Recommendations for Developing Space Suit Integrated Food Systems and Delivering Nutrition Before, During, and After Lunar EVA

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Background (Apollo/Shuttle)

- The concept of in-suit nutrition is nearly as old as the space program itself
- In-suit Nutrition Implemented (Apollo)
  - Food Stick
    - Individual preferences (some liked it, some did not)
  - Flavored (K-fortified) Drink
    - Aimed to improve hydration, little nutritional value other than Potassium
  - Helmet Port
    - For contingency use only (never used in-mission), difficult to use
- In-suit Nutrition Discontinued (Space Shuttle)
  - Fruit ‘roll-up’ stick
    - Reasons for discontinuation: messy, crew consumed before extravehicular activity (EVA), not mission critical
- What is the motivation to put nutrition back in space suits?

Artemis

- The Artemis program is targeting a higher tempo and frequency of extravehicular activities (EVAs) than any previous space program
  - 4 EVAs within 5 days
- Providing adequate nutrition support is critical
  - In-suit nutrition options should be included as part of the overall food systems in a strategy to meet crewmember needs
  - Consideration to meeting EVA caloric needs should include options to fuel before, during, and after EVA
- The ability to provide additional nutrition to support EVA performance is limited
  - In-suit nutrition should benefit the astronaut during a single EVA

General Questions

- How much and what type of EVA nutrition support should be provided in the suit and how much can be leveraged by supplementing rations before and after the EVA?
- What food formulations meet partial gravity constraints and are appropriate and safe for in-suit operations?
- What are the limitations of the suit?
- What are the functional capabilities of a suited crewmember?
- What are practices and preferences that astronauts commonly follow that should be considered?

How much is enough?

- Food system must provide addition of 200 kcal/hr EVA (x 8 hours = 1600 kcal/day)
  - Not all of this needs to be provided in the pressure suit
  - Some can be provided pre/post EVA
  - How much is necessary for enhanced performance?
- Draw from sports physiology and military literature
  - Example: Energy intake to support expenditure during a 10-hour exercise trial*
  - Approximately 21 g carbohydrate (CHO) intake per hour of exercise (~84 kcal/hr)
- Expenditure is expected to be lower during EVA
  - Reasonable target is to consume ~50-80 kcal per hour of EVA (x 8 hours ≥ 400 kcal in the suit)
- Recommendation: at least 400 kcal in the suit to support performance
  - As CHO or the equivalent energy balanced as CHO/fat/protein
  - Improve palatability, acceptability, muscle recovery, etc.
  - Providing more than ~600 kcal in the suit is not expected to add benefit to performance
  - Waste if not consumed

* Harger-Domitrovich SG, McClaughry AE, Gaskill SE, Ruby BC. Exogenous carbohydrate spares muscle glycogen in men and women during 10 h of exercise. Med Sci Sports Exerc. 2007;39(12):2171-9.

Commercial off the Shelf (COTS) Foods

- COTS bars and beverage powders were identified that met minimum nutritional requirements
  - Only if multiple servings are used

- Subset of COTS products tested
  - Did not meet both microbiological (rehydrated powders) and foreign object debris (FOD; solid food bars) requirement.

  → Limited (2-hour) window of consumption for liquid nutrition following breaking of the packaging seal
  - In agreement with FDA guidelines
  - Space exploration is not the place to get food poisoning

- Additional assessments required for any product
  - Nutritional content
    - Ensure nutrients remain within requirements of the whole diet.
  - Spatial evaluation
    - Configuration, FOD compliance, and delivery potential within the suit.
  - Sensory evaluation
    - Verify that selected products remain safe and acceptable for the duration of the EVA mission.

Examples

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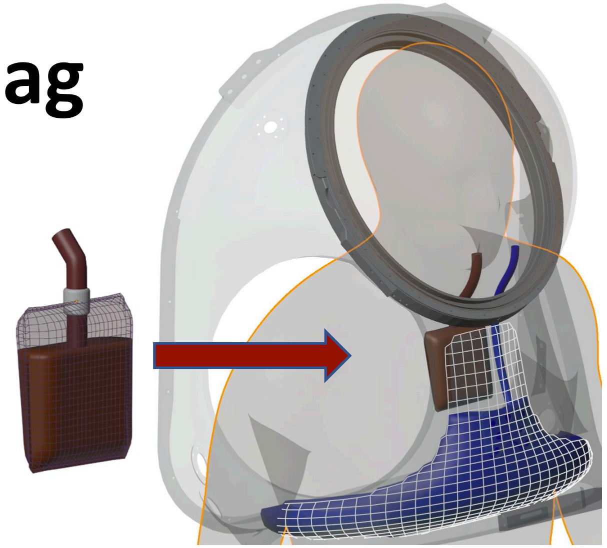
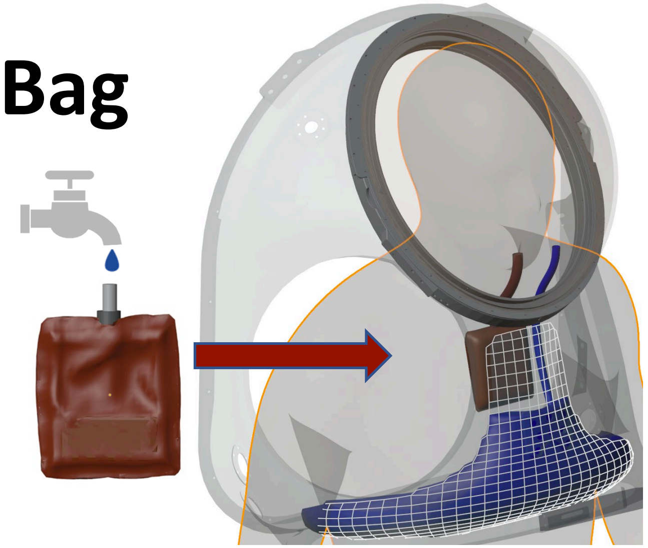
Concept Designs

Pre-filled Bag (Liquid)

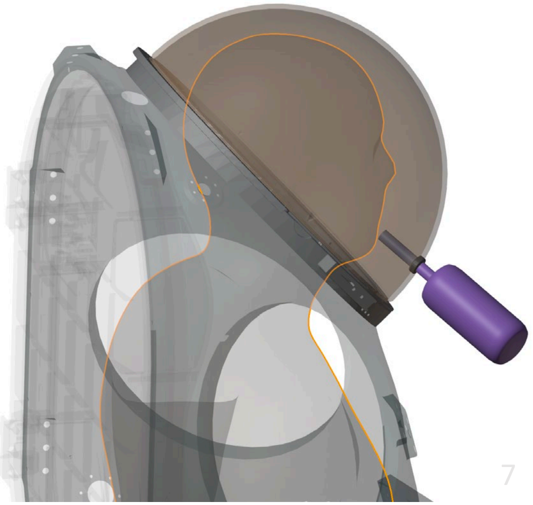


Hydratable Bag (Liquid + Powder)



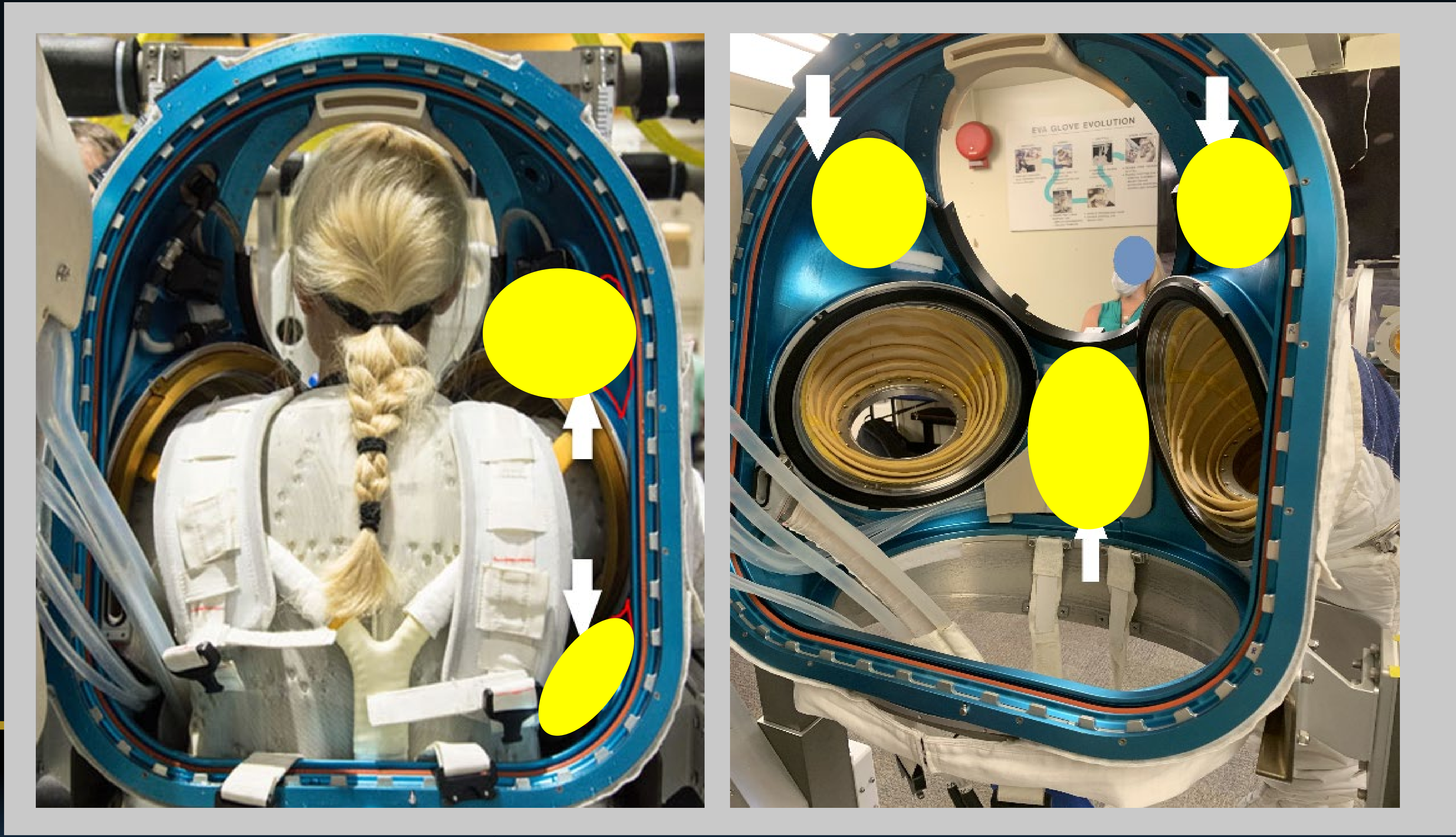
Food Stick (Solid)

Helmet Port (Liquid or Gel)



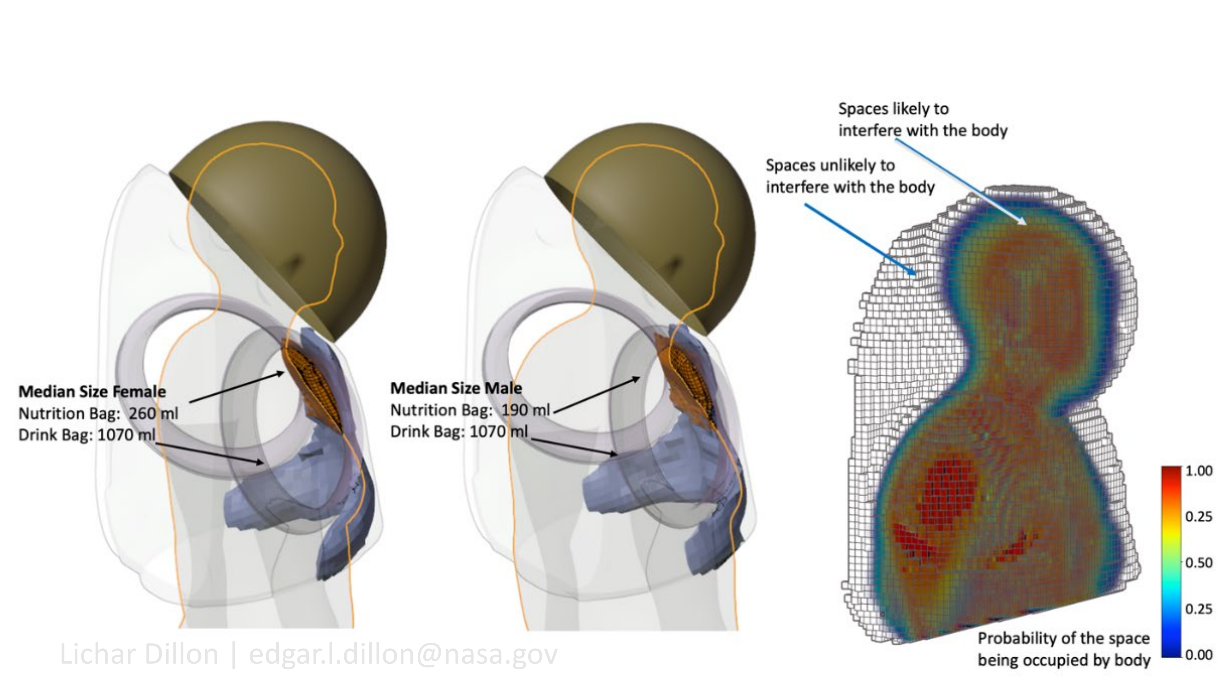
Suit Placement Considerations

- Exploration Extravehicular Mobility Unit (xEMU) Example



Volumetric Analysis Example

- Preliminary positioning of a drink bag on top of the DIDB
  - Mid-chest of current xEMU hard upper torso (HUT) designs
- Using population averages as female and male models
  - xEMU HUT and the disposable in-suit drink bag (DIDB) filled to capacity (1070 mL)
  - Maximum volume available for a median size female: 260 ml
  - Maximum volume available for a median size male: 190 ml



Working assumptions (1 kcal·mL^{-1}) demonstrates limitations at this location (400 mL required for liquids)

Astronaut Feedback

- 2 Qualtrics based questionnaires for Crew Feedback (rolled out separately)
  - General Preferences for Hydration, Nutrition, and Waste Management in Space Suits (n=25)
  - Concept Design References for In-Suit Nutrition Systems (n=17, 9 with EVA experience)

Summary (Feedback consistent with input from project SMEs)

- Ready to consume drink bags received the highest ranking (but not unanimous)
  - Limited shelf-life reduced enthusiasm for the hydratable drink bag option.
- Solid food as a high-density food option was desired by some.
  - Lack of experience & concern of messiness may have contributed to lower enthusiasm.
- Uncertain feasibility of implementing a helmet feed port
  - Concept of keeping food outside of the suit was regarded as a positive attribute
- Multiple systems should be considered

Summary Recommendations

- Future pressure suit designs should accommodate provision of at least 400 kcal to the individual confined to the suit.
  - The vehicle food system needs to provide the remaining energy before or after suited operations during regular meals.
  - COTS or developed foods
  - CHO/Fat/Protein
- Initial xEMU location considered (front of chest near the DIDB) is currently volumetrically limited to approximately 200–250 mL
  - This volume is <u>insufficient</u> to provide 400 kcal as liquid (~400 mL)
  - Other locations are possible, but were not analyzed
  - Future suit development to consider minimum of 400 mL for in-suit liquids
- Hands-free access
  - Should not interfere with jaw, head, neck motions or field of view
  - Capability to break the seal of prefilled food grade quality packaging (liquids/gels)
- Helmet feed ports
  - Requires staging of the foods prior to the EVA
  - Overcoming pressure differentials during consumption of external foods
  - Requires physiochemical (dust) mitigation

Future Work

- Expanded COTS testing and/or development of foods that meet all space flight requirements (nutritional content/ water activity/ microbiology/ FOD/ acceptability/ etc.)
  - Continue development of multiple solutions
    - Both solid and liquid
  - Continued/parallel effort at NASA in addition to xEVAS contractor

- Incorporate prototype EVA food system within environments that closely simulate realistic EVA scenarios to evaluate human factors, ergonomics, and human-system integration of system prototypes
  - Using 3D printed mockup suit components - Physical and Cognitive Exploration Simulations (PACES)
  - EVA training runs in the NBL, and/or Active Response Gravity Offload System (ARGOS)

- End-user (Crew) involvement during development

Integrated Project Team

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xEMU Suit Systems

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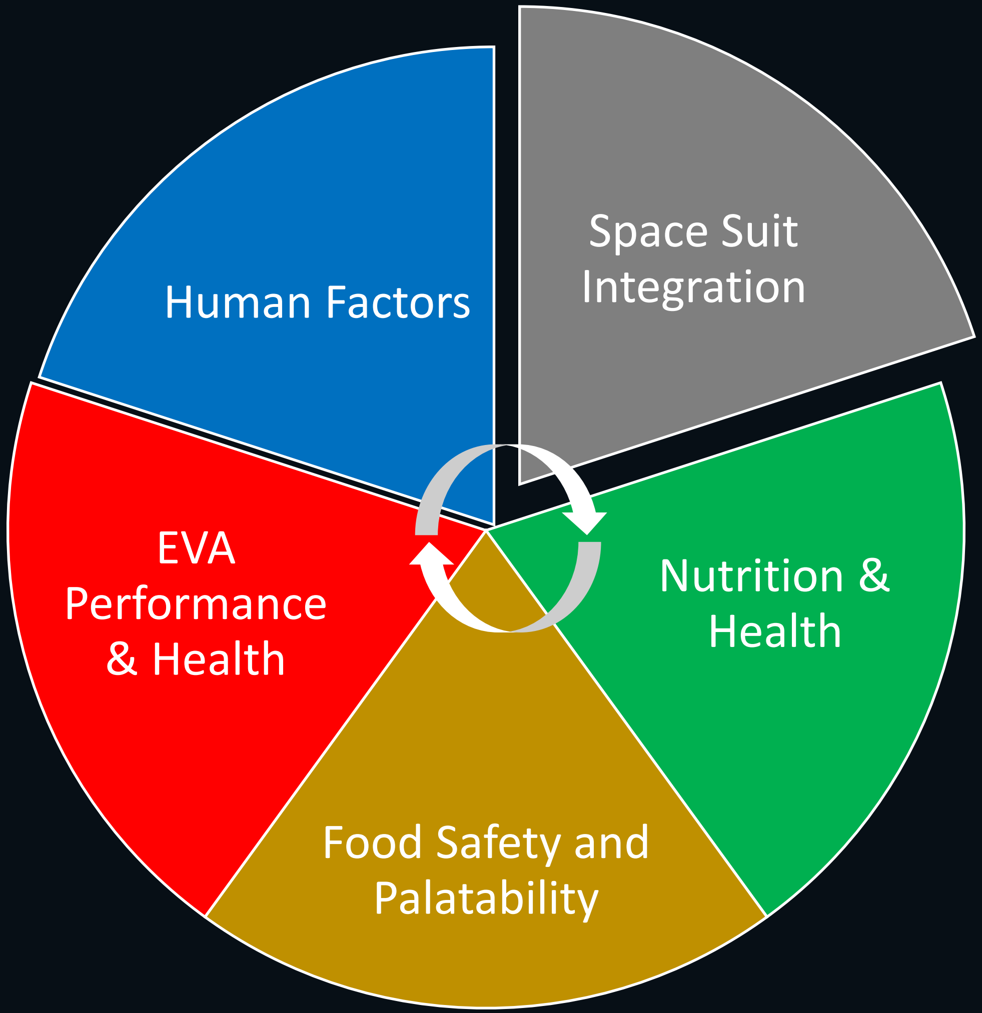


Thank you

Image: Gulf Coast at Night (NASA, International Space Station, 08/09/14)

BACKUP

ABSTRACT

INTRODUCTION

- Artemis missions will include a higher tempo and frequency of extravehicular activities (EVAs) than any previous space program. Because of the physical demands expected from the crew, future space suit designs are required to incorporate nutritional support to the astronauts during lunar surface EVAs lasting longer than 4 hours. The purpose of this project was to provide recommendations to aid the development of an in-suit system that can adequately, safely, and acceptably deliver nutrition to a crewmember while confined to a space suit during EVA.

METHODS

- Physiological, logistical, and engineering aspects of potential in-suit nutrition approaches were assessed through literature reviews, assessments of commercial off the shelf (COTS) foods, suit volumetric modeling, and feedback from subject matter experts and crewmembers. Key driving factors in the development of in-suit nutrition requirements included how much and what type of nutrition should be included, what food formulations are appropriate and safe, what are inherent limitations of space suits, what are the potential risks to the crewmember in the suit, and what practices and preferences from astronauts should be considered. Design references were conceptualized and assessed for strengths and limitations as potential in-suit nutrition systems for surface EVA.

RESULTS

- Acute exogenous energy demands vary greatly depending on activity intensity and duration, and partial energy replenishment (i.e., 60–80 kcal·hr-1 of EVA, or 460–680 kcal for EVAs lasting up to 8 hours) during activities could improve performance, safety, and recovery. COTS foods capable of providing these energy requirements exist; however, no COTS foods have been identified that pass NASA flight standards for microbiological safety and stability. In-suit nutrition delivery design references that were considered included in-suit concepts for a prefilled drink bag, a hydratable drink bag, and a solid food stick. In addition, a helmet feed port concept was considered for use with drink bags external to the suit. Volumetric models of the in-suit drink bag concepts, based on xEMU dimensions, indicate challenges of fitting formulations > 200 ml (equating to approximately 200 kcal). Astronaut feedback on the four concepts indicated that despite some individual preferences for inclusion of solid foods and helmet port designs, the prefilled drink bag concept was the most preferred. A prefilled drink bag can only be used if food safety and stability can be ensured, possibly requiring advancements in food delivery hardware.

CONCLUSION

- The ability to meet the increased need for nutrition during surface EVAs through provision of nutrients in the suited configuration would benefit overall crew health, performance, and morale, and thus increase the likelihood of mission success. It is recommended that in-suit nutrition capabilities provide at least 400–600 kcal within the suit during EVAs lasting > 4 hours and that suit designs include a dedicated volume for food grade nutrition systems. The developed food system should either allow for 1) installation of prefilled (sealed sterile) liquid nutrition in the suit and provide a mechanism to break the seal at the time that consumption is desired or 2) demonstrate that the unsealed food product shelf life allows for safe consumption after at least 12 hours of EVA.

Full report (NASA/TP-20220019344) available at https://ntrs.nasa.gov/

In-Suit Nutrition Recommendations

- Minimum of 400 kcal needed for In-Suit Nutrition
  - Minimum amount determined necessary for performance improvement
  - Food System Requirement to Supply Additional 1600 kcal for 8-hr EVA
    - Not all kcal need to be delivered in the suit, but sets a clear upper limit
    - Range of 400-600 kcal should be considered
  - Gap - xEMU primary location limited to ~200mL.
    - Future suit development to consider minimum of 400 mL for in-suit liquids.
  - Major Gap – NO current COTS products and delivery systems exist that meet requirements
    - Example: mixing powdered meal replacement with water prior to the EVA would require consumption within 2 hours of breaking package seal, thus necessitating consumption at the very beginning on an EVA
    - Risk (Foodborne Illness): 5x5 to 3x4 LxC
- Four Different Reference Delivery Systems Evaluated
  - Pros, cons and necessary forward work for each reference will be discussed
    1. Pre-filled/Sterile Liquid Nutrition
    2. Mixed powder/water Liquid Nutrition
    3. Solid Food Bar/Bites
    4. Helmet Feed Port

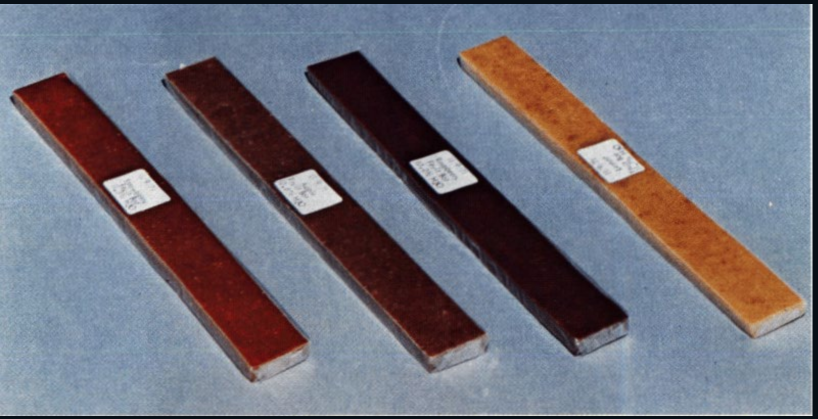
Bottom Line Up Front – November 2022 – See full report for details: “Recommendations for Developing Space Suit Integrated Food Systems and Delivering Nutrition Before, During, and After Lunar EVA”

Prefilled vs. Hydratable bags

Delivery Concept		In flight Prep	Special Capabilities Needed or Desirable	Advantages	Limitations
Drink Bag Prepackaged (Semi)Liquid	Thermostabilized	Open DURING EVA	Hands Free Access Hands Free opening/breaking seal	Ease of install/use/removal Consume when needed Variety of potential COTS	Higher launch mass (water) Delivery hardware has not been developed and feasibility is unknown
Drink Bag Powder	Rehydratable	Rehydrate BEFORE EVA	Hands Free Access Desirable: advances in engineering to extend food shelf life.	Low launch mass Ease of use/removal Variety potential COTS	Requires rehydration prior to donning pressure suit Consumed during early phase of EVA (within 2 hours of breaking seal/adding water)

Solid Bars

Delivery Concept		In flight Prep	Special Capabilities Needed or Desirable	Advantages	Limitations
Food Bar Solid	Low Moisture	Open BEFORE EVA	- Hands Free Access - Crumb prevention	- Low launch mass - Ease of install/use/removal	- Production of suitable food products (nonstick, crumb prevention, consistency, integrity, etc).



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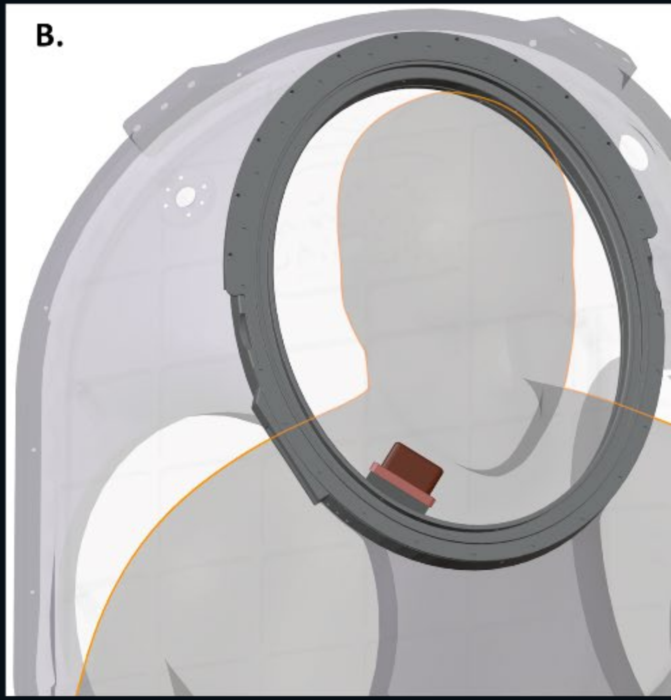

Helmet Feed Port

Delivery Concept		In flight Prep	Special Capabilities Needed or Desirable	Advantages	Limitations
Helmet Port (Semi)Liquid	See Drink Bag	Install in Restrainer Pouch Stage before EVA	- Helmet Port - Vacuum tolerant packaging - Packaging that enables equilibration of pressure with suit to enable drinking - Potential need for refrigeration - Requires procedures and equipment for staging of food system external to the pressurized vehicle prior to EVA.	- No need for handsfree operation - Option to increase volume/frequency of nutrient intake without need for revisions of suit design.	- Complicated helmet port design/ concern for helmet port integrity - Need for specialized hardware - Requires use of gloved/pressurized hands - Requires staging of food for access to system external to vehicle.

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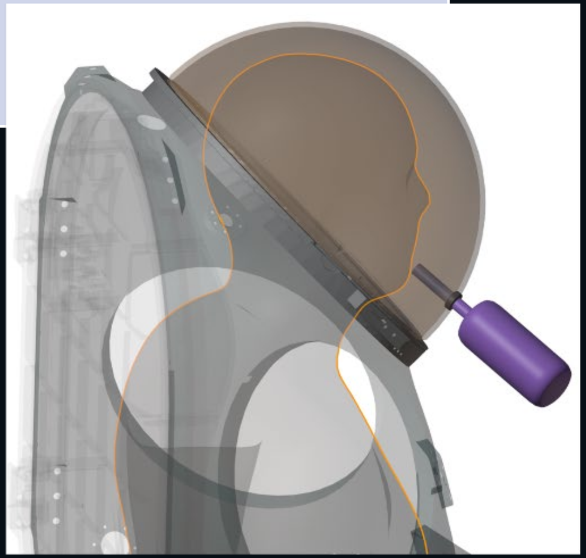

Suited Nutrition Standards

NASA-STD-3001 Volume 2

7.1.1.4 EVA Food Caloric Content

[V2 7004] For crewmembers performing EVA operations, the food system **shall** provide an additional 837 kJ (200 kcal) per EVA hour above nominal metabolic intake as defined by section 7.1.1.3, Food Caloric Content [V2 7003], in this NASA Technical Standard.

[Rationale: Additional energy and nutrients are necessary during EVA operations, as crewmember energy expenditure is greater during those activities. Consumption of an additional 837 kJ (200 kcal), similar in nutrient content to the rest of the diet, per hour of EVA would allow a crewmember to maintain lean body weight during the course of the mission. This is the metabolic energy replacement requirement for moderate to heavy EVA tasks.]

11.2.2.1 Suited Nutrition

[V2 11025] The system **shall** provide a means for crew nutrition in pressure suits designed for surface (e.g., moon or Mars) EVAs of more than 4 hours in duration or any suited activities greater than 12 hours in duration.

xEVAS Requirement

3.5.12 In-Suit Nutrition (RQMT-055)

The xEVA System spacesuit shall provide at least 1673.6 kJ (400 kcal) of crew nutrition while in a suited, pressurized configuration for EVAs of more than 4 hours duration, to be consumable at any point prior to suit doffing.

Rationale: Additional nutrients, including fluids, are necessary during suited operations as crewmember energy expenditure is greater during those activities. Nutritional supply during suited operations allows the crewmembers to maintain high performance levels throughout the duration of the EVA. Apollo astronauts strongly recommended the availability of a high-energy substance, either liquid or solid, for consumption during a surface EVA.

Consumption of additional nutrition that comes outside of xEVA System is expected to be consumed pre or post EVA. A total of 837 kJ (200kcal) per EVA hour must be provided to account for workload expenditures by a combination of EVA host vehicle and xEVA Suit System. This is the metabolic energy replacement requirement for moderate to heavy EVA tasks.

Applicability: ISS and Artemis