Human Physiology, Performance, Protection, and Operations (H-3PO) Lab

Patrick Estep, M.S., HHPC/GeoControl Systems

Jeffrey Somers, NASA Johnson Space Center

Karina Marshall-Goebel, NASA Johnson Space Center

H-3PO

- Human Physiology, Performance, Protection, and Operations Laboratory

- Resides in Houston, TX - Johnson Space Center, Bldg. 21

- Current Leads: Jeff Somers, Renita Fincke, Karina Marshall Goebel, Andrew Abercromby

- Comprised of four technical areas:
  - Applied Injury Biomechanics
  - Exercise Performance and Countermeasures
  - **Spacesuits and Exploration Operations (SSEO)**
  - Data and Software
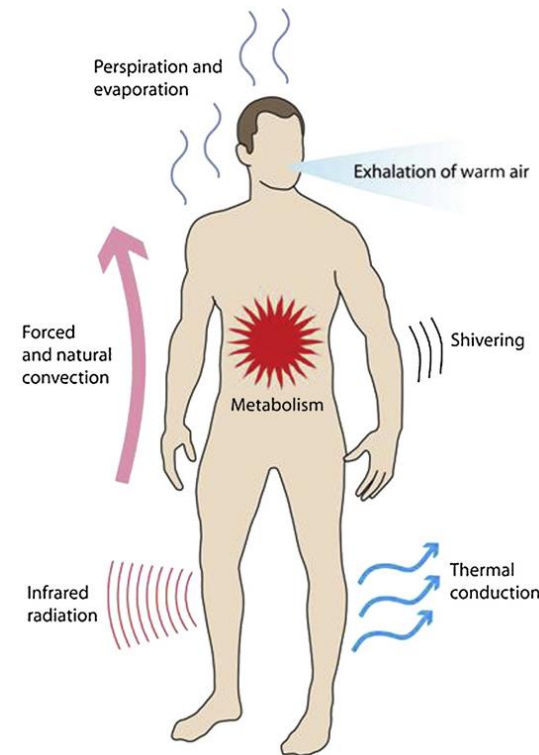
H-3PO/SSEO Not-Work

- Extracurricular activities!
  - H-3PO Olympics!
  - Weekly workouts!
  - Spartan / Tough Mudder races!
  - Annual group trips!

- Oxpecker Teams
  - Diversity and Inclusion
  - Teambuilding and Recognition

- "Feed Your Brain Friday"

- "Hungry Hungry Hippos"

SSEO

- **Spacesuits and Exploration Operations (SSEO)**
  - Multi-disciplinary team of engineers, physiologists, physicians, etc.
  - Varied backgrounds across all facets of human health and performance, including:
    - Space physiology
    - Astronautics / aeronautics
    - Kinesiology / Injury biomechanics
    - Exercise science
    - Data science / computational modeling
    - Virtual and hybrid-reality technologies

- The highlighted works presented here are funded by:
  - NASA Exploration Capabilities
  - NASA EVA and Human Surface Mobility Program
  - NASA Human Research Program

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SSEO – What do we do?

- **Programmatic support:** Identification, review, and/or development of requirements, risks, gaps, and recommendations

- **Operational support:** Training crew for prebreathe protocol. Collection, reporting, and prediction of metabolic rates during ISS EVAs.

- **Modeling:** Development of physiologic and functional models that provide individualized and task-specific prediction/monitoring of crew health, state, and performance.

- **Bioinformatics and decision support:** Integration of models, supporting software tools, visualizations/interfaces, and autonomous decision support systems.

- **Simulation Development (link):** Development of content to conduct EVA simulations, whether in shirtsleeve, virtual reality or a pressurized suit environment.

- **Testing:** Lead or support engineering evaluations and research-driven testing across multiple analog environments.

Collaboration

- Collaboration and integration with other labs and organizations to develop EVA simulation content and embedded performance measures
    - Johnson Space Center:
        - NASA Advanced Operations Concept Lab
        - Behavioral Health and Performance Lab
        - Center for Design & Space Architecture
        - Medical Operations
        - Flight Operations
        - Advanced Suit Lab
        - Astromaterials Research and Exploration Science
    - NASA Ames Research Center:
        - Fatigue Countermeasures Lab
    - Academia:
        - University of Pennsylvania
        - University of Colorado Boulder
    - Misc:
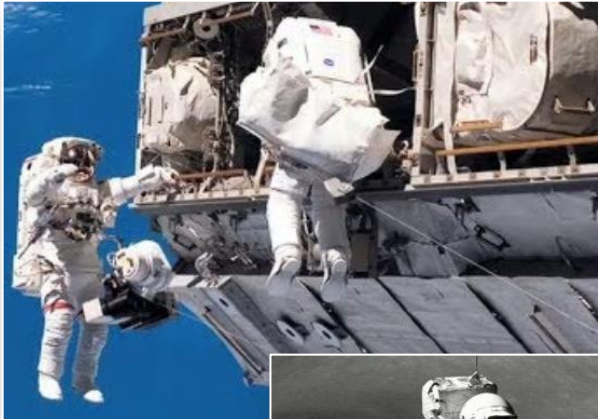   - HeroX - Collaboration with NASA Tournament Lab on crowdsourcing challenge

Background

Exploration EVA

Current Test Environments

EVA: Microgravity vs. Exploration

BLUF: Future Exploration EVA will be quite different from ISS and Shuttle EVA, and even previous Apollo EVAs!


Parameter	Current EVA	Exploration EVA
Tempo	8hr EVA/ ~ 2 months	8hr EVA every other day (24hr/crew/week)
Environment	Engineered Completely Characterized Microgravity Uncontaminated	Natural & Engineered Incomplete Characterization Partial Gravity Dust
Tasks	Construction/Maintenance	Science Construction/Maintenance
Skills / Training	Specific Skills/task-based NBL practice many hours	Generic Skills Tool-based
Mission	Specific tasks, practiced and planned	Broadly scoped timelines Real-time adjustments
Operational Support	MCC-centric Extensive personnel support	Crew-centric Delayed ground support

# Physical and Cognitive Workload & Fatigue

- EVAs are both physically and cognitively demanding

- Physical activity can affect cognitive performance, and vice versa - both positively and negatively

- Risk estimation, decision making, reaction times, coordination, attention, accuracy, and memory may all be compromised during EVA
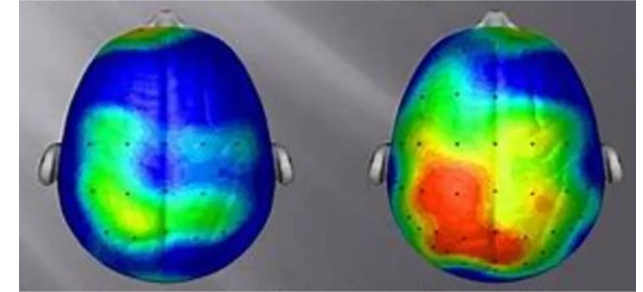
<u>Physically and cognitively realistic</u> test environments are necessary to inform and validate exploration systems and operations

Limitations of Existing EVA Simulation Environments

- Typically either physically *OR* cognitively realistic

- Limited availability and capabilities
    - Difficult / expensive to integrate physiological sensors
    - Performance measures generally limited and obtrusive
        - *Collecting core temperature data on NBL subjects requires difficult transmission of signals through the human, spacesuit, and water*
        - *Can't wear metabolic analyzers/masks during simulations with primary objectives geared towards communications*

- Learning effects between different suits and environments

- Heavy reliance on small and subjective data sets

- Limited repeatability

- <u>BLUF:</u> **No one simulation environment is perfect, so it's necessary to conduct research and testing in all of them!**
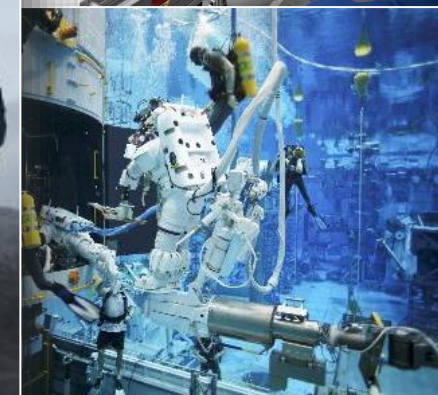
Capabilities

APACHE Environment

Demos

Suited Testing

- Support various suited testing efforts at the Neutral Buoyancy Lab (NBL) and Active Response Gravity Offload System (ARGOS) to characterize human health and performance during partial-g EVA simulations

  - Pressurized, offloaded suited testing environment with high-fidelity EVA tasks, tools, and procedures
  - Spacesuit and facility are equipped with a whole host of sensors to measure:
    - Metabolic rate, CO_2
    - Heart rate
    - Thermal parameters (e.g. core body temp)
    - Kinematics (e.g. IMU)
    - Cognitive workload
    - Hydration, nutrition, and waste management
   - Subjective/qualitative

APACHE – VR/XR Environment

- **Goal:** Create a both physically and cognitively realistic exploration EVA simulation environment using a combination of virtual reality (VR), physical reality, and hybrid reality (XR)

- Flight-like environments, scenarios, timelines, flight rules, tasks, spacesuit simulators, etc. can be implemented to realistically simulate physical and cognitive workload of exploration EVA

- Controlled hybrid-reality lab environment enables:
  - Rapid development, implementation, and demonstration of research technologies, methods, and capabilities
  - Rigorous evaluation of the extent to which they improve individual and team performance
  - Unobtrusive capture of operationally-relevant measures of EVA task performance

APACHE - Current Capabilities

- **15' x 20' footprint w/ Lunar regolith simulant**
- **Physical and cognitive workload simulators**
- **Options for long-distance ambulation**
  - Passive unidirectional treadmill
  - Omnidirectional treadmill
- **2-player operations**
- **Lunar environment (Shackleton crater) and Martian environment (Jezero crater)**
- **Physiologic sensors, computational models, and real-time informatics**
  - Metabolic rate / CO_2, Heart rate, Thermal, Cognitive/Fatigue
  - Seeking to add eye tracking, hand tracking, EEG/fNIRS, etc.
- **Embedded cognitive measures**
  - Psychomotor Vigilance Task (PVT)
  - Digital Symbol Substitution Task (DSST)
- **Realistic tools, assets, and end-to-end EVA simulation modules**
  - Aim to integrate omnidirectional treadmill and 6dof motion platform into VR/XR exploration environments
  - Aim to develop new EVA tools and procedures
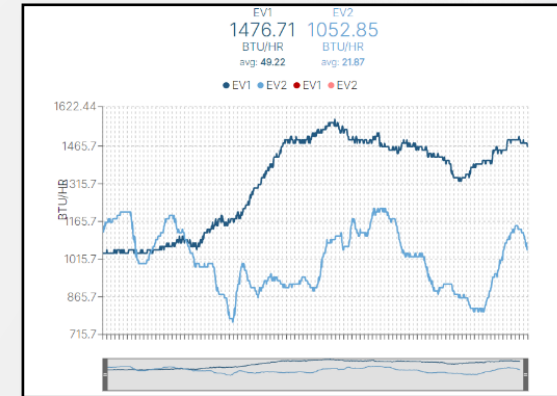
Hybrid Spacesuit Simulator

- Hybrid spacesuit simulator (HS3) was developed as a research tool to add fidelity and realism by way of adjustable physical and cognitive workload

- Developed in 2021-2022

- Next steps are to:
  - Develop adjustable sizes
  - Assess, develop, and implement new potential subsystems
  - Characterize "baseline" configuration against shirtsleeve, VR/XR, and suited test environments
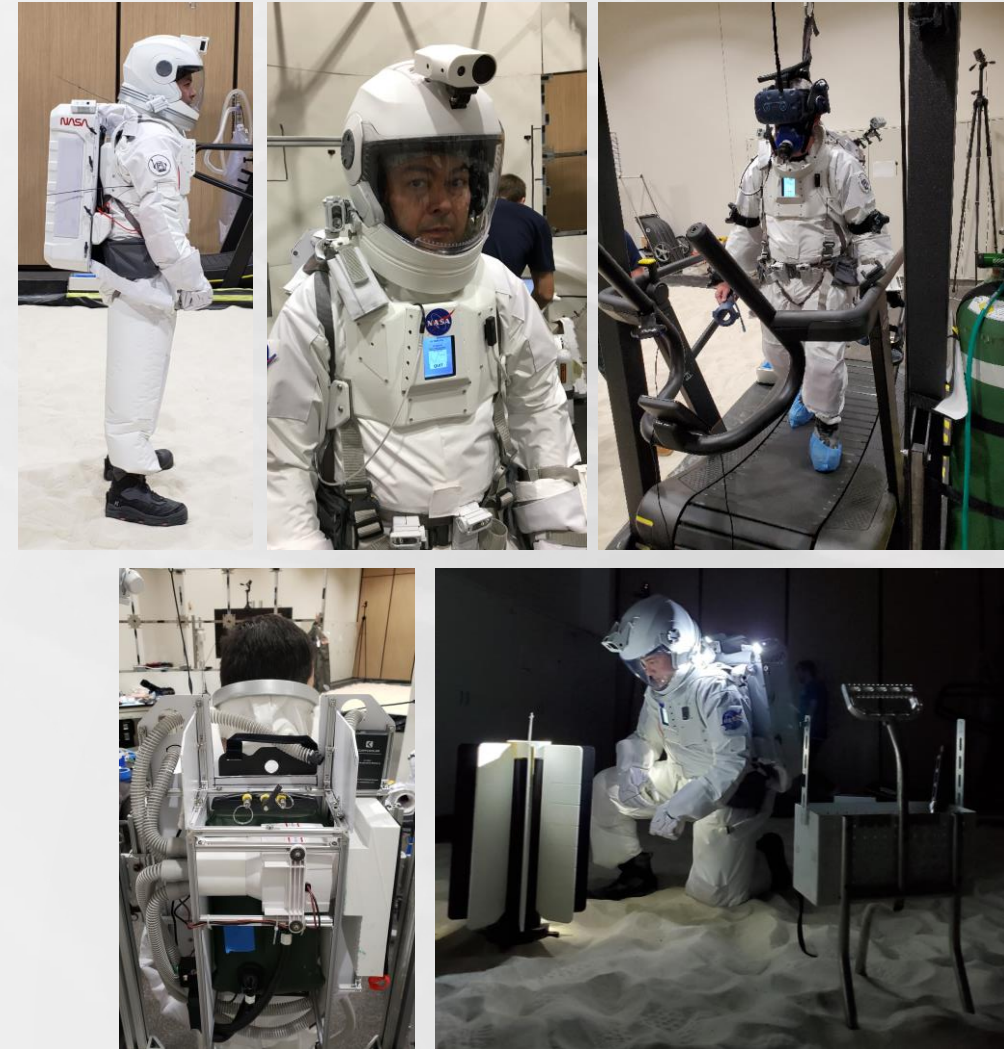
Past, Current, and Future Efforts

Key Projects

Quick Overviews

Technology Development


- **HeroX Crowdsourcing (link)**
  - Work with the public to generate additional EVA-relevant simulation content for APACHE!
    - Partnership with EPIC games, HeroX, and Buendea
  - 2,175 international innovators combined into 198 teams
  - 34 submissions resulted in 9 winners

- **Crew State and Risk Model (CSRM)**
  - Develop and validate an integrated set of HHP-relevant models across physiologic and cognitive domains that can accurately infer and predict a crewmember's current and future states

- **PersEIDS**
  - Develop and test a proof-of-concept decision support system to supplement EVAs, IVAs, and console support staff during autonomous exploration EVA simulations.
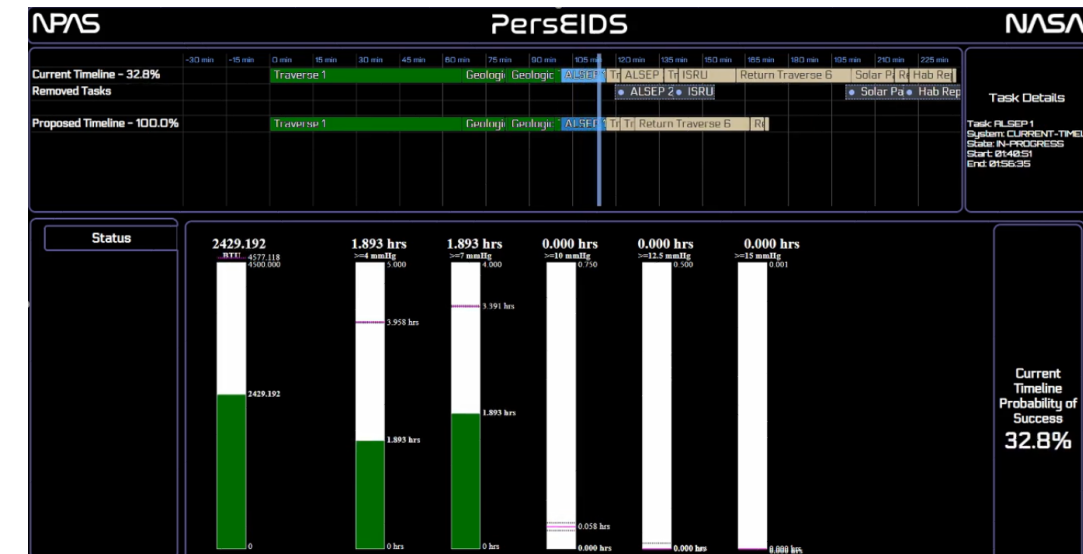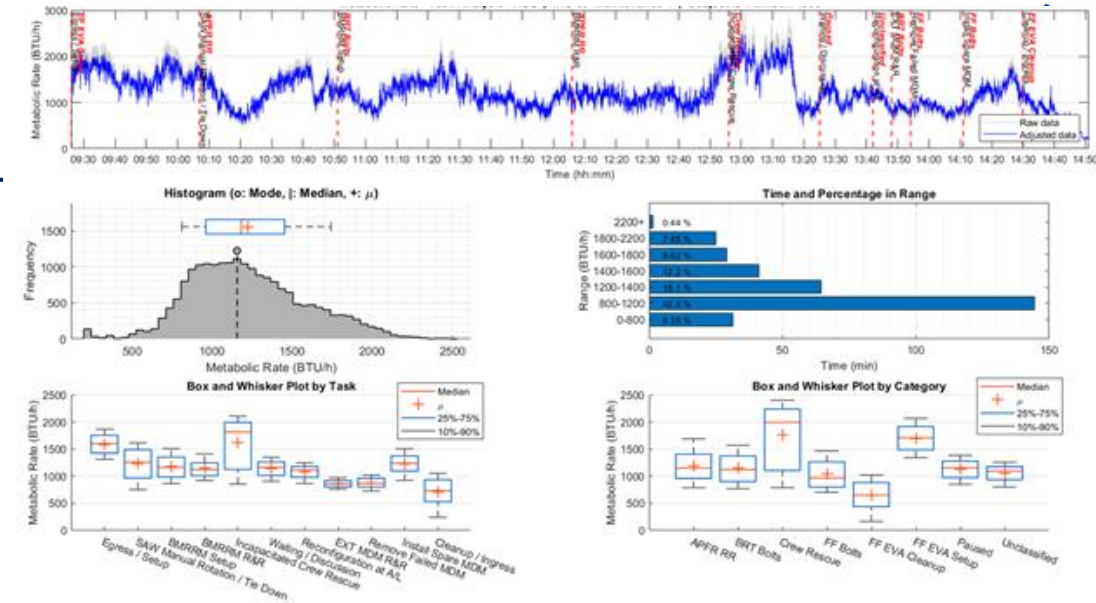
APACHE - VR/XR Testing

- **CHAPEA** (link)
  - Develop 8 end-to-end VR EVA simulations, each lasting ~6 hours, to support evaluation of proposed Martian food systems in a year-long mission.

- **Physical Workload Approximation**
  - Treadmill Comparison Study (link)
    - Characterize the voluntary metabolic rate and gait parameters during EVA-like traverses in different analog environments.
    - Results: "...a correction factor is recommended when comparing metabolic costs of ambulating in APACHE with other analog environments because of the inability to significantly change workload via the [passive] treadmill resistance."

- **Cognitive Workload**
  - Psychophysiological Monitoring for Spacewalks (link)
    - Classify cognitive workload using psychophysiological sensing during an operationally-relevant EVA in VR.
    - Results: "During the high workload simulations, participants substantially overused their simulated oxygen resources by walking too fast, identified and recalled more waypoints incorrectly with slower responses, and had more variable reaction times to green indicator lights..."
  - Implementation and Validation of Cognitive Measures in VR/XR (2023)
    - Purpose: Evaluate the ability to measure and collect cognitive workload and physiological data during a simulated science package deployment procedure
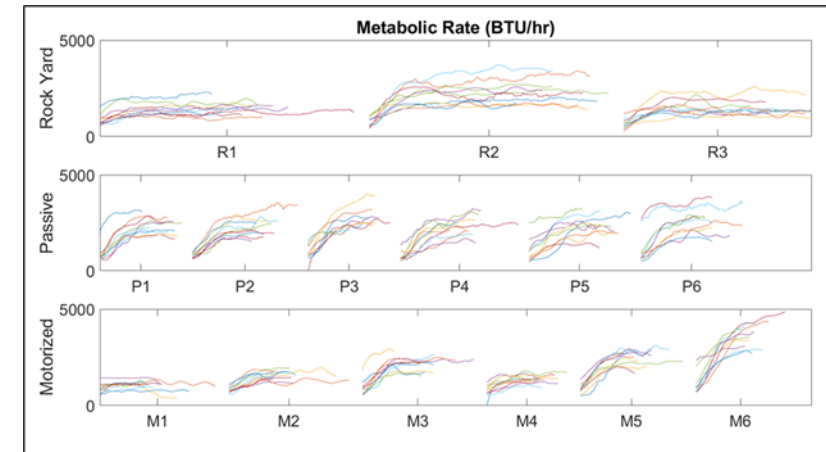
Chamber Testing

- **Exploration Atmosphere** ([link](#))
  - Decompression sickness (DCS) is a significant risk during EVA due to the difference between cabin and suit pressures (14.7 psi vs 4.3 psi). This risk is increased with higher levels of physical workload and ambulation.
  - By taking advantage of a reduced pressure, elevated oxygen habitat atmosphere, it is hypothesized that we can reduce the prebreathe time and save consumables while still adequately mitigating the risk of DCS.

  - Conducted an 11-day study with 8 subjects simulating 5 EVAs in mid-2022.

  - Initial results to be presented at AsMA 2023
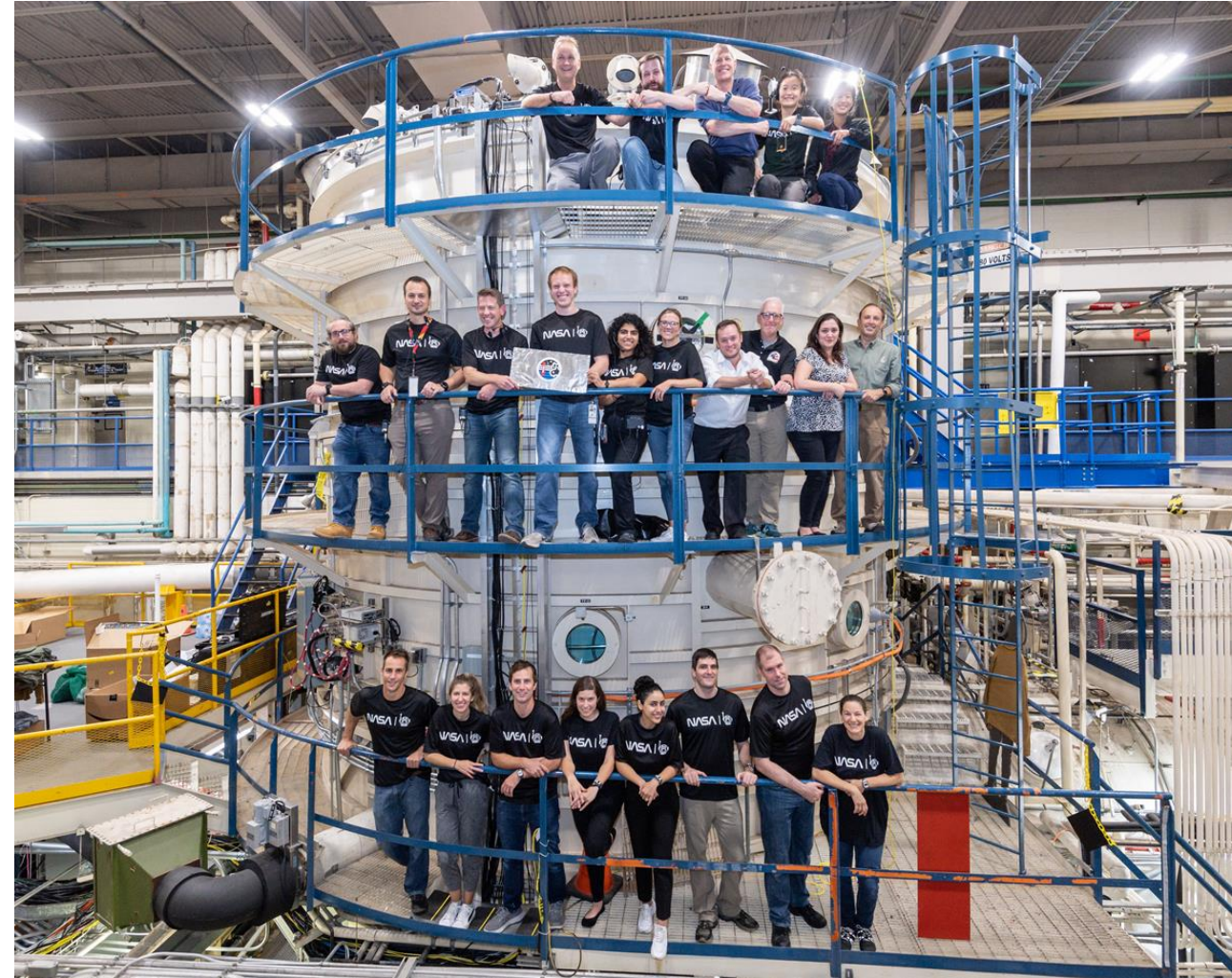
NASA Human Research Program (HRP) Projects

- Recommendations for In-suit Nutrition
  - Physiological, logistical, and engineering aspects of potential in-suit nutrition approaches and systems were assessed for strengths and limitations during exploration EVA.

- CO_2 Walkback / CO_2 Sensitivity
  - Assess physical and cognitive performance impacts of completing a simulated 1-hour contingency walk-back under various CO_2 (0-30 mmHg equivalent pCO_2 at 4.3psia) exposures to update contingency CO_2 standards and requirements

- Egress Fitness/CIPHER
  - Assess a returning crewmember's ability to conduct an abbreviated partial-g EVA simulation in a deconditioned state, to determine readiness and fitness required for future exploration missions.
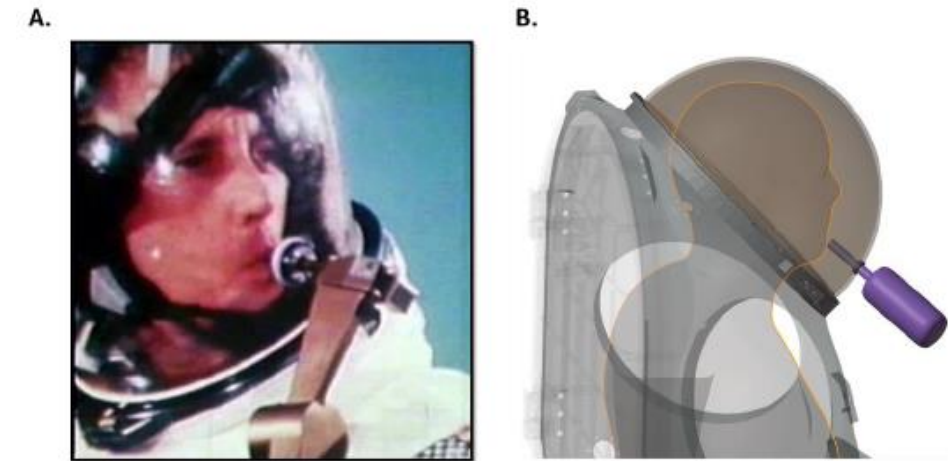

Figure 7 A. Demonstration of the Apollo contingency helmet feed port. B. Concept illustration of an external nutrition system with xEMU helmet feed port.

Summary

- EVA is challenging.

- Exploration EVA will be even more challenging.

- Protecting, enabling, and enhancing the health and performance of crewmembers is vital to the success of NASA's mission, and requires multi-faceted and interdisciplinary approaches.

Thank You!