Decadel Planning Team:
“Medical Aspects of Exploration Missions”

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Goals of Presentation

- Assess the medical aspects of an exploration mission
- Discuss breakthrough biological ideas/technologies that could enable human missions beyond Low Earth Orbit (LEO) at an acceptable level of risk
- Identify areas of research that are under funded

Overview

- Assumptions and Groundrules
- Governing Medical System Design Principles
- Medical Aspects of Exploration Missions
- Enabling Technologies
- Under Funded Biomedical Research
- Definitions of Risk
- Conclusion

Assumptions and Groundrules

- No crew return capability for medical contingencies
- Crew has been trained to be autonomous
- Six crew members
  - One physician
  - One crew member trained to the EMT-paramedic level
- 120-180 day transit time between Earth and Mars
- 7-40 minute round-trip communication
- Communication blackouts for up 30 days
- 500-600 day Mars surface stays

Governing Design Principles

- Non- or minimally-invasive
- Intelligence and automation should be built into the system
- Use of the system should be intuitive
- System mass, volume, and power consumption should be minimized
- Systems should be useable in all pressurized modules
- Systems should be sufficiently reliable to operate during the entire mission and readily upgradeable/serviceable for subsequent missions
- System design should accommodate the skill and medical training level of the crew
  - Intuitive interfaces
  - Assistive technologies
  - Comprehensive user support and feedback

Health Concerns of an Exploration Mission

- Radiation
  - Galactic Cosmic Radiation (GCR)
  - Solar Particle Events (SPE)
  - High Energy Heavy Ion Particles (HZE’s)

- Lengthy Mission Durations

- One-g, micro-g, and fractional-g mission profile

- Isolation and Confinement

- Artificial Environment

- Food and Nutrition

Radiation

- Crew exposure to radiation on exploration missions could be several orders of magnitude greater than Shuttle Missions and could exceed the allowable yearly dose of 50 rem
- Radiation exposure increases the risk of cancer, cataracts, and genetic mutation
- Organs Sensitive to Radiation
  - Highly Sensitive: lymph tissue, bone marrow, gonads, gastrointestinal tract
  - Moderately Sensitive: lungs, skin, kidneys, eyes, liver
  - Less Sensitive: central nervous system, muscles, bones, connective tissue
- Galactic Cosmic Radiation (GCR) will most likely be the limiting factor for human exploration due to crew time spent outside the habitat
- Solar Particle Events (SPE) - Requires real-time warning systems since SPE’s can deliver lethal doses of energetic particles within a few hours or days

Lengthy Mission Durations

- Lengthy mission durations increase the health risks to the crew in a number of ways
  - Radiation exposure
  - Crew Isolation
  - Crew Confinement
  - Micro-gravity deconditioning
  - Increased work/recreation scheduling required
  - Depletion of consumables and limited shelf-life items
    - Food
    - Pharmaceuticals
    - Blood replacements
- Crew performance is more likely to decrease as mission length increases
- Mass/Volume increases with mission duration
- Transit time should be minimized

Micro-gravity

- Immunological changes
- Decreased red blood cell mass
- Bone and mineral loss
  - Increased risk of renal stones
  - Increased risk of fracture
  - Increased risk of irreversible osteoperosis
- Muscle atrophy/Loss of strength
- Neurological changes
- Cardiovascular changes
- Sleep disorders
- Visual dysfunction
- Impaired thermoregulation
- The crew will endure additional physiological stress due to the Mars mission g-profile: 1-g, μ-g, 0.38g, μ-g, 1-g (not including the more extreme launch and landing loads)

Isolation and Confinement

- Extended periods of isolation and confinement increase the risk to the mission objectives
- Crew mental health can be affected in a number of ways:
  - Decrements in mood
    - Depression
    - Anxiety
    - Moral
    - Motivation
  - Conflict and aggression
  - Psychosocial induced stress
  - Decrements in cognition
- Work/Rest/Recreation schedules need to be designed carefully with minimal ground-crew influence

Artificial Environment

- The engineered environment poses a number of health concerns to the crew
  - Decreased Partial Pressure of O_2 (PPO_2)
  - Increased $PPCO_2$
  - Inhalation of foreign objects, fluids, or toxic gases
  - Off-nominal temperature and humidity levels
  - Bacterial growth
  - Water contamination
  - Chemically reactive Mars surface dust
  - Noise
  - Vibration
  - Odors
  - Visual sterility; lack of aesthetics
  - Lighting

Food and Nutrition

- Food quality and variety affects crew attitude and overall performance
  - Caloric intake needs to be sufficient, especially prior to EVA operations
  - Nutritional density
  - Palatability
  - Varied menu is essential

- Psychosocial benefit of communal meals

Enabling Medical Technologies

- Pertinent Medical Technologies for NASA
  - Autonomous monitoring and care
  - Non- or minimally-invasive therapeutics
  - Sensors
  - Medical infrastructure technologies
  - Medical training and simulation
  - Clinical medicine operations research
- Cross Functional Technologies within NASA
  - Advanced materials: reduces effects of radiation and μ-g deconditioning
    - Enables the design of artificial gravity transit vehicles
    - Reduces launch costs as strength to weight ratio increases
  - Advanced Propulsion Systems
    - Reduces effects of radiation, μ-g, limited food selection, isolation, and confinement by minimizing transit durations
- Industry Driven Technologies
  - Computer Industry: displays, voice recognition, micro-networks, wearable computers
  - Telecommunication Industry: high bandwidth, wireless operations, micro-system, secure protocols
  - Medical Industry: blood substitutes, small/lightweight diagnostic systems

Under Funded Biomedical Research

- Medical Infrastructure Technologies
  - Extended-life pharmaceuticals
  - Radiation effects on pharmaceuticals
  - Recyclable medical supplies
  - Sterilization technologies
  - Micro-gravity suction, storage, and disposal
- Medical Training and Simulation
  - Technologies that satisfy the synergistic relationship between device sophistication and crew training requirements
- Autonomous Monitoring and Care
  - Decision support
  - Robotic surgical assistant
- Non- or Minimally Invasive Therapeutics
  - Focused, high-intensity acoustic ultrasound to stop internal bleeding
- Radiation Monitoring and Prediction

Under Funded Biomedical Research (continued)

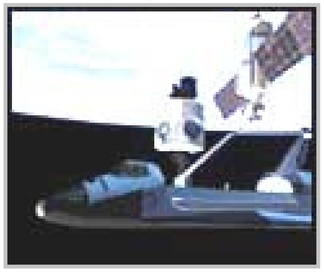
- Clincial Medicine Research
  - Expected illnesses and ambulatory medical problems, including but not limited to:
    - Orthopedic and musculoskeletal problems
    - Infectious, hematological, and immune-related diseases
    - Dermatological, ophthalmologic, and ENT problems
  - Acute medical emergencies in space including, but not limited to the following:
    - Wounds, lacerations, and burns
    - Toxic exposure and acute anaphylaxis
    - Acute radiation illness
    - Dental emergencies
    - Ophthalmologic emergencies
    - Psychiatric emergencies
  - Physiological responses to Mars dust exposure
  - Effective advanced life support

Three Levels of Risk and Implications

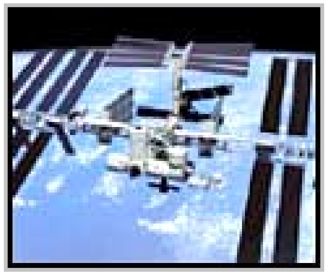
Medical Capabilities	Risk Accepted by Program	Implications
◆ ***Expedition*** • Ambulatory Care • First Aid • Basic Life Support	◆ ***High*** • Can’t fully recover from serious illness/injury • Palliative care • Permanent disability, death	◆ *No R&D* ◆ *Minimal crew medical training* ◆ *Public relations concerns if serious event occurs*
◆ ***Outpost*** + Advanced Life Support + Resuscitation + Short-term critical care + Minor surgery	◆ ***Moderate*** • Serious illness/injury treated if reasonable outcome expected, otherwise palliation • No long term care	◆ *Some R&D required* ◆ *Crew MD + assistant (paramedic)*
◆ ***Colony*** + Long-term critical care and rehabilitation + Major surgery	◆ ***Low*** • Similar outcome as if treated in Earth-based Hospital	◆ *Major R&D* ◆ *Medical staff required*

Space Medicine Vision

ISS Construction



ISS Utilization



Mars Expedition

Mars Colonization

2004 2015 2025

	ISS Construction	ISS Utilization	Mars Expedition	Mars Colonization
Characteristics	• 3 crewmembers • medical return via STS, Soyuz	• 3-7 crewmembers • medical return via STS, Soyuz, or X-38	• 4-6 crewmembers • medical return impossible • daily EVA	•12-20 crewmembers • medical return impossible
Mission Risk	• Moderate	• Low to Moderate	• High	• High
Medical Capability	• Outpost	• Outpost + Hyperbarics	• Outpost + Hyperbarics	• Colony
Medical Care Provider(s)	• 2 non-MD CMOs	• 2 non-MD CMOs	• MD • paramedic-level CMO(s)	• MD(s) • nurse(s) • paramedic-level CMO(s)

Conclusions

- A Mars mission is possible, but the level of acceptable risk to the crew must be defined at the programmatic level
- Risk drives the following:
  - Crew selection
  - Crew training requirements
  - Vehicle design
  - Use of vehicle resources
    - Storage and deployed volumes
    - Power usage
    - Data usage
    - Mass
    - Gas (oxygen, nitrogen)
  - Mission Operations/Medical Operations
  - Selected/funded medical technologies