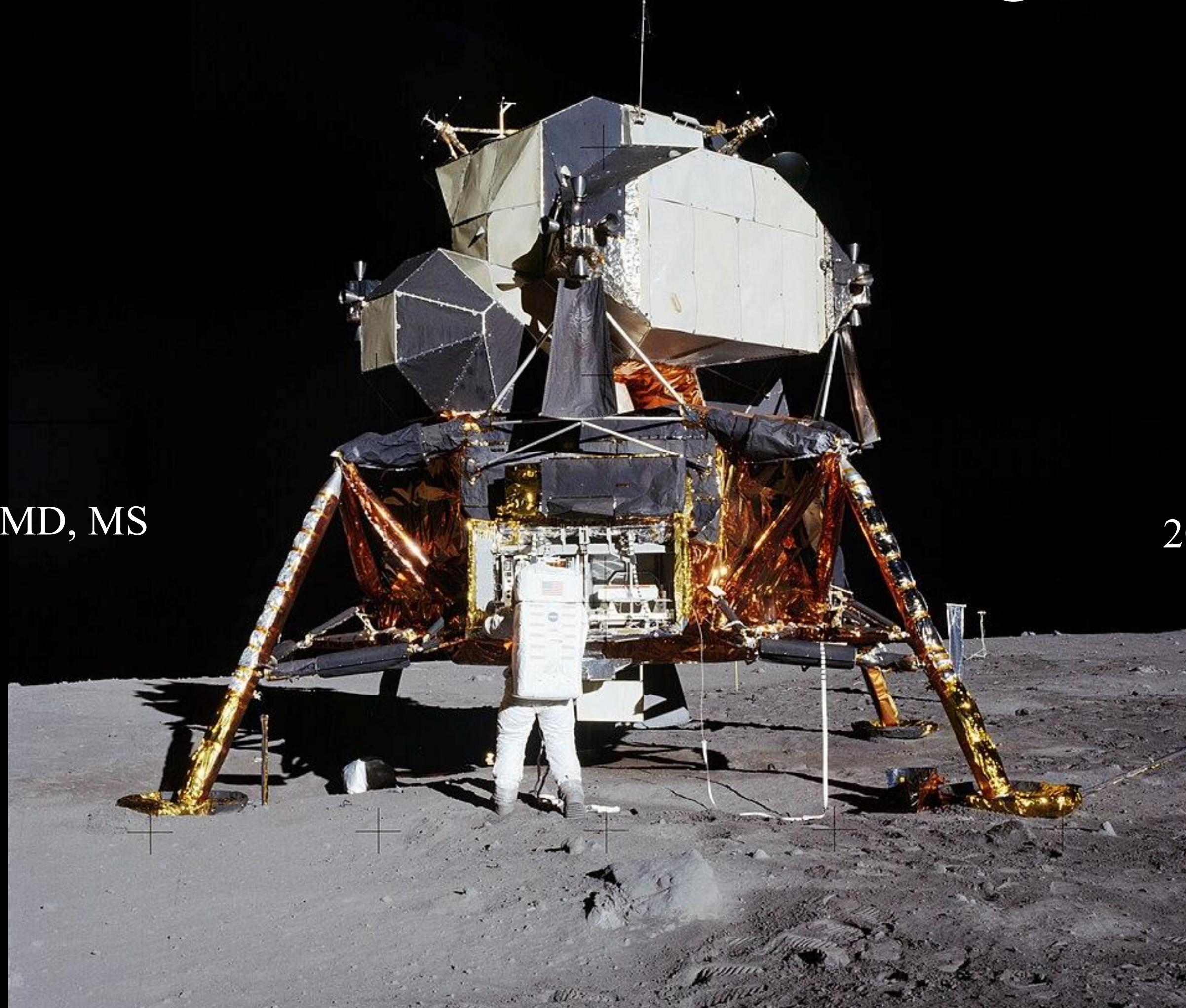
Human Health and Performance on the Lunar Surface
National Academies Briefing

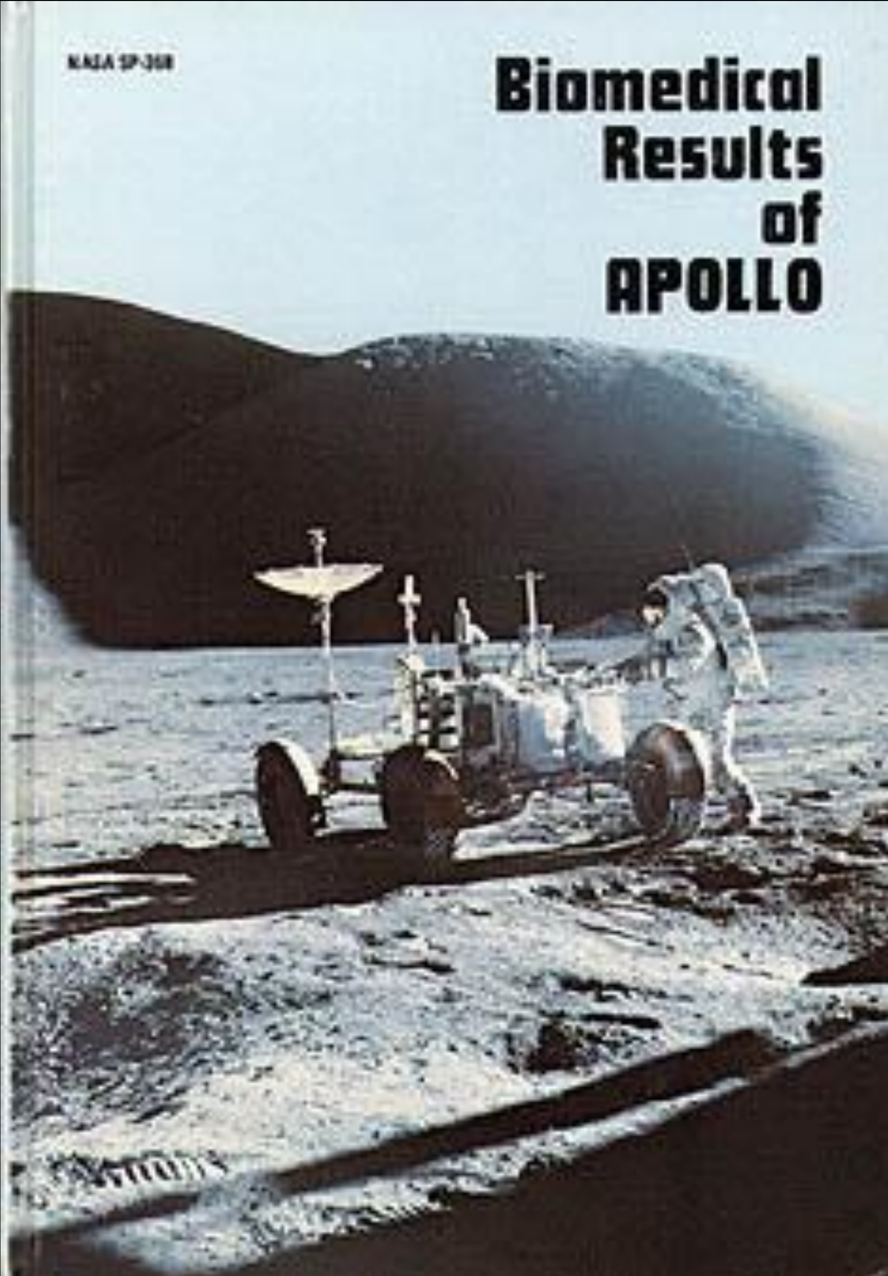


Michael Barratt, MD, MS
Astronaut Office

20 January 2026

DISCLAIMER

Not formal positions of the astronaut office or the NASA / JSC medical and research communities.



NASA/ TM–2007–214755

The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations

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Required reading for students and ‘practitioners’ involved in human lunar exploration.

Design Reference Mission (DRM) Guidance

Non-polar destinations (easier to get to, less deep-cold, less challenging lighting)

Total mission duration 1-2 weeks (commensurate with Apollo missions and Shuttle program, n = hundreds)
Surface landing following 3-7 days of 0-G coast, acute and subacute phases of 0-G adaptation completed

Two Souls (implies small spacecraft)

Main mission is science recon (assume sample return capability)

1 – 4 EVA sorties (implies 2-5/6 surface days)

Assumptions

Missions requiring agility of human operators - complexities of terrain, lava tubes, equipment deploy, etc.

Post Artemis III and subsequent (hardware and methodologies including suit and other EVA adjuncts somewhat broken in)

Combination of rookie and experienced crew (Positive effect on efficiency and mission execution)

Exploration atmosphere (Intermediate pressure, eg 8.5 – 10.5 psi with 26 – 30% O_2 concentration to accommodate EVA with reduced prebreathe overhead)

Rover as an option (adds both capability and hazards)

Assumptions (continued)

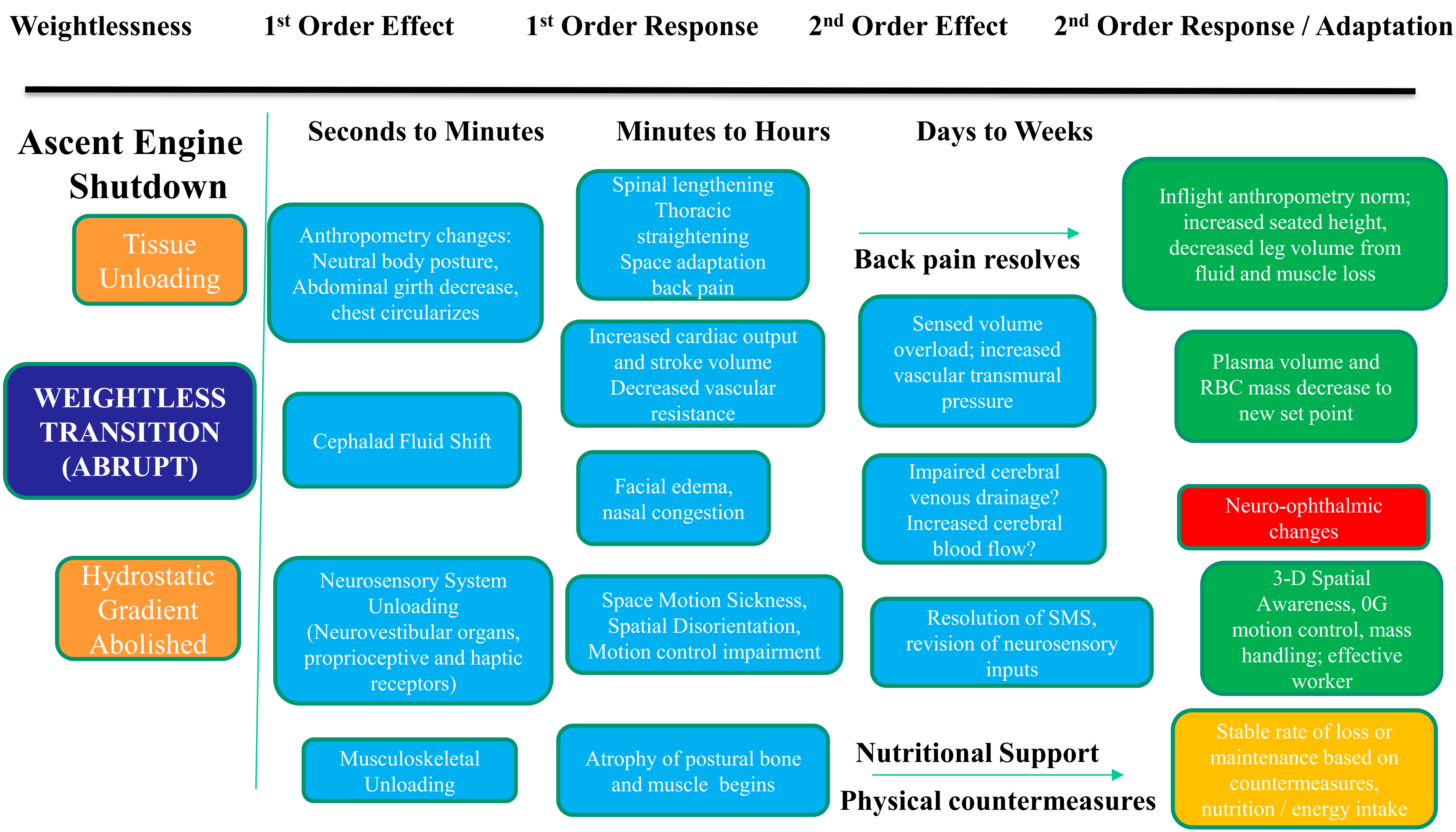
Near Realtime Com (orbiting relay and other assets available for significant fraction of time for com/data/imagery)

Lunar Sample Return capability (likely in the tens of kg range)

Customizability of deployed hardware (e.g. flat terrain vs rugged vs lava tubes)

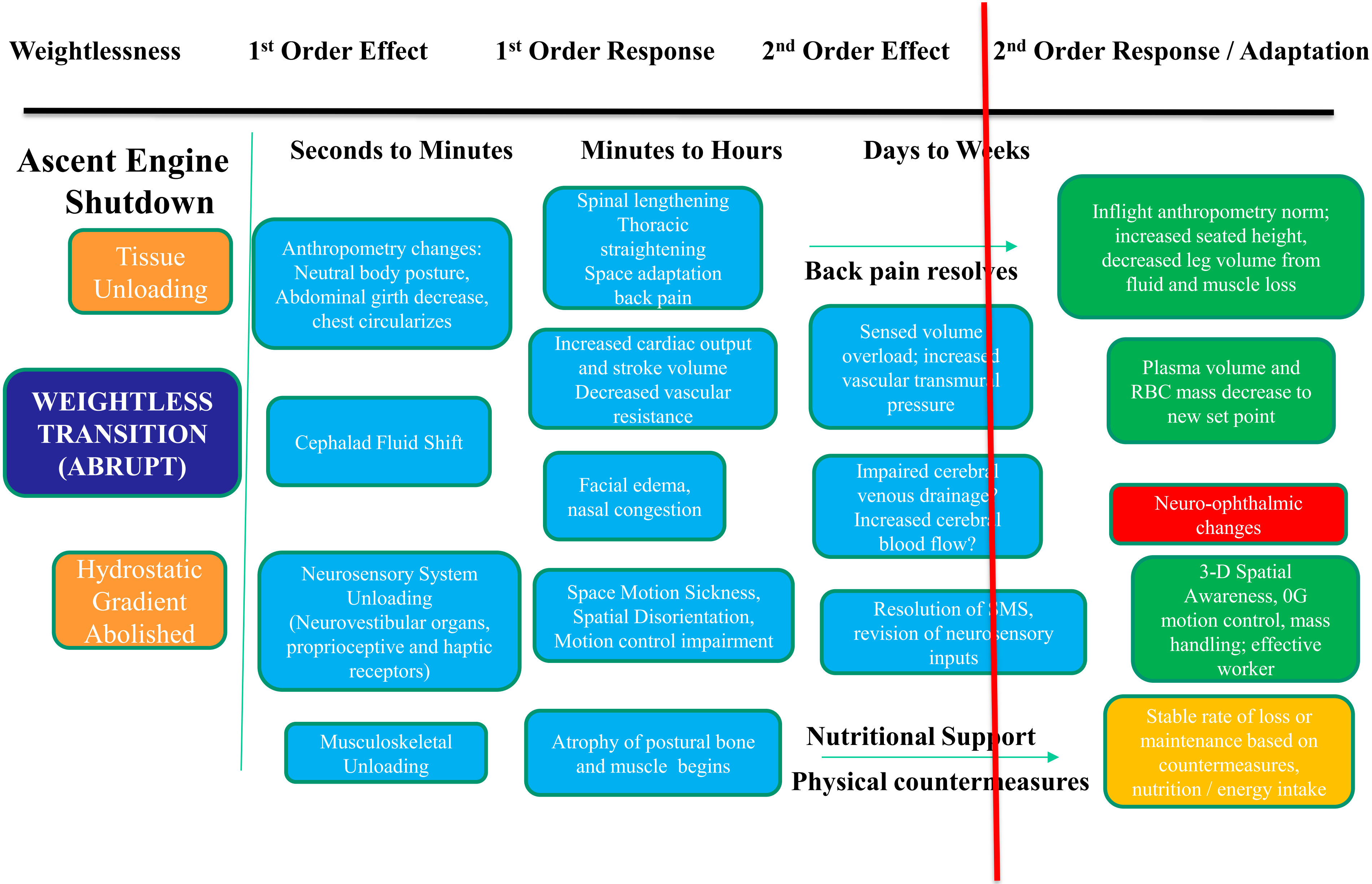
Pressure refuge for people and materials (e.g. not entire cabin going to vacuum for EVA)
Storage for meds, science equipment and enabling of onsite analysis

Major physiologic changes associated with adaptation to weightlessness.



From Human Response. In: Principles of Clinical Medicine for Space Flight, 2nd Ed. Springer. 2019

Major physiologic changes associated with adaptation to weightlessness.



Crew will be about here for surface landing.

Stated Committee Interests

Radiation Exposure (long term effects negligible; main concern is solar flares)

Immune System Changes (minimal; may be part of combined risk wrt lung issues, eg alveolar macrophages / dust / radiation)

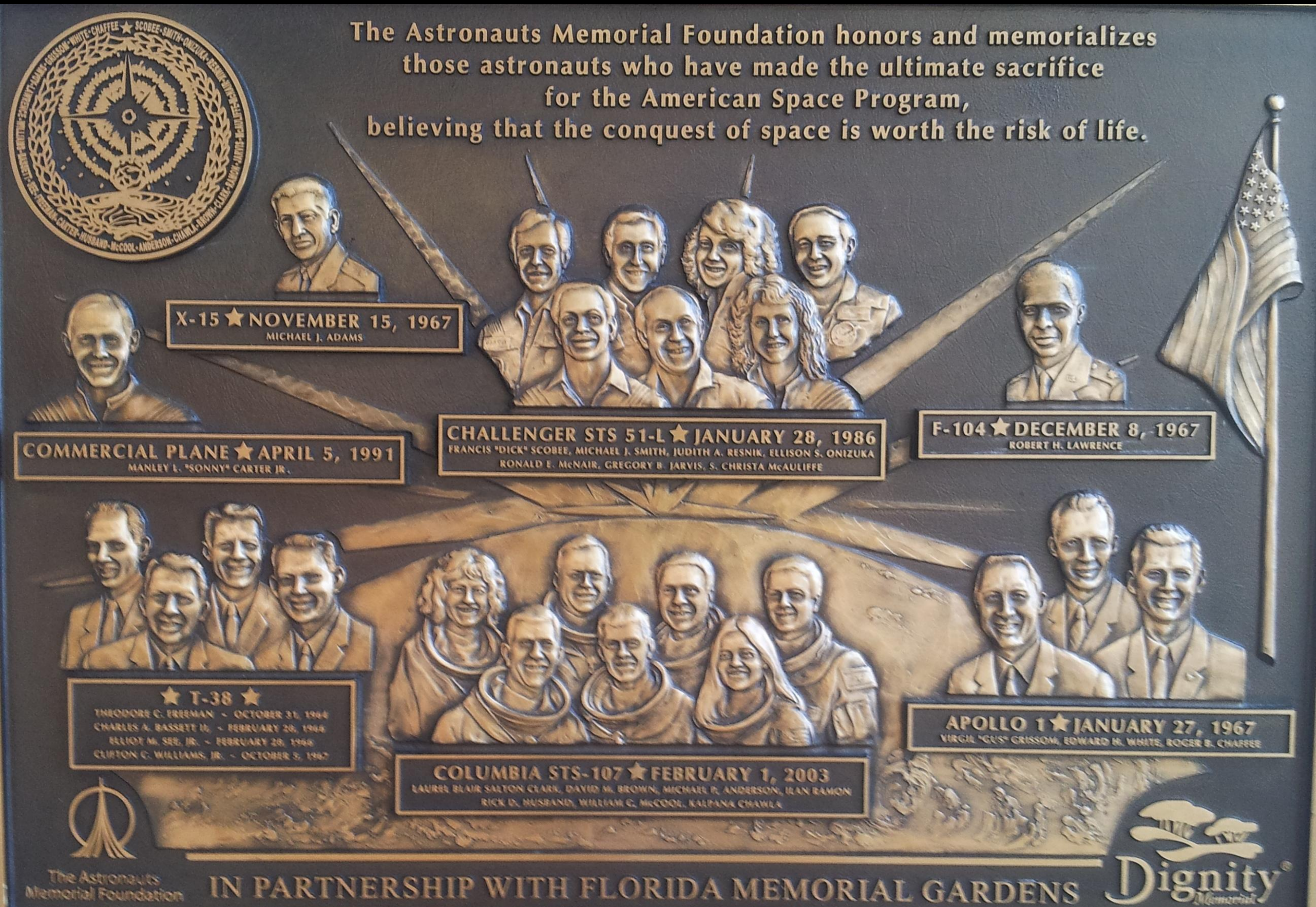
Effects on Bone Density (Negligible)

Intracranial Pressure / Eye Issues (Negligible; ancillary neurovascular findings in 1/6 G may inform risk)

Orthostatic Changes (Negligible concern)

Cardiac Function / Heat Loading, lunar vs. 0G EVAs (hardware solution, was not problematic in later Apollo missions)

Mortality and Morbidity of Space Flight Resides in Dynamic Operations



Health and Performance Hazards on Lunar Surface

What keeps us up at night

Fractional G – The ‘undiscovered country’

EVA risks - Why we are there in the first place

Dust – A fact of life in our two most near term destinations

Ionizing Radiation – Life outside Earth’s geomagnetic fields

Nonionizing Radiation (Intense solar UV radiation, RF energy from systems)

The Built Environment (atmospheric constituents and control, fire, leaks, toxic release, noise, critical hardware failure)

>> Each of these is the tip of a very large iceberg! <<

All the interesting places in the solar system are between 0 and 1G

Earth

Surface Gravity
= 1G (9.8 m/s^2)
P = 1 ATM

Mars

0.379G
P = .006 ATM

Moon

0.165G
P = 0 ATM

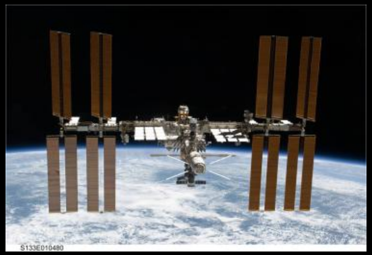
Ganymede

0.146G
P = 0 ATM

Titan

0.138G
P = 1.45 ATM
T= 94K (-179C)

ISS



0G
P = 1 ATM

Fractional Gravity
Understanding the Gravitational Dose Response

Not all systems will follow similar curve (different trip lines of physiologic relevance)

Cannot expect individual or holistic Dose Response to be linear (probable thresholds / knees in the curve)

Most relevant to long duration stays on lunar surface
Short sorties will likely provide clues if opportunities taken; eg vascular ultrasound, OCT, samples for biomarkers, etc.

EVA Risks

EVA Suit / System Failures

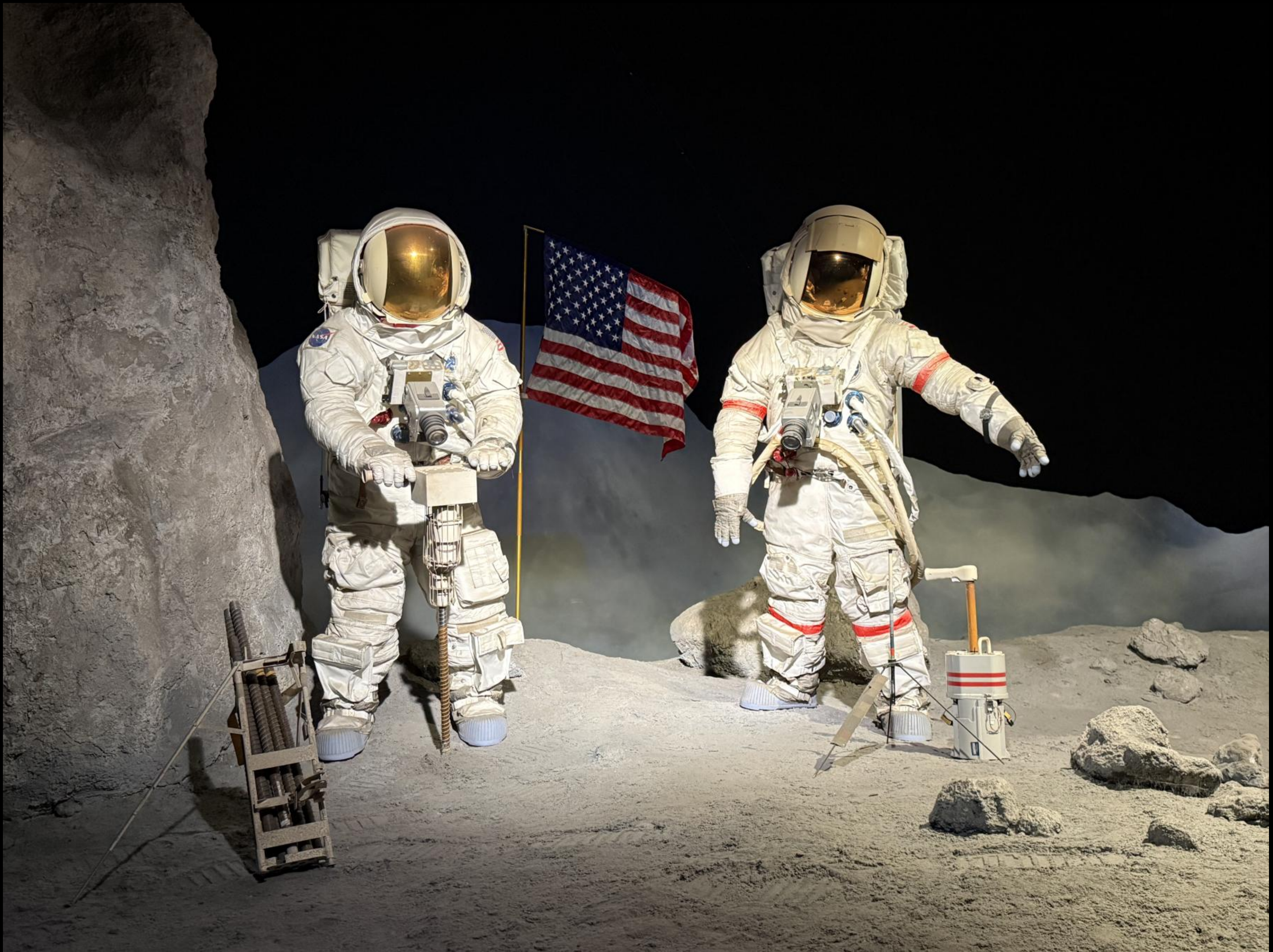
Physical / orthopedic trauma
From actual EVA and from suit

Decompression Disorders
Decompression sickness, hypoxia, barotrauma, ebullism,

Thermal stress
Whole body hypo / hyperthermia, contact thermal injury

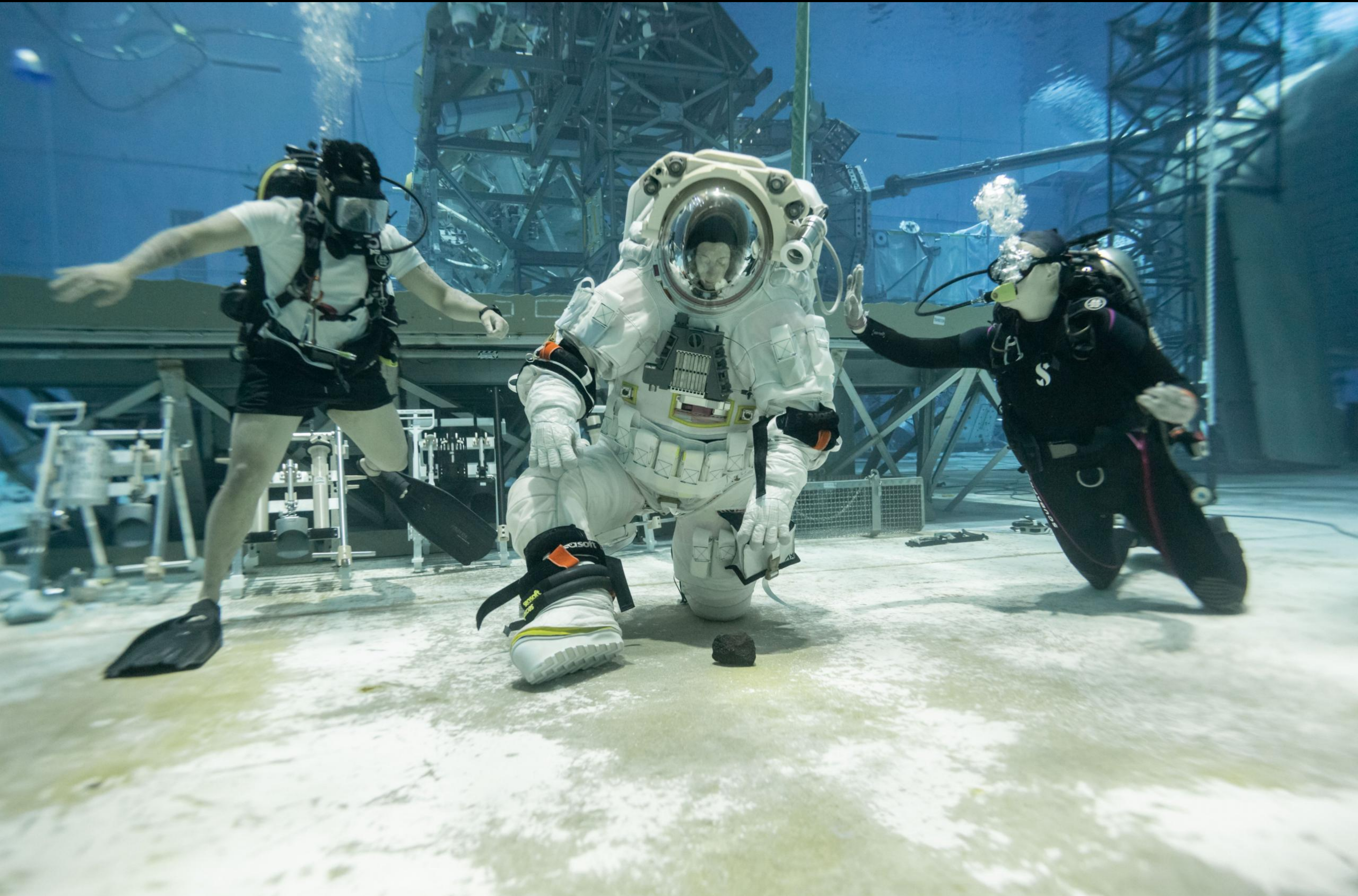
All of these have been seen in flight and/or ground testing
All have hardware and procedural mitigations

Apollo EVA Suits



Mark III Suit

Axiom Surface EVA Suit



Surface Dust

Main proximate risk to crew is sensitive equipment compromise

EVA systems, ECLSS, avionics, mechanisms

Direct risk to humans not dire but not well known

Known irritant to upper airways, eyes, nasopharynx

Toxicity studies show relatively low risk compared with other pathogenic dusts leading to occupational pneumoconiosis

Combined effects of dust, fractional G adaptive lung changes, immune dysregulation, periodic hyperoxia, ionizing radiation, physical stress not known

Mitigation for this DRM

Airlock preferred over full cabin depress

Evolved dust mitigation systems (brushing, airflow/filters, static induction)

Crew masks up between EVA ingress and ECLSS dust reduction efforts, and during transition to 0-G

Consider simple assay for biomarkers (eg sputum for immune modulators, WBC's)

Consider simple / compact PFT capability


FGB


11
MIRROR MOUNT

Ionizing Radiation

Expected lunar surface equivalent dose on the order of 1.3-1.4 mSv/day for this DRM at Solar Min (worst case)*

For two week trip, equivalent of 21-30 days on ISS at solar min (0.6-0.7 mSv/day) (5 days on surface at 1.4 mSv/day, 10 days transit at 0.8 mSv / day = 15 mSv)

Maps to long term risk of carcinogenesis, vascular damage; well within limits

Main concern is solar flares

Will need plan for sheltering in place both for translunar cruise and surface activity

Real concern for acute radiation syndromes

Local active radiation monitoring with alert capability is a must

Not available on Apollo missions

Gives crews chance to shelter independent of ground advisement

*Change'E 4 Lunar Surface Probe Data

Zhang S, Wimmer-Schweingruber RF, Yu J, Wang C, et al. First measurements of the radiation dose on the lunar surface. Sci Adv. 2020 Sep 25;6(39):eaaz1334.

Human Health Oriented Data Collection

‘Learn as you go’ with minimal mission impact

Operational Medical Data, Pre and Postflight

Operational Medical Data, Inflight

Radiation dosimetry; biomonitoring during dynamic flight; cabin air and dust samples;

Relevant Metadata

All ECLSS parameters

Accelerometry, vehicle descent / ascent and surface rover

Consider U/S for decompression stress

Actigraphy for sleep (easy)

‘Lunar Dipstick’ (One meter probe to embed and leve in surface to look at protective effects of regolith; radiation in form of TEPC like collectors, temp, vib, ESD, etc.)

Artemis Mission Medical Evaluation Document (AMMERD) Collaboration Status

Mission Effectivity: Artemis III-V

NASA's Human Research Program & Human Health and Performance Directorate are collaborating to define required health measure collections on Artemis crews. Early Artemis missions provide novel, unique environments and operations that serve as a proving ground to inform future Artemis and Mars missions.

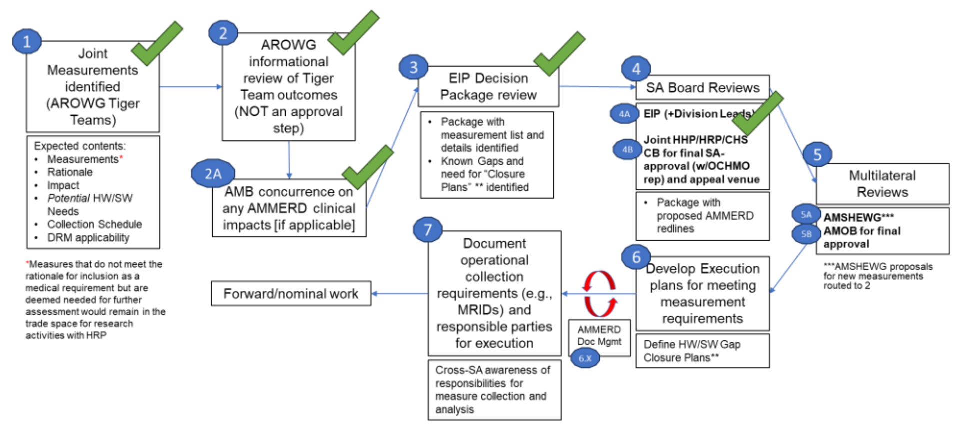
Definitions: Criteria for AMMERDs

AMMERDs

ISS MED-Bs

- Clinical care – includes screening, selection, preventive strategies (immunizations, prophylactic measures), and all preflight, inflight and postflight medical care to optimize crew member health.
  - Occupational Health/Preventive Medicine – individual monitoring of occupational impacts for the individual crew member (hearing conservation, radiation monitoring, etc.) that also guide rehabilitation postflight.
- Population Surveillance – data collection to identify exposures, effects, or outcomes on the astronaut population as a whole, and are training-specific, flight-specific (i.e., Soyuz vs Orion vs Shuttle) and mission-specific (i.e. LEO short or long duration vs Lunar orbit or landing vs Mars landing). These data and outcomes drive design of missions, vehicles, and countermeasures; and feedback to preventive strategies for the population that may include selection, countermeasures, training, and medical support.
- Research – hypothesis-driven research that seeks to address a specific, measurable, and answerable question based on evidence.

AMMERD Development/Approval Process



Parting Comments

There are no show stoppers to this DRM wrt crew health and performance.
Only mindful application of what is already known

Much of what made Apollo successful was a learn as you go approach and rapid evolution / iteration of solutions between missions

** This type of agility is critical for lunar exploration

Paying attention to habitability pays forward in health and performance; true n Apollo, on ISS, and will be so in the new era

Questions?

Backup Material

ACUTE RESPONSE

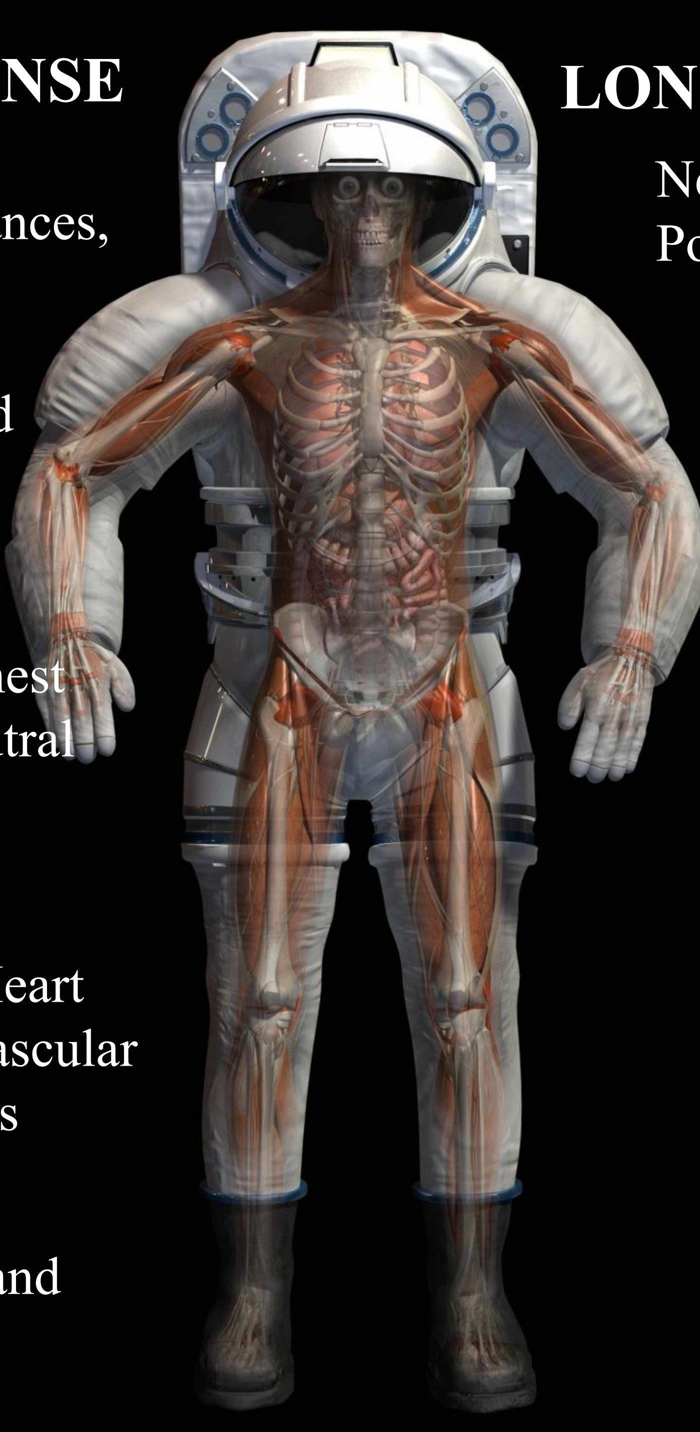
Neurosensory disturbances, space motion sickness

Fluid shift to chest and head; facial puffiness, head discomfort

Abd girth decrease, chest diameter increase, neutral body posture

CVP and thoracic pressure decrease, Heart volumes increase, vascular compliance increases

Onset of atrophy of postural musculature and skeletal mass



LONGTERM ADAPTATION

Neurosensory adaptation, 3 D Position sense and locomotion

Down regulation of plasma volume and rbc mass 12-15%; discomfort improves. Cerebral vascular dynamics drive neuroanatomic and ocular changes, possible ICP increase

CO $\uparrow$41%, SV $\uparrow$35%, MAP $\downarrow$, SVR $\downarrow$39%, but symp tone increased

Bone, muscle, aerobic fitness determined by sum of physical countermeasures, nutrition, other factors (individual, metabolic, etc.)

Immunology / Infectious Disease

Neuroscience and Biobehavioral Reviews 115 (2020) 68–76

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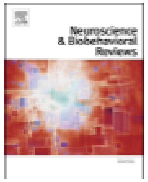

Review Article

Countermeasures-based Improvements in Stress, Immune System Dysregulation and Latent Herpesvirus Reactivation onboard the International Space Station – Relevance for Deep Space Missions and Terrestrial Medicine

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A R T I C L E I N F O

Keywords:
Stress
immunity
spaceflight
confinement
exercise
gravity
viral reactivation

A B S T R A C T

The International Space Station (ISS) has continued to evolve from an operational perspective and multiple studies have monitored both stress and the immune system of ISS astronauts. Alterations were ascribed to a potentially synergistic array of factors, including microgravity, radiation, psychological stress, and circadian misalignment. Comparing similar data across 12 years of ISS construction and operations, we report that immunity, stress, and the reactivation of latent herpesviruses have all improved in ISS astronauts. Major physiological improvements seem to have initiated approximately 2012, a period coinciding with improvements onboard ISS including cargo delivery and resupply frequency, personal communication, exercise equipment and protocols, food quality and variety, nutritional supplementation, and schedule management. We conclude that spaceflight associated immune dysregulation has been positively influenced by operational improvements and biomedical countermeasures onboard ISS. Although an operational challenge, agencies should therefore incorporate, within vehicle design limitations, these dietary, operational, and stress-relieving countermeasures into deep space mission planning. Specific countermeasures that have benefited astronauts could serve as a therapy augment for terrestrial acquired immunodeficiency patients.

Pearls from Biomedical Results of Apollo

People who were concerned with the future of man in space quickly became aligned with one of two points of view. On the one side, there were the more cautious and conservative members of the medical and scientific community who genuinely believed man could never survive the rigors of the experience proposed for him. The spirit in the other camp ranged from sanguine to certain. Some physicians, particularly those with experience in aeronautical systems, were optimistic. …. It became the task of the medical team to work toward bringing these divergent views toward a safe middle ground [**582**] where unfounded fears did not impede the forward progress of the space program, and unbounded optimism did not cause us to proceed at a pace that might compromise the health or safety of the individuals who ventured into space.

Pearls from Biomedical Results of Apollo

Opportunities for inflight medical investigations were severely restricted on the Apollo missions because of conflict with the principal operational objectives. Furtherance of the understanding of the effects of space flight on human physiological functioning had to rely almost exclusively on comparison of preflight and postflight observations. These were carefully selected to focus attention on the areas which appeared most likely to be affected, for example, cardiovascular function.

Pearls from Biomedical Results of Apollo

On the other hand, there was some concern regarding the ability of the cardiovascular system to withstand acceleration stresses associated with lunar descent and ascent. Headward acceleration (+Gz) was imposed during the Lunar Module descent after three to four days of weightlessness, and a near one-g (+Gz) force was produced by the ascent profile after a day or more of 1/6-g exposure. Also, the results of postflight tests were expected to show important differences in cardiovascular responsiveness between crewmen who walked on the moon and those who remained in weightless flight

Pearls from Biomedical Results of Apollo

Although several of the Apollo 11 and Apollo 12 astronauts had positive motion sickness histories, none of these crewmen reported any difficulties either during weightless flight or on the lunar surface. The complete absence of vestibular problems during lunar surface activity throughout the Apollo Program has proved significant. Before the Apollo 11 mission, many predictions had been made regarding possible disorientation and postural stability problems that might occur on the lunar surface.

Extravehicular activity in one sixth g on the lunar surface resulted in no disorientation or vestibular disturbances. Apparently, one-sixth g is an adequate stimulus for the otolith organs to provide sensory information regarding gravitational upright and, hence, maintenance of posture.

Pearls from Biomedical Results of Apollo

Extravehicular activity at one-sixth g on the lunar surface resulted in no disorientation or vestibular disturbance, nor was there any apparent change in the sensitivity of the vestibular system on suddenly returning to one g. Indeed, there was only one episode of postflight vestibular disturbance.

Some felt man would be disoriented in lunar gravity, and, when he attempted to walk on the moon, would become motion sick and vertiginous and be unable to move in a given direction. This fear was resoundingly demonstrated to be baseless by Apollo 11.

Apollo 11 demonstrated that man could indeed fly the Lunar Module after having flown only a training device, which was, of course, not an exact duplicate. In fact, not only could he fly the vehicle near the lunar surface and effect a landing, but he could change the coordinates of that landing based upon terrain characteristics making such a change necessary.