis

In-flight Post-void Ultrasound

Ground Post-void Ultrasound
Return to Earth gravity
Capsule Egress
Medical and Non-medical Risk

Mission Risk

Total Risk

Non-Medical Risk

Medical Risk

Mass/Volume of Medical System

Ideal Mission Risk

0
There are more risks than medical

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Months</td>
<td>1 Year</td>
<td>1 Month</td>
</tr>
<tr>
<td><strong>Renal Stone Formation</strong></td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td><strong>Inflight Medical Conditions</strong></td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td><strong>Vision Alterations</strong></td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td><strong>Cardiac Rhythm Problems</strong></td>
<td>Accepted with Monitoring</td>
<td>Accepted with Monitoring</td>
</tr>
<tr>
<td><strong>Cognitive or Behavioral Conditions</strong></td>
<td>Accepted with Monitoring</td>
<td>Requires Mitigation</td>
</tr>
<tr>
<td><strong>Space Radiation Exposure</strong></td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td><strong>Inadequate Food and Nutrition</strong></td>
<td>Accepted / Optimize</td>
<td>Accepted / Optimize</td>
</tr>
<tr>
<td><strong>EVA Operations</strong></td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td><strong>Psychosocial Adaptation within a Team</strong></td>
<td>Accepted with Monitoring</td>
<td>Accepted with Monitoring</td>
</tr>
<tr>
<td><strong>Inadequate Human-System Interaction Design</strong></td>
<td>Accepted with Monitoring</td>
<td>Accepted with Monitoring</td>
</tr>
</tbody>
</table>
Implementation requires a Health and Performance System
## NASA Engineering Life Cycle

The NASA Engineering Life Cycle is a framework for managing the development and operation of space projects. It includes phases, project life-cycle gates, and reviews that ensure projects are defined, developed, tested, and operated in a disciplined manner.

### NASA Life-Cycle Phases

<table>
<thead>
<tr>
<th>Project Life-Cycle Phases</th>
<th>Approval for Formulation</th>
<th>Formulation</th>
<th>Approval for Implementation</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Phase A: Concept Studies</td>
<td>Phase A: Concept &amp; Technology Development</td>
<td>Phase B: Preliminary Design &amp; Technology Completion</td>
<td>Phase C: Final Design &amp; Fabrication</td>
<td>Phase D: System Assembly, Integration &amp; Test, Launch &amp; Checkout</td>
</tr>
</tbody>
</table>

### Project Life-Cycle Gates & Reviews

- **KDP A**: MCR
- **KDP B**: SRR & SDR
- **KDP C**: PDR
- **KDP D**: CDR & SIR
- **KDP E**: ORR & FRR
- **KDP F**:

### Years

See 7120.5E for acronym definitions.
Medical Systems Engineering

Crew Health and Performance System
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
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
Stepwise Progression

- **Gateway-Artemis**
  - 2024

- **Deep Space Transport**
  - 2027

- **Precursor**
  - 2029

- **Mars**
  - 2033

Human System Requirements:
- Test System Data Management
- Ground Optimize for 42 Day Mission
- Deploy System Data Handling
- Initial Ground Operations Changes
- Exercise Deep Space Comm, Autonomy, and Decision Paths
- Deploy Revised Ground Ops
- Optimally Autonomous Crew
- Redefined Ground Operations Paradigm

Ground System Requirements:
Perspective

• Less than 600 people - The entire human experience in space

• 19 years – we’ve had a constant human presence in low earth orbit

• Every day we fly we learn more, but each step farther out requires re-examining our assumptions and reassessing the current state of technology.

• Medicine and Engineering are intimately tied together in reducing the risks humans face in spaceflight.
Our work continues…

• 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.
Consumables Resupply

Current Operational Models Sufficient For Pharmacy Provision

Current Operational Models Inadequate For Pharmacy Provision
Stability Evidence: Flown Studies

- Altered Medication
- Unaltered Medication

Du et al. 2011
Chuong et al. 2011
Wotring 2016

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

API and Physical Characteristics

- Unpublished Results
- Unpublished Results

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

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

Unaltered Medication
Medication
Pharmacogenomics

Individualized susceptibility to therapeutic effects

Alteration of microbiome and bacterial antibiotic resistance

Pharmacogenomics

Individualized susceptibility to therapeutic effects

Alteration of microbiome and bacterial antibiotic resistance
27Apr17 crew note from HMS-ULTRSND-SCAN-CMO:
You know what would really help us? If we had pictures of a "perfect case" for each type of image. Given the time lag between ground and ISS - and the minute adjustments we are making for the correct image- the ground is like "3 seconds ago". If we had a picture of what we should make each image look like, we will print it out and have it above the machine so we can more quickly get to what you want and then stabilize for the ground to catch up. I think it will also help cosmonauts considerably given the high amount of commanding/translation. Just a thought - but I think it would help us be more efficient.
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.

Good composition

but I think it would help us be more efficient.
Remote -> Autonomy

Augmented Reality Training
Tietronix
Sensor Technology

Reveal LINQ ICM + MyCareLink Patient Monitor

In-flight Post-void Ultrasound

Ground Post-void Ultrasound
Where are we today?

Data Sent/Collective by MDA System via Telemetry with CFS (CCSDS Protocol)
Mars Telecommunication - Three Main Challenges

- Three major challenges face all communication with deep space (CLA):
  - **Capacity**: The link data rate or average daily volume
  - **Latency**: Speed of light delay between the planets
  - **Availability**: The percentage of time (over a day/Sol, week, month or year) that an asset has access to a link

- Deep Space Network CLA needs to be considered for the case of crew support needs
- What data rates are acceptable for Store-and-Forward type crew support? Emergency medical support? Behavioral health support?
- What if emergencies occur during planned daily link outages (due to Mars occultation)?

![Image of communication technologies]

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>
<thead>
<tr>
<th>LEO: ISS</th>
<th>Frequency Band</th>
<th>Maturity</th>
<th>S/C Aperture</th>
<th>S/C Tx Power</th>
<th>Ground Rx/Tx</th>
<th>Data Rate @2AU (MegaBits/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ku-band</td>
<td>TRL 10 / Operational</td>
<td>2 m</td>
<td>&gt;2 W</td>
<td>TDRSS Relay</td>
<td>Return: 90-110 (1/19: 517)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
<td>Forward: 25 (1/19: 50)*</td>
</tr>
<tr>
<td>MARS Current State-of-the-art (MRO SDST)</td>
<td>X-band</td>
<td>TRL 10 / Operational</td>
<td>3 m</td>
<td>100 W</td>
<td>1x34 m DSN Station</td>
<td>Return: 1-2</td>
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<tr>
<td></td>
<td>Ka-band</td>
<td>TRL 10 / Operational</td>
<td>None</td>
<td>35 W</td>
<td>1x34 m DSN Station</td>
<td>Return: 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
<td>Forward: 0</td>
</tr>
<tr>
<td>Next Generation Mars Trunks</td>
<td>Ka-band / DSRC</td>
<td>TRL 3-4</td>
<td>5 m</td>
<td>1 kW</td>
<td>1x34 m DSN Station</td>
<td>Return: EST 250</td>
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<tr>
<td>(Future human missions)</td>
<td>Optical / Lasercomm / DGC</td>
<td>TRL 6</td>
<td>22 cm</td>
<td>4 W</td>
<td>1x34 m DSN Station</td>
<td>Return: EST 125</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>N/A</td>
<td></td>
<td>Forward: &gt; 5.2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Return: &gt; 0.1</td>
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<td></td>
<td></td>
<td></td>
<td>Return: &gt; 600</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Forward: &gt; 25</td>
</tr>
</tbody>
</table>

* - Expected performance after Jan 2019 upgrade

Source: SCaN Team (M.Seibert, J.Schier, D.Abraham, D.Cornwell, G.Fujikawa)
We’re not bringing an Intensive Care Unit

Crew Health and Performance System

These technologies exist today

Medical

Notional
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
Risks to Health & Human Performance won’t occur in isolation

Example Factors Affecting Performance

- Physical Deconditioning
- Chronic Radiation Effects
- Depression/Team Dynamics
- Loss of Real Time support
- Insufficient Medical Capability

Where are the red lines and when will we hit them?
Amundsen and Scott Pole Race

Differences between Scott and Amundsen expeditions

Scott
- Overtchnologization (16 men, 23 dogs, 10 ponies, 13 sledges, 2 motor sledges)
- Followed what was tried before “because it worked”
- Thin margin of error
- Last minute decisions
- Died 12 miles short of his last food depot

Amundsen
- Focused preparation (5 men, 20 dogs)
- Made a new path
- Significant margin of error
- Lots and lots of preparation and field testing
- Got to Pole first and lived
There are evidence-based ways to systematically identify and match what is needed from a health perspective with what gets fielded in a mission.