Protecting Astronaut Health: A Grand Challenge for Prolonged Spaceflight and Inter-Planetary Exploration

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ASU Course LIA 194:
Living In Space: Know Before You Go!
21 April 2023
• proving humans can survive in space
  – Soviet cosmonaut, Yuri Gagarin
  – 12 April 1961

• proving humans could land and return from an extra-terrestrial body
  – US astronauts Neal Armstrong and Buzz Aldrin
  – moon landing, 20 July 1969
Expansion of Human Space Travel

- extended survival in low earth orbit (LEO) in orbiting space stations (1973-present)

- back to moon
  - Artemis III (2025?)
  - (cis)lunar gateway (?)
  - permanent moon base (?)

- and beyond (?)
Projected Major Expansion in Space Exploration and Space Commerce

- space-for-military superiority
- space-for-space economy
- space-for-earth economy
In-Space Economy

In-Space Economy Classification:
1) Human Spaceflight
   - Crewed Spacecrafts & Shuttles
   - Human Landers
2) Cargo Transportation & Landers
   - Robotic Landers (Moon, Mars)
   - Re-Entry Capsules (Earth, Mars)
   - Cargo Resuply
   - Reusable Satellites
3) Spacecraft
   - Crewed Rovers
   - Robotic Rovers
   - Drones, Hoppers
4) Space Stations & Habitats
5) Surface Habitats & Structures
6) In-Space Manufacturing (ISM)
   - In-Space Production
   - Space Food, Space Agriculture
   - Microgravity Manufacturing
   - Additive Manufacturing
   - In-Space Assembly, Construction, etc.
7) Space Resources
   - ISRU (In-Situ Resource Utilization)
   - Pure Substances (Ice, Oxygen, Metals)
   - Space, Lunar & Asteroid Mining
   - Prospecting, Processing, Recycling
8) Space Utilities
   - Energy, Power-Beaming
   - In-Space Internet, Data Relay
   - Navigation
   - Water, Propellant
9) Space Transportation
   - Space Tugs, Space Trucks
   - Orbital Transfer Vehicles (OTV)
   - On-Orbit Servicing, Maintenance
   - Propellant Replenishment (Depots)
   - Active Debris Removal
   - On-Orbit Inspection
   - Space Mobility, Space Logistics
10) Miscellaneous
    - Microgravity Services
    - In-Orbit Computing, Storage
    - Space-Flow Items
    - Space Suits & Garments
    - Commercial Astronauts
    - Space Entertainment & Advertising
    - Space Traffic Management
    - Space Tourism Support, etc.

*Original creation by Erik Kulu since 2020 inspired by ISMC.*
The Rapid Rise of Private Sector Space Commerce and a New Civilian Space Workforce

- “astropreneurs”
- “astronaut homesteaders”
Humans in Space

- how to thrive in high-risk non-physiological environments for extended periods?
- how to mitigate the short- and long-term adverse health risks from life off-earth?
- how to design and construct sustainable habitats on the moon and beyond?
Humans in Space

- to rocket scientists and engineers, humans are a problem
- humans are a complex, irritating component that comes with wide variation in physical and mental traits creating diverse and often unknown vulnerabilities that could threaten mission success
- everything we take for granted on earth has to be rethought, released, rehearsed
Space-Induced Changes in Different Body Systems

- major knowledge gaps
- small ‘N’ problem: limited number of individuals in space to date
- LEO environments very different from deep space missions
- need for prolonged follow-up (longitudinal studies)
- reversible versus irreversible changes
- additional as yet unknown and unpredicted adverse risks
- eventual need for genetic modification for sustainable health augmentation (non-heritable), enhancement (heritable) in long duration missions and off-earth habitats?
- human reproduction in space
Altered Health in LEO Environments

https://www.nature.com/articles/s41526-021-00143-x
Space Adaption Syndrome: Humpty Dumpty Head, Chicken Legs

- increased cranial pressure (ICP) due to body fluid redistribution in reduced gravity
- “The full-head sensation never completely goes away. It feels like standing on your head 24 hours a day.”
  
  Scott Kelly
SANS:
Spaceflight-Associated Neuro-Ocular Syndrome

[Images of iris comparisons preflight and postflight]
In-Mission Ophthalmic Monitoring
The Glymphatic System (Ocular and CNS)
Alzheimer's Disease and Neurodegeneration: Beta-Amyloid and TAU Neurotoxic Proteins

- Beta-Amyloid Plaques
- TAU - Neurofibrillary Tangles
Glymphatic Drainage of Brain Metabolic Waste Products: Impaired Clearance with Increased IOP/ICP and Sleep Disturbance

- impaired removal of amyloid and TAU proteins
- predisposition to accelerated neurodegeneration?
Bone-Loss in Microgravity

- bones of legs, pelvis and lower back lose 20 times as much mass as upper body bones
- loss of bone mineral density/month
  - femur (1.6%), pelvis (1.4%), lower spine (1.1%)
  - whole body (0.35%)
- much higher demineralization than osteoporotic bone loss in post-menopausal women on earth
- urinary excretion of excess calcium (hypercalciuria)
  - predisposition to renal/bladder stones high levels of hydration
On-Station Exercising to Mitigate Bone and Muscle Atrophy
Disrupted Sleep in Reduced Gravity: Altered Circadian Rhythms
Sleep Disorders and Dreaming in LEO

- among most common perturbations
- dissatisfaction with depth and duration of sleep
- 75% astronauts use sleeping pills
- disruption of five stages of sleep and cascading neurohormonal alterations
  - pineal gland, hypothalamus and pituitary functions
  - increased secretion of growth hormone
- adverse impact on cognitive and emotional behaviors
  - decision making, reasoning, irritability
  - complex spectrum of emotional responses, including overt clinical psychiatric conditions
Psychological Fragility Induced by Isolation and Confinement

- people don’t anticipate how much they miss the natural world until they can’t access it
Mental Health Resiliency in Long Duration Missions in High Risk/High Stress Environments

- anxiety, despondency, depression, withdrawal and isolation
- impulsivity, mania, aggression, violence
- hallucinations
- resentment of workload and acceptance/conformity with critical SOPs needed for mission success
- conflict risk management
- cross-cultural clashes
- “irrational antagonism”: emerges after c.6 weeks
  - cumulative intolerance and annoyances at previously innocuous events
Learning to Tolerate Less Than Optimal Living Quarters

personal hygiene

ISS: smelly, noisy and awash in microbes and crumbs

- everything floats
- the benefits of anosmia

HOW TO ASTRONAUT
AN INSIDER’S GUIDE TO LEAVING PLANET EARTH

TERRY VIRTS
NASA astronaut and International Space Station commander
The NASA Twins Study: Comprehensive MultiOmics Profiling of Extended Spaceflight Duration in LEO (One Year)

Spaceflight and Human Health

- redistribution of body fluids and hemodynamic changes
- altered functions in multiple organ systems
- new (epi)genetic expression patterns in multiple cell types
- perturbed cell trafficking movements
- different gut absorption of nutrients and drugs
- immune dysregulation
- Reactivation of latent viral infections (herpes, GBV)
- microbiome dysbiosis (composition, virulence, antibiotic resistance)
- accelerated features similar to biological aging on earth
Radiation:
The Omnipresent Health Risk in Space Flight

doi.org/10.17226/26155 (2021)

Commander Moonkin Campos:
Artemis I return 1/10/2023
Radiation Risk Exposure in Space:
GCR = Gamma Cosmic Rays  SPE = Solar Particle Events

Chronic low-dose rate 24/7 whole-body exposure to GCR (protons, helium ions and heavy ions) and secondary particles (neutrons)

Acute high-dose and high-dose rate short-term whole-body exposure during SPE (mostly protons, can be shielded)

Individual, age-dependent and sex-specific differences in radiation sensitivity and susceptibility

Chronic or late effects
- Cancer
- Cataract
- Degenerative diseases of brain, lung cardiovascular, digestive endocrine, immune and reproductive systems

Acute effects
- Acute radiation syndrome
- Prodromal syndrome
- Hematopoietic syndrome
- Skin effects

https://www.nature.com/articles/s41526-023-00262-7 (2023)
Space-Acquired Radiation Mutation Damage to Gametes and Enhanced Risk of Fetal Abnormalities (Teratogenicity)

- cryogenic storage of astronaut eggs/sperm harvested before mission for IVF use on return (or loss of life of donor on mission)
- analogous situation to use of IVF for donors facing high dose cancer chemotherapy
Medical Emergencies in Space

- limited medical supplies, equipment and crew training
- limited on-board pharmacy
- limited storage for blood and blood derivatives (35 day shelf-life)
- faster deterioration of medicines and reduced shelf-life versus earth
- rapid evacuation from locations beyond LEO not currently feasible
Ranking of the Most Likely In-Mission Health Emergencies

- cardiovascular
  - clotting
  - myocardial infarction due to altered myocardial mass
- infections
- trauma, hemorrhage, shock
- acute radiation sickness (Moon and beyond)

individual or multiple cases
Returning to Earth: Biological Readaptation

- **days**
  - impact of sudden postural shifts: fainting, vertigo, nystagmus
- **weeks**
  - variable persistent balance and walking problems
  - dysconjugate gaze (cross-eyed)
  - back/joint pain as spine/tendons recompress under Earth’s gravitation
  - vision
- **month to years**
  - restoring muscle and bone mass
  - normal sleep patterns
Returning to Earth: Unknown Unknowns

- long-term health effects?
- influence of mission duration and location on risks?
- DNA mutation and cancer predisposition?
- chronic immune dysregulation and persistent subclinical inflammatory states?
  - autoimmunity, susceptibility to infection, cancer
- vision
  - SANS, accelerated cataracts?
- neurodegeneration?
  - impaired brain glymphatic drainage and accumulation of neurotoxic materials
Human Health and Performance in Space

countermeasures for spaceflight-specific health conditions

infrastructure and life support systems for off-earth habits and extended duration missions

current dependency on terrestrial biomedical interventions

no current demonstration of feasibility of large-scale construction beyond LEO
The Elephant in the Room: Unresolved Fundamental Issues in Space Exploration
Human Health in Off-Earth Locations: Moon Base

THE BRICK MOON AND OTHER STORIES
Edward Everett Hale

HISTORICAL ANALOGS FOR THE STIMULATION OF SPACE COMMERCE
Monographs in Aerospace History, no. 54
Roger D. Launius

[Image showing a lunar base and astronauts]
Future Issues in Space Exploration: Microbial Biocontamination, Biocontainment and Biosafety Risks

- two-way traffic: from the earth and back-to-earth
- microbial mutation and selection in off-earth locations
  - evolution of ‘stress adaptation’ phenotypes not present in terrestrial ancestors?
  - new microbial species?
  - need for new classes of antimicrobial drugs?
Fundamental Issues in Space Exploration

- feasibility of reproduction in reduced gravity environments?
The Critical Role of Mechanical Forces in Early Embryonic Development
and
Life-Long Maintenance of Complex 3D-Tissue and Organ Structures
Critical Stages in Human Prenatal Development and Risk of Fetal Abnormalities

https://www.flickr.com/photos/11304375@N07/7178272407
Toroidal Colonies: Gerard O’Neill Princeton 1975

- giant space pods
- rotate to simulate earth’s gravity
- position at Lagrange points to maintain a stable orbit
ARTEMIS PREPARES FOR MARS

Testing landing and ascent capabilities

Expanding the range of surface exploration and ISRU demonstrations

Gateway augmented with international habitat for increased capabilities

Foundation Surface Habitat and Habitable Mobility Platform delivered to complete Artemis Base Camp

Expanded habitation capability added to Gateway to enable Mars mission dress rehearsal at the Moon

Mars mission dress rehearsal with longer in-space and surface durations

SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

Overview of Space Bioprocess Engineering Challenges: Technologies, Components, and Platforms

Enable Transformational Space Exploration and Scientific Discovery
- High-Mass Planetary Surface Access
- All Access Mobility
- Surviving Extreme Space Environments
- New Tools of Discovery

Manage In-Space Resources
- Abundant Power
- Space Way Station

Expand Human Presence in Space
- Economical Space Access
- Space Health and Medicine
- Space Settlement

In situ Resource Utilization
- Carbon Fixation
- Nitrogen Fixation
- Regolith Enrichment

Food and Pharmaceuticals
- Food and Medicine
- Microbiome Engineering
- Microbial Nutrition

In situ Manufacturing
- Bioplastics Production
- Bioceramic Synthesis

Loop Closure
- Anaerobic Digestion

Systems Design
- Human Health and Performance

Platform Evolution
- Small Satellites
- Space Station
- Rovers
- Artemis
- Lunar/Martian Habitation

Increasing cost & complexity
The Moon: The First Extraterrestrial Location for Human Planetary Exploration

- first or last?
- insurmountable barriers for onward travel?
  - sustainable habitats
  - health, reproduction, genetic modification
Why Humans?

- technology advances in robotics, autonomous systems and AI will outperform humans and dramatically expand the repertoire of machine-based capabilities to benefit humans on-earth
Robots and Asteroid Mining
Next Generation In-Craft Robots
Future Issues in Space Exploration: Construction of New Communities in Space

- technical feasibility of large-scale habitat engineering (time-lines)?
- affordability (cost-effectiveness and conflicting societal priorities on earth)?
- role of robotics, autonomous systems and AI versus humans?
- off-earth reproduction, citizenship and nationhood?
- heritable genetic modification for off-earth survival (Homo astrum, Homo ares, Homo astral)?
- hybrid humans: fusion of eugenic genetics and integrated physical devices (Homo cyborgensis)?
Slides Available @
https://casi.asu.edu/presentations/
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